D6.3 Final Report on the Innovation Strategy and Targeted Activities

Version 1.0 *(final)*

Date

27 April 2022

Grant Agreement number:	**823914**
Project acronym:	**ARIADNEplus**
Project title:	**Advanced Research Infrastructure for Archaeological Dataset Networking in Europe - plus**
Funding Scheme:	**H2020-INFRAIA-2018-1**
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ARIADNEplus is a project funded by the European Commission under the Horizon 2020 Programme, contract no. H2020-INFRAIA-2018-1-823914. The views and opinions expressed in this document are the sole responsibility of the authors and do not necessarily reflect the views of the European Commission.

About this document

This document is a contractual deliverable of the ARIADNE - Advanced Research Infrastructure for Archaeological Dataset Networking in Europe – Plus project. It presents the Final Report on the Innovation Strategy and Targeted Activities (D6.3) that has been produced under WP6 "Fostering Innovation and Impact". The research leading to these results has received funding from the European Community's Horizon 2020 Programme (H2020-INFRAIA-2018-1) under grant agreement n° 823914. But the content of this document cannot be considered to reflect the views of the European Commission.

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1 Executive Summary

ARIADNE/plus objectives

The overall objective of the initial ARIADNE project was to help the archaeological research and data management communities in Europe to more effectively share and reuse data resources which are dispersed and often difficult to discover and access. For this purpose the project implemented a digital infrastructure and services that enable registration, aggregation, integration, and search and retrieval of data records which describe and link to the available data.

ARIADNEplus takes the next steps to enable data sharing and collaborative (re)use for archaeological research across institutional and national, as well as disciplinary boundaries.

The existing ARIADNE data is being extended geographically, temporally and thematically by incorporating datasets from more providers and research domains. The records are integrated using Linked Data technologies and methods that enable novel ways to search and access data. Several enhanced and new research services are provided using a Cloud-based data management and access platform, enabling innovative and effective ways of carrying out digital research in archaeology.

The overall mission of ARIADNEplus is: *to integrate and effectively serve a research community that studies the past to better understand the present with the tools and the methodology of the future, in the service of European culture and society.*

The ARIADNEplus innovation strategy

The ARIADNEplus innovation strategy aims to promote significant advances in archaeological research and data management in Europe and beyond.

This report presents the innovation strategy addressing its different dimensions. The main dimensions of the strategy are:

- *Research policies:* Alignment with the European research policies on FAIR data and repositories, Open Science practices, and the European Open Science Cloud (EOSC) initiative.
- *Stakeholder and user base:* Extension of the stakeholder and user base in Europe and beyond, taking account of community needs regarding data, technical services and training.
- *Data standardisation:* Standardisation of archaeological datasets based on the ISO standard CIDOC-CRM, domain-specific extensions of the ontology, and core domain vocabularies.
- *Data integration:* Increase of the data aggregated by ARIADNE through incorporation of datasets from a greater number of archaeological research domains.
- *Data infrastructure:* Implementation and operation of a Cloud-based platform for data aggregation, integration, discovery, access and use across across institutional and national, as well as disciplinary boundaries.
- *Service portfolio:* Provision of enhanced and new services and environments for digital archaeology on the Cloud-based platform.

Structure and content of the report

This report presents the implementation of the project innovation strategy, the activities and results achieved to date, and planned further innovation activities within and beyond the formal lifecycle of the project.

Chapter 2 describes how ARIADNEplus builds on the achievements of the initial ARIADNE project and gives an overview of the goals for the different dimensions of the innovation strategy.

Chapter 3 highlights the alignment of ARIADNEplus with the current European policies regarding FAIR research data and repositories, Open Science practices, and the European Open Science Cloud (EOSC) initiative.

Chapter 4 describes the elements of the innovation strategy which concern the stakeholder community, standardisation and integration of archaeological datasets, and providing research data services and environments for digital archaeology.

Each of the thematic sections of the chapters 3 and 4 outline the respective innovation strategies, describe background and developments, and summarise related innovation activities and results.

Outlook

This report is presented in month 40 of 48 of the lifecycle of the ARIADNEplus project. In the final eight months the project will complete the activities of the current plan of activities of the innovation strategy.

A first impact evaluation report was delivered in July 2021 (D6.2) showing good results across all lines of project activities. The final account and evaluation of the outcomes and impacts will be presented in December 2022 (D6.4). Also in December 2022 the sustainability plan (D6.5) will be presented. The plan will have special focus on the sustainability of the service provision beyond the funded period of the project.

2 Overview of the innovation strategy

This chapter highlights how ARIADNEplus builds on the achievements of the initial ARIADNE project and gives an overview of the goals for the different dimensions of the innovation strategy.

2.1 Building on the achievements of the initial ARIADNE project

The initial four-year ARIADNE project (until January 2017) was an Integrating Activity funded under the 7th Framework Programme of Research and Development (FP7) of the Europen Union. The second round, ARIADNEplus, funded from January 2019 to December 2022 under the EU Horizon 2020 Programme is also such a project. An Integrating Activity aims to integrate, within the European Research Area (ERA), the community of a field of research.

The overall objectives of the first round of the ARIADNE initiative have been to build a community of archaeological institutions in Europe interested in making their data findable and accessible through a digital research infrastructure. The infrastructure should aggregate and integrate records of data items from their repositories and databases, and provide a portal for discovering and accessing items in the distributed sources. Support for the data sharing community focused on guidance in the preparation of what nowadays is commonly called FAIR data, particularly use of common data models and vocabularies to enable interoperability for search and access.

2.1.1 Key achievements of ARIADNE

The ARIADNE Impact Report addresses all impact areas and gives a detailed account of ARIADNE's achievements (ARIADNE 2017a). The report states that the project achieved good results in all evaluation areas, and highlights that it:

- Accomplished its goal to provide a digital infrastructure and services for searching and accessing archaeological data in repositories and databases of institutions in different European countries;
- Increased interoperability of datasets based on a common model (ARIADNE Catalogue Data Model), improved vocabularies (e.g. vocabulary mapping tools), and other methods;
- Implemented a European-level data portal providing advanced search capability for 'what' (subjects), 'where' (location) and 'when' (cultural chronology / date ranges).
- Made available additional high-value services (e.g. 3D artefact and landscape services), and demonstrated advanced capability in making data more accessible and useful (e.g. fieldwork reports through metadata extraction with natural language processing methods);
- Achieved a large 'footprint' in the sector regarding the numbers of institutions and researchers that have been informed and involved, including potential providers of additional datasets.

The core of the ARIADNE project has been the building of a European-level platform where dispersed archaeological data resources can be registered, shared, discovered and accessed (Aloia et al. 2017). Such a platform did not exist before and its implementation arguably is ARIADNE's key innovation for the archaeological community in Europe (and beyond). The ARIADNE Impact Report concludes that the project not only had a strong impact, but that it could become a lasting impact, especially by exploiting the high potential for further advances provided by the data sharing and access infrastructure.

2.1.2 Realising the full potential

ARIADNE built a solid basis for the next steps in data sharing and use for research across institutional and national, as well as disciplinary boundaries. ARIADNE established a common platform for archaeological data sharing, discovery and access, and seeded it with representative datasets from repositories and databases of project partners. The digital infrastructure and services span the whole chain from data aggregation to search and access services for the integrated data.

ARIADNEplus extends the coverage of ARIADNE for regions, time-spans, and archaeological domains, and provides a Cloud-based platform that in addition to the data search and access portal offers enhanced and new research-focused services.

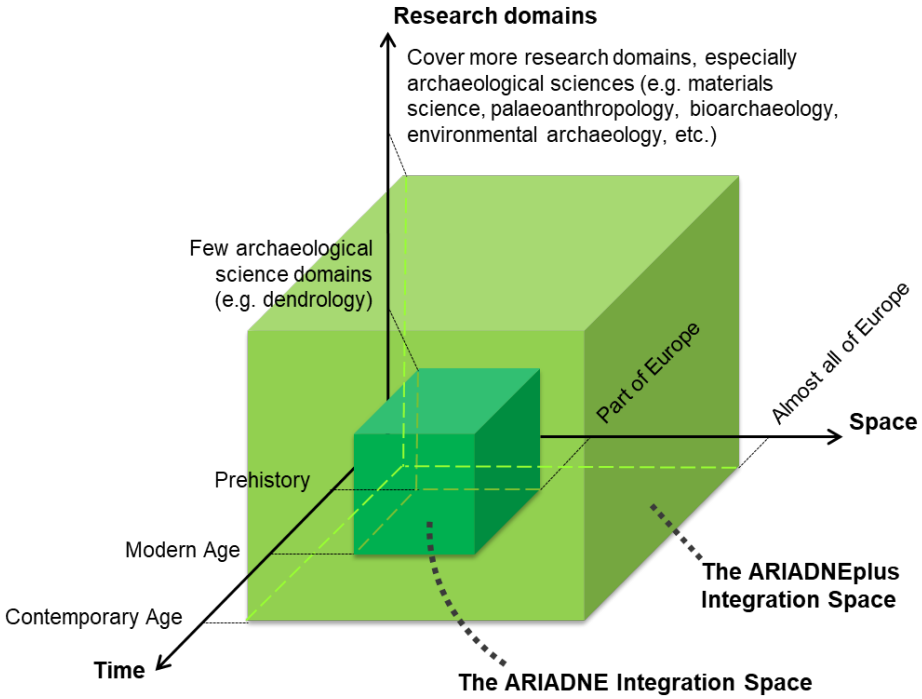

Figure 1: Extension of the ARIADNE integration scope in time, space and content.

Figure 1 illustrates how ARIADNEplus progressively extends the integration scope regarding archaeological research domains, time-span and geographic coverage.

ARIADNE mainly integrated data records from monument and site inventories, excavation archives, fieldwork reports and artefact databases, along with a few specialist topics such as, for example, dendrochronology. ARIADNEplus incorporates datasets from a wide range of research domains, e.g. archaeological materials science, bioarchaeology, environmental archaeology, among others. Indeed, the ARIADNE initiative aims to progressively extend its research communities and data integration scope, expand the thematic, geographic as well as time-span coverage, pushing it back to the earliest traces of human presence on Earth and forward to recent times.

The ARIADNE consortium had 23 partners while ARIADNEplus comprises 37 formal partners in 23 European countries and one each in Israel, Japan, Argentina and the United States. Thus the initiative is more strongly present now not only around Europe, but also in other world regions.

The ARIADNEplus network was extended further by the addition of 16 associate institutions and projects, including heritage authorities, archaeological institutes, as well as domain research and

technology centres.[1] Associates extend the footprint of ARIADNEplus to additional European countries as well as thematically, e.g. through the ROCEEH project in the field of Palaeanthropology in regions of Africa, the Levant, Eurasia and Europe.

2.2 Dimensions and goals of the innovation strategy

The ARIADNEplus innovation strategy aims to bring about significant advances of archaeological research and data management regarding different dimensions. The main dimensions are alignment with the latest European research policies, extension of the stakeholder and user community, integration of datasets from many archaeological research domains, and a portfolio of e-infrastructure services for digital archeology.

The goals of the innovation strategy for these dimensions are summarised in the sections that follow. Chapters 3 and 4 outline in greater detail the respective innovation strategies, describe background and developments, and summarise related innovation activities and results.

High-level overview of the innovation strategy

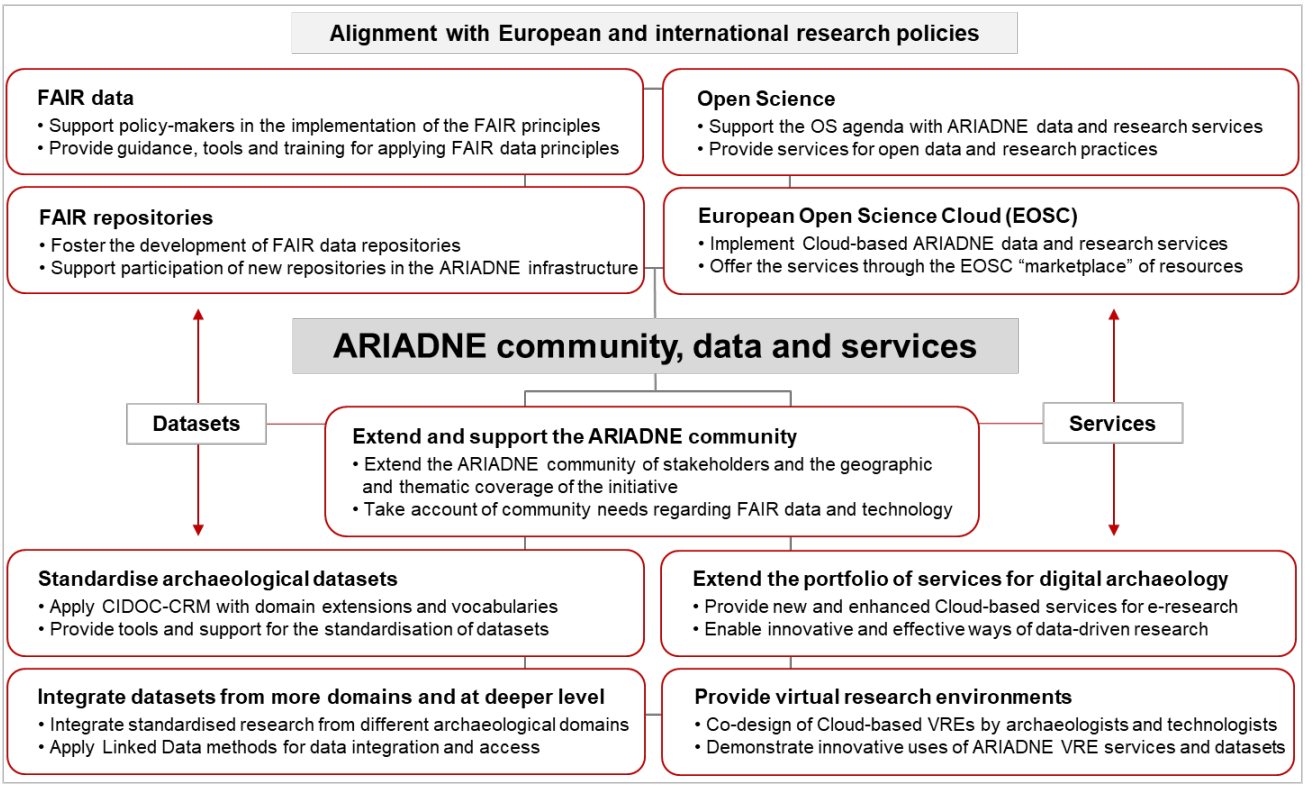

Figure 2: High-level overview of the innovation strategy.

[1] ARIADNEplus: Associate Partners, https://ariadne-infrastructure.eu/associate-partners2/

2.2.1 Alignment with European research policies

FAIR data

- Support domain policy-making bodies in the implementation of the FAIR data principles in archaeological research and data management.
- Foster FAIR data practices of researchers and data managers through guidelines, training workshops and learning resources.
- Provide tools for FAIR data management, e.g., online Data Management Plan templates and guidance.

FAIR repositories

- Collaborate with the SEADDA COST Action to foster the development of FAIR archaeological data repositories in countries where the research community lacks an appropriate repository.
- Help initiatives for new repositories plan participation in the ARIADNE data infrastructure already at an early stage, and support advanced initiatives with available services, for example, use of data description and mapping services for their datasets.

Open Science

- Support the Open Science agenda in archaeology with the research data services of the ARIADNE initiative, enabling sharing and (re)use of archaeological data across institutional and national, as well as disciplinary boundaries.
- Provide tools and services for open data practices, from planning FAIR data sharing to a portal for discovery and (re)use of shared data

European Open Science Cloud (EOSC)

- Develop Cloud-based ARIADNEplus data and research services to avoid scholars implementing and maintaining information technology and software, instead focusing on their research tasks.
- Cooperate with other e-infrastructures for digital humanities and heritage research regarding synergies, e.g., through harmonisation of data catalogues.
- Create a mapping between the ARIADNEplus catalogue model and the EOSC model for data and research services, and provide services through the EOSC.

2.2.2 ARIADNE community, data and services

ARIADNE community

- Maintain and extend the community of stakeholders that support sharing of archaeological research data through the ARIADNE data infrastructure, including stakeholders of non-European countries.
- Expand the geographic and thematic coverage of the ARIADNE initiative by taking on board associate institutions and projects.
- Take account of needs of archaeological researchers, data managers and repositories to ensure that the technical and other services such as training meet their requirements.

Standardisation of datasets

- Foster the standardisation of archaeological datasets based on the ISO standard CIDOC Conceptual Reference Model (CIDOC-CRM), domain-specific extensions of this ontology, and core domain vocabularies (e.g., PeriodO for cultural periods, Getty AAT for subjects of datasets).
- Provide tools for mapping datasets to the CRM and domain extensions of the ontology as well as for mapping national and institutional vocabularies to the large and multilingual Getty AAT thesaurus.

Integration of datasets from more domains and at deeper level

- Integrate data from a wider range of archaeological research domains than the original ARIADNE project, e.g. palaeoanthropology, bioarchaeology, environmental archaeology, marine and underwater archaeology, mortuary archaeology, built structures, inscriptions (epigraphy, rock carvings), scientific analyses of materials and dataing.
- Enhance the CIDOC-CRM based ARIADNE data catalogue model and create CRM-based Application Profiles to cover datasets as well as individual items from the extended range of archaeological domains.
- Apply Linked Data methods and technology for data integration and discovery and access on the ARIADNE data portal. Provide also programmatic access to the knowledge graph of the Linked Data to explore semantic relations between data for research questions as well as to reuse and interlink ARIADNE data with other datasets.

Extending the portfolio of services for digital archaeology

- Offer Cloud-based data and research services to avoid scholars investing effort to implement and maintain information technology and software for research.
- Enhance the search facilities of the Cloud-based data portal to provide an effective research tool, e.g., explore patterns in integrated data and compare results for different regions and cultural periods.
- Provide a range of new and enhanced services for data-based archaeological research beyond what the data portal allows, e.g., analysing many data objects (e.g. natural language processing of documents) as well as studying single objects (e.g. 3D models).

Providing virtual research environments

- Foster co-design of Virtual Research Environments (VREs) by archaeologists and technology experts.
- Provide Cloud-based VREs that combine services as needed by archaeological researchers of different domains.
- Demonstrate innovative uses of VRE services and datasets in ARIADNEplus pilots.

The chapters that follow outline the different innovation dimensions and respective strategies in greater detail, describe background and developments, and summarise related innovation activities and results.

3 Alignment with European research policies

The ARIADNEplus innovation strategy is aligned with the current European policies regarding FAIR research data and repositories, Open Science practices, and the European Open Science Cloud (EOSC) initiative. The sections of this chapter outline the respective ARIADNEplus innovation strategies, describe background and developments, and summarise related innovation activities and results.

3.1 FAIR data

3.1.1 Project FAIR data strategy

Application of the principles of FAIR data (Findable, Accessible, Interoperable and Reuseable) has become a cornerstone of the research data policy of the European Commission and national research funders (Expert Group on FAIR Data 2018). Available FAIR data are also a core requirement for the success of the European Open Science Cloud initiative (EOSC FAIR Working Group 2020).

ARIADNEplus is funded under the Horizon 2020 Programme as the Integrating Activity for archaeological research datasets. ARIADNEplus therefore is committed to promote the FAIR data agenda in the archaeological sector in Europe (and beyond), in line with the respective policies of the European Commission and EU member states.

The promotion and support of the FAIR data agenda by ARIADNEplus takes various forms, including support of major archaeological organisations for promoting the agenda, provision of guidance and tools FAIR data management plans (DMPs), FAIR as part of training activities, and an online hub of training materials.

3.1.2 Background and developments

Over the last few years the FAIR data principles, published in April 2016, have been adopted by different stakeholders for the sharing and reuse of research data through data repositories and infrastructures, including the ARIADNE initiative.

The FAIR data principles require "*that all research objects should be Findable, Accessible, Interoperable and Reusable (FAIR) both for machines and for people"* (Wilkinson et al. 2016). The 15 principles address important attributes of research data, for example, globally unique and persistent identifiers, rich metadata, use of community vocabularies, registration in a searchable resource, and release with a clear data usage license (Wilkinson et al. 2016; see also Mons et al. 2017). The European Commission has brought together an Expert Group on FAIR Data to analyse what is needed for "turning FAIR into reality" and suggest concrete actions for all stakeholders (Expert Group on FAIR Data 2018).

Compliance of research data with the FAIR principles is seen as an important success factor for the European Open Science Cloud (EOSC), which is intended to federate and provide access to services of national and thematic research e-infrastructures, including FAIR data services. Many initiatives and projects are supporting the FAIR data agenda, e.g., FAIRsFAIR[2], GO-FAIR[3], RDA FAIR Data Maturity

[2] FAIRsFAIR, https://www.fairsfair.eu

[3] Go-FAIR, https://www.go-fair.org

Model WG[4], among others. But the effort to realise and manage large volumes of FAIR data from all disciplines as envisaged for the EOSC will be substantial.

While there is a FAIR "boom" in the international research data management community no wide knowledge among researchers of how to apply the principles can be assumed. In the large Figshare 'State of Open Data' surveys, the percentage of researchers who claimed to be familiar with FAIR increased from 15% in 2018 to 28% in 2021. Other respondents had heard of FAIR, but did not consider themselves familiar with the principles (2021: 38%), or had never heard of the principles (2021: 34%).[5] David et al. (2020) warn that "FAIRness literacy" of researchers is the Achilles' heel of applying the principles, and underline that for developing such literacy it must be made clear what the principles require in practice.

It is expected that research funders will in future make data-related costs eligible for FAIR data only. This will require a lot of investment in training of FAIR data managers of research organisations, repositories and other research infrastructure. Barend Mons, chairman of the first High Level Expert Group on the EOSC, estimates that for the EOSC to be successful over the next decade 500,000 data managers would need to be trained to make research data FAIR, one data expert per 20 researchers (Mons 2016).

ARIADNEplus and the FAIR principles

The ARIADNEplus project is committed to developing and sharing expertise in the application of the FAIR principles in the field of archaeological research and data management. In the ARIADNEplus community needs survey in 2019, how to apply FAIR data principles in archaeology ranked at the top of suggested training offers for researchers and data managers, with 94.5% of respondents considering this as helpful or very helpful (67.3% very helpful) (ARIADNEplus 2019: 121).

The adoption of the FAIR principles is being promoted by project activities that provide practical guidance and materials, training and tools (e.g. online templates) for good practice in research data management and sharing, and evaluate the take-up of FAIR data practices (e.g., by archaeological data repositories). The activities address archaeological research organisations, researchers and repository managers, and are present in different project work packages and tasks.

From these activities significant contributions to capacity building and take-up of the FAIR principles are expected. The contributions are as practical as possible, distinct from the broad wave of available general information on the FAIR principles. ARIADNEplus guidance and training on FAIR data focuses on what matters for archaeological researchers and data managers specifically. There is a now a growing interest of archaeologists in FAIR data management. The latest ARIADNEplus training workshop on the tools for data management planning (29 March 2022) had 89 participants (ARIADNEplus 2022c), compared to 42 participants in a workshop two years earlier (17 March 2020).

ARIADNEplus also supports the European Archaeological Council (EAC) and the European Association of Archaeologists (EAA) for the implementation of the FAIR data agenda in the European sector of archaeology. The EAC Board proposed a collaboration with ARIADNEplus on the promotion of the FAIR principles, and the EAC has chosen ARIADNEplus' sister project SEADDA for this purpose as its network comprises partners from almost all European countries. Representatives of both institutions sit on the Strategic Advisory Board of ARIADNEplus ensuring a regular exchange on related matters (see *Section 4.1.2*).

[4] Research Data Alliance: FAIR Data Maturity Model WG, https://www.rd-alliance.org/groups/fair-data-maturity-model-wg

[5] Figshare (2018, 2019, 2020, 2021); see also Khodiyar 2021.

An essential contribution by ARIADNEplus to the FAIR data agenda in the sector are the results of the survey of FAIR and open access archaeological repositories (see *Section 4.1.2*). ARIADNEplus has also been present with presentations on FAIR archaeological data at conferences of the European Association of Archaeologists (EAA), Computer Applications in Archaeology (CAA) International, and others.

At the international level a collaboration on the implementation of the FAIR data principles in archaeology has been initiated related to the Coalition for Archaeological Synthesis (CfAS)[6], involving American and European archaeological research centres and data repositories. The overall goal of CfAS is to advance comparative and synthetic research in archaeology for which FAIR datasets are required to enable aggregation and analysis.

An application in 2020 for a grant of the US National Science Foundation (NSF) for workshops of the international collaboration on FAIR data was graded highly, but the NSF ran out of funding that year and invited the applicants to resubmit. Recently a proposal for a much larger 3-year grant under the NSF FAIROS (FAIR Open Science) Programme[7] has been submitted jointly by the Alexandria Archive Institute (Open Context repository, USA) and the ARIADNEplus partners Digital Antiquity (tDAR repository, USA) and Archaeology Data Service (UK).

3.1.3 Innovation activities and results

The innovation activities in brief

- Support domain policy-making bodies in the implementation of the FAIR data principles in archaeological research and data management.
- Foster FAIR data practices of researchers and data managers through guidelines, training workshops and learning resources.
- Provide tools for FAIR data management, e.g., online Data Management Plan templates and guidance.

Selected highlights of results

- *Collaboration with major European archaeological bodies on the FAIR data agenda in archaeology:* ARIADNEplus supports the European Archaeological Council (EAC) and the European Association of Archaeologists (EAA) for the implementation of the FAIR data agenda in the European sector of archaeology. Representatives of both institutions sit on the Strategic Advisory Board of ARIADNEplus ensuring a regular exchange on related matters. An essential contribution by ARIADNEplus to the FAIR data agenda in the sector are the results of the survey of FAIR and open access archaeological repositories (see *Section 4.1.2*).
- *Responding to the demand for practical FAIR guidelines:* Researchers and data managers in the fields of humanities and cultural heritage increasingly look for practical guidelines on what is meant by FAIR data and how to create and make it available for reuse. For this purpose ARIADNEplus promoted the PARTHENOS FAIRify Guide that is available in nine languages. At present the guide has been downloaded 3,258 times from the Zenodo repository[8], with an increase of the unique downloads of 32.3% in the last 10 months.

[6] Coalition for Archaeological Synthesis (CfAS), http://www.archsynth.org

[7] NSF FAIROS (FAIR Open Science) programme, https://www.nsf.gov/pubs/2022/nsf22553/nsf22553.htm

[8] PARTHENOS: Guidelines to FAIRify data management and make data reusable. Zenodo, https://doi.org/10.5281/zenodo.3368858

- *Providing tools for archaeological FAIR Data Management Plans (DMPs):* ARIADNEplus provides interactive online tools and guidance for DMPs[9] which allow archaeologists create plans that conform to the requirements of the European Framework Programme and Science Europe, the association of major public research funders and research organisations in Europe. The tools and guidance support creating domain-specific DMPs so that archaeological projects funded by other organisations will also benefit from using them.
- *Promoting data-related good practices:* To support data-related good practices ARIADNEplus also offers the Training Hub[10], populated with Web-accessible resources selected specifically for archaeological researchers and data managers. The thematically grouped resources (currently 67) from both partners and other providers are in formats such as online courses, training modules with videos, downloadable tools and tutorials, and more.

Further activities within and beyond the project

- *Training and support for FAIR:* Continue providing training and other support for FAIR data management by archaeological researchers and data managers.
- *Beyond the project:* Further promote the use of the FAIR data management guidance and tools. Training will be provided by partners whose missions include this tasks, i.e., university institutes, research centres and data repositories.

3.2 FAIR repositories

3.2.1 Project FAIR repositories strategy

The objective of the ARIADNE data infrastructure is to allow researchers and other users to discover and access archaeological data held and shared by repositories across Europe and beyond. But in many countries there is a lack of FAIR data repositories where archaeologists can safely archive and make accessible the data of their projects.

This issue is being addressed by ARIADNEplus' sister project Saving European Archaeology from a Digital Dark Age (SEADDA)[11], a COST Action that is being led by the ARIADNEplus partner Archaeology Data Service (ADS). Several partners and institutions from other countries are members of the SEADDA network, with representation from nearly all European countries, not only those in the EU.

SEADDA fosters the development of FAIR archaeological data repositories in countries where the research community still needs an appropriate repository, while ARIADNEplus supports finding and accessing data that is being shared through existing and new repositories. In this strategy for FAIR repositories ARIADNEplus provides the perspective for new repositories of data federation and integration in the European and international pool of shared archaeological data.

3.2.2 Background and developments

Sharing of FAIR research data requires trusted data repositories. This is one of the key recommend-dations of the *Turning FAIR into Reality* report which states: *"Research data should be made available by means of Trusted Digital Repositories, and where possible in those with a mission and expertise to*

[9] ARIADNEplus Data Management Plan Tools, https://vast-lab.org/dmp/index.html

[10] ARIADNEplus: Training Hub, http://www.training.ariadne-infrastructure.eu

[11] SEADDA - Saving European Archaeology from the Digital Dark Age https://www.seadda.eu

support a specific discipline or interdisciplinary research community" (Expert Group on FAIR Data 2018: 43).

That discipline-specific repositories will suit the FAIR requirements best is also emphasised in a report of the All European Academies (ALLEA) on FAIR data sharing in the humanities. The report recommends: *"Use disciplinary repositories where they exist, as they are more likely to be developed around domain expertise, disciplinary practices and community-based standards, which will promote the findability, accessibility, interoperability and ultimately the reuse and value of your data. The level of curation available in a repository is key to data quality and reusability"* (ALLEA 2020: 29).

But many archaeologists in European and other countries do not yet have available such a repository where they can deposit and make their data available to the research community and other users. Ideally such a repository has a national scope and is mandated by research funders for depositing data from archaeological investigations. This provides advantages in several respects, including clear orientation of all stakeholders, expertise in archiving archaeological data, cost-effectiveness of data curation and access (e.g. economies of scale), among others. From the perspective of ARIADNEplus one or only few core repositories per country from which data records can be aggregated is of course the preferred scenario (Geser 2019a; Geser 2019b: 195-196).

Benchmarks for national-level archaeological data repositories exist, for example, the Archaeology Data Service (UK)[12] and the Data Station of DANS (Netherlands)[13], both are ARIADNEplus partners. In the United States, Digital Antiquity at the Arizona State University (also a partner in ARIADNEplus) aspires to provide a national-level repository with tDAR, The Digital Archaeological Record[14] (McManamon et al. 2017; Witze 2019). Digital Antiquity is a collaborative organisation that involves many institutions and is being supported by the Society for American Archaeology. ARIADNE has inspired project partners in other countries to promote the building of archaeological repositories or collections in their country (see the articles in Richards and Niccolucci 2019).

In European and other countries much effort will be necessary to create more data archiving solutions so that archaeologists can safely deposit and make FAIR data available to the research community and other users. Existing document repositories within university libraries and other institutions are considered inadequate for disciplinary research data. Curation requires dedicated data repositories and curators with a background in the respective domains (on stewardship of archaeological data see Wright and Richards 2018).

ARIADNEplus and FAIR archaeological repositories

Thanks to the large network of members of ARIADNEplus' sister project SEADDA the lack of appropriate repositories for archaeological data is being addressed in many European countries and beyond. The SEADDA network brings archaeologists and FAIR data management specialists together to share expertise, provide knowledge and training in matters of data archiving and access, and help archaeological communities to address problems in the most appropriate way within their own countries.

In the division of work with SEADDA, ARIADNEplus provides developers of new repositories the perspective of data federation and integration in the European and international pool of shared archaeological data. ARIADNEplus can help new repositories plan participation in the research

[12] Archaeology Data Service (UK), https://archaeologydataservice.ac.uk

[13] Data Station Archaeology, formerly the E-Depot for Dutch Archaeology (Netherlands), https://dans.knaw.nl/en/data-stations/archaeology/

[14] tDAR - The Digital Archaeological Record (USA), http://www.tdar.org

infrastructure at an early stage, so that subsequently, records of FAIR data can be easily aggregated and integrated.

For example, the British Institute at Ankara (BIAA), a member of SEADDA, holds documentation of archaeological research in Turkey and the Black Sea region from the 1940s to the present day. Since 2019 they have been preparing datasets and implementing a digital repository (Çayırezmez 2020; Çayırezmez et al. 2021). In 2021, the BIAA become an associate partner of ARIADNEplus and is working to provide data to the ARIADNE initiative.

3.2.3 Innovation activities and results

The innovation activities in brief

- Collaborate with the SEADDA COST Action to foster the development of FAIR archaeological data repositories in countries where the research community lacks an appropriate repository.
- Help initiatives for new repositories plan participation in the ARIADNE data infrastructure already at an early stage, and support advanced initiatives with available services, for example, use of data description and mapping services for their datasets.

Selected highlights of results

- *Survey of archaeological repositories – knowing where they stand regarding FAIR and open access data:* In 2021 ARIADNEplus conducted a survey of archaeological repositories for an evaluation to what extent their current data policies and practices conform to ideals of FAIR and open access data, which increasingly inform regulations of research funders, councils and other institutions (Geser et al. 2022). 60 repositories within the SEADDA network and others participated in the survey which makes this reality check the largest thus far for repositories of one discipline. Based on the results, suggestions are given for required advice and support for further progress towards FAIR and open access data, where necessary (see *Section 4.1.2*).
- *Supporting new FAIR data repositories to contribute to the ARIADNE initiative:* New repository projects can plan contributing to the ARIADNE initiative early on in their development. ARIADNE-plus provides expert support and tried-and-tested tools for the integration of their data in the European and international pool of shared archaeological data.

Further activities within and beyond the project

- *Continue supporting new repositories:* Continue the collaboration with SEADDA and support new repositories with tools for preparing integration of their data in the European and international pool of shared archaeological data.
- *Beyond the project:* Keep monitoring the development of new repositories for future integration.

3.3 Open Science

3.3.1 Project Open Science strategy

ARIADNEplus' EU-funded research data infrastructure supports the Open Science agenda set by the European Commission and the related ambitions of the archaeological community for FAIR and open access data. Open Science using shared digital tools and data is expected to enable novel forms of research collaboration and more accessible research results, extending the societal relevance and reach of archaeological knowledge. ARIADNEplus provides essential means for Open Science, from tools for FAIR data management planning of archaeological projects to the aggregation and integration of shared data in a portal for discovery, access and (re)use across institutional and national, as well as disciplinary boundaries.

3.3.2 Background and developments

The vision of Open Science is making the research process and results as transparent and accessible as possible in order to advance scientific knowledge and increase innovation and societal benefits through science and technology. In the expected transformation of research practices through Open Science innovative ICT-enabled research is understood to play a key role. Open Science using digital methods and tools can enhance research collaboration, involvement of citizens, and transparency and relevance of more accessible research results.

In practice, proponents have different perspectives on Open Science and emphasise some aspects more than others. Fecher and Friesike (2014) distinguish five Open Science schools of thought that centre on different goals: openly available platforms, tools and services for research; collaborative knowledge creation; making science and scientific knowledge accessible for everyone; enabling participation of citizens; and the creation of new metrics for relevant impacts of scientific work.

The core but difficult to grasp element of Open Science is "openness". A report of the ERA-net project e-InfraNet discusses the concept of openness in the contexts of research, content/data, software, infrastructure, standards, and innovation. The report suggests openness as the *"default modus operandi"* for all publicly funded research and educational resources, with "open" as the preferable approach *"not as an end in itself or as an ideology"* (e-InfraNet 2013: 10).

Open Science was introduced as a priority and guiding principle of research policy at the European level by Carlos Moedas, the Commissioner for Research, Science and Innovation, 2014-2019. The Commissioner adopted the concept of "open innovation" and pushed for more openness of research in the European Research Area (ERA). A commissioned study describes the background and requirements for this initiative (European Commission 2016b).

From 2016 to 2020 the Open Science Policy Platform (OSPP) expert group advised the European Commission on how to further develop and practically implement Open Science policy. In 2018 the OSPP issued recommendations for several ambitions of the European Commission for Open Science (OSPP 2018). The ambitions concern the FAIR data agenda (see *Section 3.1*) and the European Open Science Cloud (see *Section 3.4*); incentives and rewards for researchers to engage in open science practices; development of skills and new metrics for such practices (e.g. altmetrics); agreed standards of research integrity and reproducible research results; and enabling the general public to make significant and recognised contributions (citizen science).[15] In their final report, the OSPP members outlined for these ambitions practical commitments for implementation, barriers and examples of

[15] See also: European Commission: Open Science, https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/our-digital-future/open-science_en

progress of different stakeholders, and a vision to create a shared research knowledge system by 2030 (OSPP 2020).

In European Commission research policy documents the term Open Science is now being used regularly when open access to research outputs such as publications, data, software, algorithms, etc. is addressed. The clearest expression of the Commission's priorities in formal terms are the mandatory rules to follow by researchers of projects funded under the Horizon Europe programme (see the overview in Openscience.eu 2022). The rules focus on open access to the research results (publications, data) and other measures to ensure reproducibility.

Going beyond these rules, recommended open science practices, for example, include open collaboration with citizens to co-create research & innovation agendas and content (e.g., citizen science), participation in open peer-review, use of open research infrastructures for knowledge and data sharing (European Commission 2021).

The ambitions of the European Commission are not the only ones, and for many researchers not the primary reference regarding Open Science. Among the numerous possible references one merits to be highlighted, the UNESCO *Recommendation of Open Science.* Adopted by the 41st Session of the UNESCO General Conference in November 2021, this elaborated document represents the broadest consensus on Open Science worldwide.

ARIADNEplus and Open Science

Open Science is of course also highly relevant for archaeological research and data access and (re)use supported by ARIADNEplus. Open Science using shared digital tools and data is expected to enable novel forms of research collaboration and more accessible research results, extending the societal relevance and reach of archaeological knowledge.

The needs and challenges of open research practices and resources have been discussed in the archaeological community (e.g. Aspöck 2019; Beck & Neylon 2012; Beck 2013; Costa et al. 2012; Fernández Cacho 2021; Kansa 2012; Lake 2012; Wilson & Edwards 2015). A widely referenced publication on *Open Science in Archaeology* by Marwick et al. (2017), a large group of recognised archaeological researchers, has greatly added to the awareness of the open research and data agenda in the field.

An open data imperative is particularly strong in this field: archaeological research and preventive work is generally done in the public interest, and excavations destroy primary archaeological evidence, therefore their documentation should be openly accessible. Openness should become embedded in archaeological practices as *"the default modus operandi"* (e-InfraNet 2013) so that the collected data is available for further research on past cultures and generation of knowledge relevant for current societal issues (e.g. climate change, environmental issues, migration).

ARIADNEplus supports the Open Science agenda set by the European Commission and the ambitions of the archaeological community in this regard. ARIADNEplus provides a research data sharing infrastructure and therefore has a focus on the FAIR and open data part of the agenda, from tools for FAIR data management of researchers (see *Section 3.1.3*) up to the data discovery and access portal and other research data services (see *Section 4.4.2*). Furthermore, the D4Science platform ARIADNE-plus uses supports Open Science practices such as sharing of research procedures and software (Assante et al. 2019).

3.3.3 Innovation activities and results

The innovation activities in brief

- Support the Open Science agenda in archaeology with the research data services of the ARIADNE initiative, enabling sharing and (re)use of archaeological data across institutional and national, as well as disciplinary boundaries.
- Provide tools and services for open data practices, from planning FAIR data sharing to a portal for discovery and (re)use of shared data.

Selected highlights of results

- *Support of the Open Science agenda in archaeology:* The research data services of the ARIADNE initiative support the Open Science agenda set by the European Commission, particularly the ambitions of the archaeological research community for FAIR and open data practices.
- *Providing essential means for Open Science:* ARIADNEplus provides essential means for Open Science, from tools for FAIR data management of archaeological projects (see *Section 3.1.3*) to the integration of shared data in a portal for discovery, access and use across institutional and national, as well as disciplinary boundaries (see *Section 4.4.2*).

Further activities within and beyond the project

- *Continue supporting the Open Science agenda:* Keep supporting the Open Science agenda in archaeology with the research data sharing services of the ARIADNE initiative.
- *Beyond the project:* Maintain the services supporting FAIR and open data practices of archaeological researchers and data managers.

3.4 European Open Science Cloud (EOSC)

3.4.1 Project Cloud strategy

ARIADNEplus follows the vision of the European Open Science Cloud (EOSC) by providing a wide range of data services for researchers and other users on a Cloud-based platform. While ARIADNEplus enabled this on the fully operational D4Science Cloud platform[16], federation of services of ARIADNEplus and other providers by the EOSC is expected to allow improved use of resources, economies of scale and cost-savings across research e-infrastructures. The federation will be established based on catalogues of e-infrastructure resources (e.g., services, software, data) that provide information to the EOSC "marketplace". Among other uses this will enable e-infrastructures in the EOSC eco-system accessing available resources relevant for their users, e.g., ARIADNEplus research and data services, and vice versa.

3.4.2 Background and developments

The European Open Science Cloud (EOSC) initiative, launched in April 2016 (European Commission 2016a), aims to provide a trusted virtual platform for researchers to make accessing and using available services of research e-infrastructures of different countries and disciplines easier and more efficient. The overall goals of the EOSC are to remove the current lack of integration of research e-

[16] D4Science (CNR-ISTI, Pisa, Italy), https://www.d4science.org

infrastructures, support the sharing and (re)use of services and FAIR data resources, and promote Open Science practices (as addressed above).

A Commission Staff Working Document (2018) gives an overview of the EOSC implementation roadmap. It describes the EOSC model by distinguishing six lines of required implementation actions. These action lines are for *"a pan-European federation of data infrastructures built around a federating core and providing access to a wide range of publicly funded services supplied at national, regional and institutional levels, and to complementary commercial services"* (European Commission 2018a: 9). The working paper summarises the action lines in a figure that presents the general setup of the EOSC (Figure 2).

Figure 2: The six lines of action of the EOSC model. Source: European Commission 2018a: 9.

The "Architecture" section makes clear that the EOSC, implemented as a federation of infrastructures, should provide *"the solution to the current fragmentation in research data infrastructures which are insufficiently interoperable"*. Regarding "Data" the core role of the FAIR data principles is highlighted.

In November 2018 the initial EOSC Portal was launched. It was built and maintained by the first wave of EOSC-related projects, and developed further by the EOSC Enhance project as a gateway to information and resources in EOSC.[17] From 2019-2021 the EOSC initiative was coordinated by the EOSC Executive Board and its working groups, supported by the EOSCsecretariat.eu.[18] Multiple projects funded by Horizon 2020 have helped the initiative progress towards the creation of an EOSC ecosystem and engaging a wide range of stakeholders and communities.

The current implementation phase under Horizon Europe is being coordinated by the EOSC Association[19] and its Task Forces, based on a Co-programmed European Partnership with the European Commission. Key reference documents are the Memorandum of Understanding (MoU) established between the EOSC Association and the European Commission (EOSC Partnership 2021), and the Strategic Research and Innovation Agenda (SRIA) of the partnership (EOSC Executive Board 2021).

[17] EOSC Portal, https://eosc-portal.eu/about-eosc-portal

[18] EOSCsecretariat.eu, https://www.eoscsecretariat.eu

[19] EOSC Association, https://www.eosc.eu

Concerning the technical setup, the EOSC initiative, supported by EOSC-Future[20] and other projects, is expected in the current implementation phase (2021-2022) to provide the core functions of an operational EOSC ecosystem:

"The system will be based on three layers: (1) the federating core (or EOSC-Core), (2) the federation of existing and planned research data infrastructures, and (3) a service layer comprising common services and thematic services (EOSC-Exchange). Building on existing research data infrastructures, EOSC will grow through a series of iterations. Each iteration will add more functionalities and services for a wider user base and satisfy a broader range of use cases" (EOSC Executive Board 2021: 56-57).

Thus the EOSC will depend on a federation of services from research e-infrastructures that will be brought together in a pool of services, provided by the EOSC-Exchange layer as a catalogue and marketplace of available services[21] (for more details see EOSC Executive Board 2021: 66-73).

Most important to note is that these services are intended to support the entire lifecycle of data but will be provided by the underlying research e-infrastructures, not the EOSC: *"While the EOSC-Core does provide frameworks to discover, share, access and reuse resources, it is the services federated via the EOSC-Core that actually transfer, store, process or preserve research data"* (EOSC Executive Board 2021: 67).

Therefore for ARIADNEplus the core connection with the EOSC is the EOSC catalogue and marketplace. The EOSC catalogue serves as a register for research data services and other resources, while the marketplace is the entry point for researchers to the resources accessible via the EOSC.

ARIADNEplus and the EOSC

As elaborated by Niccolucci and Richards (2019), alignment and integration with the EOSC is part of the innovation objective and approach of ARIADNEplus, which is "*based on the provision of innovative and advanced web services in a cloud environment, coherent with the vision, and integrated in the implementation of the EOSC. ARIADNEplus will progressively set up an ecosystem for digital archaeological research which incorporates data and services and enables the use of cloud-based Virtual Research Environments (VRE)*". Further, referring to envisaged impact, *"The overall strategy with regard to improved use of resources, economies of scale and cost-savings is Cloud-based virtualisation and integration in the EOSC"* (Niccolucci and Richards 2019: 9 and 23).

ARIADNEplus follows the EOSC vision of providing a wide range of e-research services on a Cloud-based platform. Virtual Research Environments (VREs) on the platform will allow researchers to use such services for different archaeological research tasks and types of data (see *Section 4.5*). Providing research services and VREs online means researchers can invest less effort in acquiring and managing the tools themselves. The approach allows cost-savings for the research community, while also creating opportunities for research groups to jointly address research questions.

While this is enabled by ARIADNEplus on the fully operational Cloud-based D4Science platform[22], integration of ARIADNEplus, and other domain research e-infrastructures, with the EOSC will be established based on catalogues of domain resources that exchange information with the EOSC catalogue & marketplace (see above).

The ARIADNEplus AO-Cat (ARIADNE Object Catalogue) model (ARIADNEplus 2020b) is an enhanced version of the CRMpe model designed by the PARTHENOS e-infrastructures cluster project for social

[20] EOSC-Future (H2020, 4/2021- 9/2023), https://eoscfuture.eu

[21] EOSC Portal Catalogue and Marketplace, https://marketplace.eosc-portal.eu

[22] D4Science (CNR-ISTI, Pisa, Italy), https://www.d4science.org

sciences and humanities catalogues (Frosini et al. 2018).[23] While it has advanced considerably, the ARIADNEplus AO-Cat model still allows alignment and synergies with other humanities and heritage catalogues.

How to map the AO-Cat model (or parts of it) to the EOSC catalogue model to enable interoperability and (ideally) automatic exchange of information about data and research services is being investigated. But it is understood that ARIADNEplus will not register datasets in the EOSC as these are maintained by partner institutions and projects.

Regarding e-research services a mapping of the D4Science catalogue with the EOSC catalogue exists and descriptions of some Cloud-based services provided by CNR-ISTI for ARIADNEplus can already be found in the EOSC "marketplace"; for example, the Visual Media Service VRE[24] and the more generic RPrototypingLab VRE[25]. In general, a platform-level integration of the D4Science platform with the EOSC should allow connecting the ARIADNEplus part of D4Science in a transparent way with the EOSC (e.g., federated identity service).

ARIADNEplus also includes a research group, one of the "task forces" of the WP Innovation, that investigates synergies between the project and other research and data infrastructures in the field of humanities and heritage. This concerns synergies with infrastructures in which ARIADNEplus members participate, as well as others. Examples at the European level are DARIAH[26] (humanities), E-RIHS[27] (heritage science), Europeana[28] (cultural heritage), SSHOC[29] (social sciences & humanities); at the national level examples such as Huma-Num[30] (humanities) in France and NFDI[31] (NFDI4Culture: cultural heritage) in Germany.

3.4.3 Innovation activities and results

The innovation activities in brief

- Develop Cloud-based ARIADNEplus data and research services to avoid scholars implementing and maintaining information technology and software, instead focusing on their research tasks.
- Cooperate with other e-infrastructures for digital humanities and heritage research regarding synergies, e.g., through harmonisation of data catalogues.
- Create a mapping between the ARIADNEplus catalogue model and the EOSC model for data and research services, and provide services through the EOSC.

Selected highlights of results

- *Cooperation with other e-infrastructures:* ARIADNEplus continued its cooperation with relevant other e-infrastructure projects. For example, the Social Sciences and Humanities Open Cloud

[23] PARTHENOS (H2020, 5/2015-10/2019), http://www.parthenos-project.eu; CRMpe stands for CIDOC Conceptual Reference Model (CRM) – Parthenos entities (pe).

[24] EOSC Marketplace: D4Science Infrastructure: Visual Media Service VRE, https://marketplace.eosc-portal.eu/services/visual-media-service-virtual-research-environment

[25] EOSC Marketplace: D4Science Infrastructure: RPrototypingLab VRE, https://marketplace.eosc-portal.eu/services/rprototypinglab-virtual-research-environment

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

[27] E-RIHS - European Research Infrastructure for Heritage Science, http://www.e-rihs.eu

[28] Europeana, https://pro.europeana.eu

[29] SSHOC - Social Sciences and Humanities Open Cloud, https://sshopencloud.eu

[30] Huma-Num, http://www.huma-num.fr

[31] NFDI - German National Research Data Infrastructure, https://www.nfdi.de/association/?lang=en

(SSHOC) project recognises the ARIADNE infrastructure (portal & services) as one of the "SSHOCingly good and sustainable tools" (SSHOC 2022: 28-29), and it is also registered in the SSH Open Marketplace.[32]

- *Harmonisation of data catalogues:* The ARIADNEplus data catalogue model (AO-Cat) builds on the CRMpe model designed by the PARTHENOS e-infrastructures cluster project for SSH catalogues. While it has advanced considerably, the AO-Cat model still allows alignment and synergies with other humanities and heritage data catalogues.
- *Cloud-based ARIADNEplus data and research services:* ARIADNEplus develops new and enhanced services that are provided on the Cloud-based D4Science platform (see *Section 4.4*). This allows cost-savings for the research community and improved use of resources, e.g., when services are shared on the European Open Science Cloud (EOSC).
- *Sharing of data and research services through the EOSC:* A mapping of the D4Science services catalogue with the EOSC catalogue exists and descriptions of some Cloud-based services provided by CNR-ISTI for ARIADNEplus can already be found in the EOSC "marketplace" (e.g., the Visual Media Service and the more generic RPrototypingLab).

Further activities within and beyond the project

- *Sharing of more data and research services through the EOSC:* Share the Cloud-based ARIADNEplus services through the EOSC catalogue of services, allowing other research e-infrastructures and centres in the EOSC eco-system access ARIADNEplus services to support their users, and vice versa.
- *Beyond the project:* Maintain the ARIADNEplus data and research services that are implemented on the Cloud-based D4Science platform.

[32] SSH Open Marketplace: ARIADNE Portal, https://marketplace.sshopencloud.eu/tool-or-service/VjLUsM

4 ARIADNEplus community, data resources and services

This chapter describes essential elements of the innovation strategy which concern building the stakeholder community, standardisation and integration of archaeological datasets, and providing services and environments for data-based research (digital archaeology). More specifically the chapter covers:

- Extending the stakeholder community and taking account of community needs,
- Standardisation of archaeological datasets,
- Integration of datasets from more archaeological domains and at deeper level,
- Extending the portfolio of services for digital archaeology,
- Providing Virtual Research Environments (VREs).

The sections that follow outline the respective ARIADNEplus innovation strategies, describe background and developments, and summarise related innovation activities and results.

4.1 Extending and supporting the ARIADNE community

4.1.1 Project community extension strategy

ARIADNEplus extends the community of the ARIADNE initiative regarding both its geographic and thematic coverage. Involving more national and international stakeholders and data providers is essential for driving the adoption of the research e-infrastructure services, extending the pool of shared data resources, and ensuring the sustainability of the data-centered and other services.

Special attention regarding stakeholders is being devoted to coordination with major archaeological agencies and associations, e.g. the European Archaeological Council (EAC) and the European Association of Archaeologists (EAA). The strategic collaboration of ARIADNEplus and the SEADDA network, with representation from nearly all European countries, is addressed under the FAIR repositories theme. In this collaboration ARIADNEplus provides the perspective for new repositories to be included in the European and international pool of shared archaeological data (see *Section 3.2*).

ARIADNEplus is being recognised by archaeological institutions and projects as the leading integrator of archaeological data resources. Therefore the project increasingly receives requests to join the ARIADNE initiative as associate partner institution or project, which extends its geographic footprint and the thematic coverage of the data pool.

ARIADNEplus also investigates user community needs to ensure that their demands are being met by the technical and other services such as training for FAIR and open access data sharing. Provision of services in line with the requirements of archaeological researchers, data managers and repositories is crucial to achieve the expected innovation and impact in the archaeological sector in Europe and beyond.

4.1.2 Background and developments

In January 2019 ARIADNEplus started with a consortium of 41 partners[33] while the initial ARIADNE project had 23 partners. The consortium now comprises 37 formal partners in 23 European countries and one each in Israel, Japan, Argentina and the United States. These are the Israel Antiquities Authority, the National Research Institute for Cultural Properties (NARA) in Japan, the Instituto de Antropología de Córdoba (CONICET-IDACOR) in Argentina, and the Arizona State University (Center for Digital Antiquity, tDAR repository) in the United States. Thus the ARIADNE initiative is present now, not only more strongly across Europe, but also in other world regions.

One of the task forces of the WP Innovation has a special focus on North Africa, aiming to help bringing online archival collections of archaeological investigations conducted in the region for decades. This is being progressed by the North African Heritage Archive Network (NAHAN)[34] under the lead of ARIADNEplus partner Associazione Internazionale di Archeologia Classica (Italy), with participation of archives in Europe and North African countries. The NAHAN platform will be launched in the coming months with initial content from European partners, while the digitisation of collections in North Africa is underway.

High-level recognition and support

Already in 2015 the European Archaeological Council (EAC) strongly encouraged organisations to participate in the ARIADNE initiative. The EAC is comprised of heads of national bodies responsible under law for the management of the archaeological heritage in the Council of Europe member states.

In their Amersfoort Agenda, setting the agenda for the future of archaeological heritage management in Europe, the Council emphasises *"the need to share, connect and provide access to archaeological information with the help of digital technologies. The key to this aspiration is to improve collaboration – we need to share rather than exchange. It is essential to encourage the development of European data-sharing networks and projects in the field of archaeology. The ARIADNE project is an excellent European initiative in this regard and participation in this project should be strongly encouraged"* (Schut et al. 2015: 21).

The recognition of the ARIADNE initiative as leading integrator of archaeological data resources in Europe is confirmed by participation in the ARIADNEplus Scientific Advisory Board of Leonard de Wit, Past President and now Honorary Member of the EAC Board.

For the European Association of Archaeologists (EAA), Felipe Criado Boado, Past President, and Eszter Bánffy, the new President of the EAA, sit on the ARIADNEplus Scientific Advisory Board.

Both institutions take a keen interest in the FAIR data agenda and have suggested a collaboration with ARIADNEplus and its sister project SEADDA for the promotion of the agenda in the European sector of archaeology. Essential contributions for this are summarised in *Section 3.1* on FAIR data and *Section 3.2* on FAIR repositories; see also the summary of the FAIR repositories survey below.

Increasing number of associate partner institutions and projects

ARIADNEplus is being recognised by archaeological institutions and projects as the core integrator of archaeological data resources and driving the FAIR data agenda in the domain. Therefore ARIADNEplus increasingly receives requests to join the ARIADNE network as associate partner institution or project. Indeed, the network has already been extended further by at present 16 associate institutions and

[33] ARIADNEplus partners, https://ariadne-infrastructure.eu/partners/

[34] North African Heritage Archive Network (NAHAN), https://www.nahanweb.org

projects, including heritage authorities, archaeological institutes, as well as domain research and technology centres.[35]

Associate institutions extend the geographic footprint of ARIADNEplus to additional European and other countries, for example, the Directorate for Protection of Cultural Heritage of the Ministry of Culture of the Republic of North Macedonia; the Monuments Board of the Slovak Republic, the State administration authority in Slovakia for the protection of monuments and historic sites; the Mathematical Institute of the Serbian Academy of Sciences and Arts, leading the digitisation of archaeology and heritage resources in Serbia (Ognjanović et al. 2019); the British Institute at Ankara, currently building a digital repository of their research in Turkey and the Black Sea region since the 1940s (Çayırezmez 2020; Çayırezmez et al. 2021).

Associate projects extend the thematic coverage of ARIADNEplus, for example, ROCEEH[36] in the field of Palaeanthropology in regions of Africa, the Levant, Eurasia and Europe; data from the ROCEEH Out of Africa Database (ROAD) is already included in the ARIADNEplus portal; dataARC[37] promotes interdisciplinary research on long-term human-ecodynamics in the North Atlantic region; and Thanados[38] will integrate their database of Early Medieval cemeteries (600 until 1100 AD) from the area of present day Austria with related datasets of the ARIADNEplus catalogue.

Taking account of community needs

ARIADNEplus investigates user community needs to ensure that their demands are being met by the technical and other services, such as training. The core groups of the community are archaeological researchers, professionals in preventive/rescue archaeology, archaeological heritage administrators/ managers, and data managers and repositories.

Other groups are being addressed where appropriate. For example, the project integrates metal-detectorists and other finds by amateurs in countries where this is permitted, and the registration of finds in national databases has been enabled.[39] Records of such databases managed by ARIADNEplus partners are being integrated in the ARIADNE data portal. The portal and other data services will also be relevant to citizen scientists, educators and students, and other users interested in archaeology.

The sections that follow highlight some results of the broad survey on community needs (2019), the FAIR archaeological repositories survey (2021), and the study on the impacts of the COVID-19 pandemic on archaeology and cultural heritage (2021). Furthermore, needs of ARIADNEplus thematic communities have been investigated in workshops on use cases of virtual research environment, which are described in *Section 4.5.2*.

User community needs survey

In 2019 ARIADNEplus carried out a survey on user community needs regarding data sharing, access and (re)use, enhanced and new services, and training needs (ARIADNEplus 2019). The survey results are based on 484 questionnaires received from all 27 ARIADNEplus partner countries and a few other countries. The organisational background of most respondents is a university or public research

[35] ARIADNEplus: Associate Partners, https://ariadne-infrastructure.eu/associate-partners2/

[36] ROCEEH - The role of Culture in Early Expansions of Humans (Heidelberg Academy of Sciences and Humanities, Germany), http://www.roceeh.net

[37] dataARC - Enabling Research on the Long-Term Human Ecodynamics of the North Atlantic, https://www.data-arc.org

[38] Thanados - The Anthropological and Archaeological Database of Sepultures, https://thanados.net

[39] For example, Digitale Metaldetektorfund (DIME) in Denmark, https://www.metaldetektorfund.dk; FindSampo in Finland, https://dev.loytosampo.fi/en/; Portable Antiquities of the Netherlands (PAN), https://portable-antiquities.nl

organisation (53%), museum (19%), governmental institution (15%) or a private company or research institute (8%). Regarding professional activities, 53% are archaeological researchers (field work), 9% laboratory-based researcher, 13% managers of an institutional repository or other data access services, 7% managers of project databases, 7% directors of an archaeological institute or research centre/laboratory, 12% other (various academic, technical and data management activities).

The most important survey results concern the enhanced and new services for researchers and data managers (see *Section 4.4.2*). A very encouraging survey result was that respondents very much appreciated services that were already implemented by the original ARIADNE project (and which they may have already used): Register a dataset in a portal that allows the searching of data from many providers; Discover and access archaeological data stored in repositories in different European and other countries; Spatially and/or chronologically defined search options.

Services for searching and visualising geospatial datasets were the highest ranked among the new services, and meanwhile the ARIADNE data portal has been enhanced to support this (see *Section 4.4.2*). Respondents were also particularly interested in services for working with visual content (e.g. 3D models, LiDAR imagery). The original ARIADNE Visual Media Services have been developed further and are being provided on the Cloud-based D4Science platform. Furthermore, respondents were very interested in using Linked Data to interlink their own and other datasets. Project datasets in Linked Data formats will be made available (e.g. via an API) to external developers for interlinking datasets (see *Section 4.3.2*).

Lowest on the list was a service for mapping databases to the CIDOC-CRM, extended for archaeological research data. This result did not come as a surprise because the service is specifically for data managers (project databases, repositories) and these made up only 20% of the survey respondents.

Regarding training needs both researchers and data managers appreciated most training in the application of the FAIR data principles, which ARIADNEplus is committed to support (see *Section 3.1.3*).

FAIR repositories survey

In 2021 ARIADNEplus carried out a survey of archaeological repositories for an evaluation of to what extent their current data policies and practices conform to ideals of FAIR and open access data, which increasingly inform regulations of research funders, councils and other institutions. 60 archaeological repositories related to the SEADDA network and others participated in the survey, 43 operative and 17 currently being set up, which makes the reality check of this survey the largest thus far for repositories of one discipline (Geser et al. 2022).

The survey responses provide information on one or more repositories located in most European countries as well as repositories in other countries. Most of the organisations at which the repositories are or will be based are research centres or institutes (20), universities (13), and heritage authorities or agencies (16). The sample of repositories also includes five based at museums, two at archival institutions, and one is being provided by a national archaeological association.

The survey results can enable heritage and research authorities, councils and other institutions to reinforce or put in place regulations and support that bring current repository policies and practices closer to the envisaged ideals of FAIR and open access data. The survey results most relevant for these institutions, ARIADNEplus and SEADDA include:

- *Support of FAIR and open data policies:* A clear position from heritage authorities is most needed in this regard; 39 repositories (65%) required regulations and 36 (60%) clear guidelines from the authorities. Also, other support is needed; for example 28 repositories (47%) considered training of repository staff to support new policies on open/FAIR data as important.

- *Data discovery:* 24 repositories (40%) do not have a metadata search interface and 35 (58%) do not share metadata with external search platforms. The organisational and technical reasons for this would be worth investigating in order to advise on how metadata could be provided to external search platforms such as the ARIADNE data portal.
- *Control of data access:* At 21 repositories (35%), data are only accessible to legitimate registered users and/or with permission granted. In addition, 15 repositories (25%) have restrictions for some data, while 24 repositories (40%) have an open access approach (i.e. no registration is required). These results corroborate that open access regulations by heritage authorities, councils and other institutions are necessary for reducing barriers to data access.
- *Improving access with technology and data standards:* In this regard repositories often considered: Improve or replace the existing data management system (50%), improve the quality of metadata (57%), provide metadata to external search platforms/engines (45%), use of Linked Data to interlink internal and other (meta)data (43%).

  For some operational repositories that were dissatisfied with their data management system the main reason appeared to be enabling better access to complex or high-volume data objects, e.g. 3D models and LiDAR data (which is supported by the ARIADNEplus Visual Media Service, see *Section 4.4.2*).

  Respondents of both repositories in operation and in preparation indicated interest in providing metadata to external search platforms (such as the ARIADNE portal) and possibly to interlink their own and other (meta)data using a Linked Data approach (which is promoted by ARIADNEplus, see *Section 4.3.2*).

A critical issue is that many repositories do not collect and analyse information about data access and reuse:

- *Data access:* Of 56 respondents, 29 (52%) said that their repository does not collect and analyse data access figures, although this might allow identification of where access procedures could be improved and how better reporting of repository usage could be developed.
- *Data reuse:* No information about data reuse (e.g. references in publications and other sources) is being collected according to 47 of 56 respondents (84%), despite the fact that reuse for new research and other purposes best demonstrates that funds for data preservation and access are well invested.

Nonetheless, it is encouraging for the open/FAIR data agenda that 24 of the 27 repositories (89%) that analyse data access reported that during the COVID-19 pandemic overall there was increased access, with increases ranging from 5% to over 100%. It seems likely that the COVID-19 crisis made archaeologists more aware of the importance of publicly shared data, data repositories and discovery and access services.

Study on the impact of COVID-19 on archaeology and cultural heritage

In 2021 ARIADNEplus carried out a study to understand the impacts of the COVID-19 pandemic on the sectors of archaeology and cultural heritage, and how the project could contribute to recovery, beneficial changes in digital practices, and future resilience (ARIADNEplus 2021d: 6-17).

Impact on archaeology

In academic archaeology, site-based fieldwork and public archaeology, as well as laboratory work has been affected. Planned fieldwork campaigns and field schools with students and volunteers in 2020 and 2021 had to be cancelled. In coming years less funding for archaeological projects may be available.

The impact on preventive or development-led archaeology carried out by companies and public organisations appears to be lower, at least compared to the economic crisis some years ago which forced many contract archaeology businesses to close. However, some companies had to furlough staff and terminate temporary contracts; the situation for smaller companies and self-employed archaeologists has become insecure.

In academic archaeology the knock-on effect of the COVID-19 crisis will be felt for a long time, particularly by graduate students and early-career archaeologists due to the disruptions of field and laboratory work and reduced employment chances. Established archaeologists had more time to analyse data from past field seasons, prepare publications, and applications for new research and public archaeology projects. Also, an increase in access to available data in digital repositories has been observed.

In addition to looking for reuseable new and legacy data, archaeologists also explored tools for improving digital documentation and online platforms for collaborative research, for example virtual support by subject experts of local groups of field archaeologists.

Impact on cultural heritage

The impact of the COVID-19 crisis on cultural heritage institutions such as museums, monuments and other heritage sites and routes has been tremendous. Due to a drastic decrease in tourism and local attendance they have seen their in-person engagement plummet and a lot of income has been lost. The situation for many institutions and their staff has become insecure and even more so for freelance professionals.

The main positive effect highlighted by all impact surveys is that the COVID-19 crisis has brought about an increased focus of cultural heritage institutions on digital communication, online content and experiences of cultural heritage.

What increased most was use of social media platforms whereas offering online experiences which required more time, resources, and skills to develop them was less common. Where well-resourced institutions had already invested in online exhibitions, virtual museum applications, 3D models of heritage objects these were of course re-activated and promoted.

In media articles such cultural heritage experiences were often highlighted, however, the COVID-19 crisis showed that many institutions still need to extend their online offer with engaging visual content such as 3D models and other advanced content.

Conclusions for ARIADNEplus

The COVID-19 crisis arguably increases the value and impact of the work of ARIADNEplus and SEADDA on FAIR and open access data (e.g. DMP tools, guidance and training), digital repositories and data discovery and access services.

Archaeologists who, due to the COVID-19 crisis, could not carry out fieldwork to collect new data showed interest in exploiting already existing documentation. For these purposes, the ARIADNEplus Cloud-based Natural Language Processing (NLP) services, which support extraction of information from archaeological documents such as fieldwork reports, are relevant (see *Section 4.4.2*).

During the COVID-19 crisis archaeologists also used online platforms to carry out research tasks, for example virtual support by subject experts of local groups of field archaeologists. ARIADNEplus aims to provide virtual research environments for different tasks and data types (see *Section 4.5*).

The ARIADNEplus Visual Media Services (VMS) are relevant for cultural heritage institutions interested in using 3D models and other advanced visual content (e.g., Reflectance Transformation Imaging – RTI) for the presentation of heritage sites and objects. The VMS have already been presented to heritage

institutions and supporting businesses to collect their interest and requirements for using the service (see *Section 4.4.2*).

4.1.3 Innovation activities and results

The innovation activities in brief

- Maintain and extend the community of stakeholders that support sharing of archaeological research data through the ARIADNE data infrastructure, including stakeholders of non-European countries.
- Expand the geographic and thematic coverage of the ARIADNE initiative by taking on board associate institutions and projects.
- Take account of needs of archaeological researchers, data managers and repositories to ensure that the technical and other services such as training meet their requirements.

Selected highlights of results

- *Extension of the network of formal stakeholders:* The ARIADNE consortium has been extended from 23 formal partners of the original ARIADNE project to 41 of ARIADNEplus, including partners in Israel, Japan, Argentina and the United States.
- *Associate partner institutions and projects:* The geographic and thematic coverage of the ARIADNE network has been extended further by at present 12 associate partner institutions and projects (based on cooperation agreements), including heritage authorities, archaeological institutes, as well as domain research and technology centres.
- *Recognition and support by the major European archaeological bodies:* The ARIADNE initiative is being recognised by the European Archaeological Council (EAC) and the European Association of Archaeologists (EAA) as the leading integrator of archaeological data resources. Former and current presidents of both sit on the ARIADNEplus Scientific Advisory Board.
- *Taking account of community needs:* Needs of the stakeholder and user community regarding technical and other services such as training have been investigated in surveys and studies (e.g., on the impact of COVID-19 on archaeology and cultural heritage). The results have been taken account of in the development and provision of ARIADNEplus services.

Further activities within and beyond the project

- *Involve additional associate partner institutions and projects:* ARIADNEplus welcomes and will involve more associates to extend further the geographic and thematic coverage of the network.
- *Investigate requirements of new groups of service users:* Funded as the European research data infrastructure for archaeology, the core groups ARIADNE supports are archaeological researchers and data curators, including heritage administrators and professionals. Going beyond these groups, requirements of potential users such as citizen scientists, educators and students will be investigated.
- *Beyond the project:* Involve the stakeholders in sustaining and further developing the ARIADNE infrastructure and services for data sharing and digital research in archaeology.

4.2 Standardisation of archaeological datasets

4.2.1 Project datasets standardisation strategy

A major strand of ARIADNEplus' innovation strategy is the standardisation of archaeological datasets based on the ISO standard CIDOC Conceptual Reference Model (CIDOC-CRM), domain-specific extensions of this ontology, and vocabularies such as the PeriodO gazetteer for cultural periods and the Getty Art & Architecture Thesaurus (AAT) for subjects. Archaeological institutions that already provide data to the ARIADNE portal prepare their datasets using these standards. Promoted by ARIADNE/plus this standardisation is increasingly being adopted by databases of archaeological projects and research communities. This increases the overall "FAIRness" of archaeological data as the FAIR principles include as requirements that (meta)data should meet domain relevant community standards, be described with accurate and relevant attributes, encoded using a formal, shared and broadly applicable language for knowledge representation, i.e., the W3C Resource Description Framework (RDF) in the case of CIDOC-CRM, Getty AAT and aligned vocabularies of ARIADNE data providers.

4.2.2 Background and developments

CIDOC CRM based standardisation of datasets

ARIADNEplus promotes standardisation of archaeological datasets based on the ISO standard CIDOC Conceptual Reference Model (CRM) and domain-specific extensions. While always building on the core CIDOC-CRM ontology, such extensions allow a richer representation of conceptual relations of particular domains of archaeological research.

In the original ARIADNE project the CRM extensions CRMarcheo for excavations, CRMba for archaeological buildings, and CRMtex for the study of ancient texts (e.g. epigraphy) have been developed (in the case of CRMtex continued in ARIADNEplus).[40] Promoted further by ARIADNEplus these extensions, especially CRMarcheo, are increasingly being adopted by archaeological database development and research projects.

Moraitou et al. (2019) and Gergatsoulis et al. (2021) acknowledge the ARIADNE CRM extensions as key resources for semantic interoperability of data resources in archaeology. Examples from ARIADNE partners in France using CRMarchaeo illustrate that the usage ranges from single excavation archives (Marlet et al. 2019b), to large databases such as ArSol soil archives (Marlet et al. 2016), on to a whole digital research ecosystem like OpenArchaeo of the MASA Consortium[41] (Marlet et al. 2019a; Marlet & Rodier 2019).

There are a number of other database projects from ARIADNEplus network organisations as well as others using ARIADNE CRM extensions in Europe (e.g. Aspöck et al. 2016; De Haas & Van Leusen 2020; Rousset et al. 2019; Tufféry & Le Goff 2017; Van Ruymbeke et al. 2018). But the standardisation extends to other world regions as well. A particularly interesting example in international cooperation is the BE-ARCHAEO project, one of the Marie Skłodowska-Curie RISE Actions which bridge R&I domains in Europe and worldwide. In the BE-ARCHAEO project the CRMarcheo is being used for data from excavations of Kofun period sites in Japan (Lombardo et al. 2020).[42]

[40] CIDOC Conceptual Reference Model: Compatible models & Collaborations, http://www.cidoc-crm.org/collaborations

[41] MASA - Mémoires des Archéologues et des Sites Archéologiques (MASA) is the archaeological consortium of the Huma-Num digital research infrastructure, https://masa.hypotheses.org

[42] BE-ARCHAEO (MSCA-RISE project, 2/2019-7/2023), https://www.bearchaeo.com

Importantly, the ARIADNE initiative not only provides CRM extensions but also FORTH-ICS's Mapping Memory Manager (3M) system[43], the most advanced tool for mapping databases to the CRM and extensions or application profiles. The system can be accessed and used in the ARIADNEplus D4Science space.

Using and supporting core vocabularies

A major part of the data standardisation of the ARIADNE initiative in the field of archaeology is using and supporting essential domain vocabularies for data integration such as the PeriodO gazetteer for cultural periods and the Art & Architecture Thesaurus (AAT) for subjects of research objects. For locations the general WGS84 (World Geodetic System 1984) standard is being used.

PeriodO[44] is a gazetteer that records the spatial and temporal boundaries assigned to a given cultural period by an authoritative source. The description of a period includes a unique identifier (URI) which allows clear and stable linking and integration of data resources which refer to the same period (Rabinowitz 2014; Rabinowitz et al. 2016; Shaw et al. 2018). ARIADNE adopted PeriodO because when users of the data portal conduct searches using named periods, e.g. "Iron Age", they can discover resources from different countries, although the "Iron Age" has a different time-span in France, England and Ireland.

ARIADNE partners contributed one of the largest collections to this essential system, including 606 named periods from Paleolithic to Modern times (including time-ranges) for 24 European countries and regions. ARIADNEplus partners provided an additional 290 periods, of which the ROCEEH project contributed 134 periods from the Out of Africa Database (ROAD) common in Paleoanthropology which relate to regions of Africa, the Levant, Eurasia and Europe. Through the PeriodO system other institutions and projects can also use the cultural periods mobilised by ARIADNE/plus, enabling wider interlinking of data in Linked Data initiatives.

Using the Getty AAT as a "semantic hub": The Getty Research Institute provides vocabularies as Linked Open Data in RDF/SKOS format (Harpring 2018). These include the widely used, very rich and multilingual Art & Architecture Thesaurus (AAT)[45], which ARIADNE has selected as a common "semantic hub" for the subjects of data collections and records.

In order to enable subject-based searches across collections and records, partners map subject terms from their thesauri or term lists to AAT concepts (Binding and Tudhope 2016). In ARIADNEplus the total number of mappings of national and institutional vocabularies to the AAT amounts to over 15,700 of at present 22 partners, up from over 6,400 of 12 partners in the original ARIADNE project.

For such mappings ARIADNEplus provides a browser-based interactive Vocabulary Matching Tool[46] on the D4Science platform. Other data interoperability initiatives where providers use different vocabularies can benefit from using this freely available service.

[43] Mapping Memory Manager - 3M (Institute of Computer Science, Foundation for Research and Technology – Hellas)), http://www.ics.forth.gr/isl/3M

[44] PeriodO - Periods, Organized (Adam Rabinowitz et al., Institute of Classical Archaeology, UT Austin), http://perio.do

[45] Getty Research Institute: The Getty Vocabularies, http://vocab.getty.edu

[46] Vocabulary Matching Tool (Hypermedia Research Group, University of South-Wales), http://heritagedata.org/vocabularyMatchingTool/

4.2.3 Innovation activities and results

The innovation activities in brief

- Foster the standardisation of archaeological datasets based on the ISO standard CIDOC Conceptual Reference Model (CIDOC-CRM), domain-specific extensions of this ontology, and core domain vocabularies (e.g., PeriodO for cultural periods, Getty AAT for subjects of datasets).
- Provide tools for mapping datasets to the CRM and domain extensions of the ontology as well as for mapping national and institutional vocabularies to the large and multilingual Getty AAT thesaurus.

Selected highlights of results

- *Fostering standardisation of datasets based on CIDOC-CRM and domain-specific extensions:* ARIADNEplus promotes standardisation and integration of archaeological datasets based on the ISO standard CIDOC-CRM and domain-specific extensions, which have been created by members of the ARIADNE/plus projects.
- *Recognition and increasing adoption of the CRM extensions:* The CRM extensions are acknowledged as key resources for semantic interoperability of archaeological data, and are increasingly adopted by database development and research projects.
- *Tool for mapping datasets to the CRM and extensions:* The ARIADNE initiative not only provides domain-specific extensions of the CRM but also the Mapping Memory Manager (3M) system, the most advanced tool for mapping databases to the CRM and extensions. The system can be accessed and used in the ARIADNEplus D4Science space.
- *Use and support of core vocabularies – PeriodO and Getty AAT:*

- *PeriodO:* The ARIADNE initiative has adopted the PeriodO gazetteer for spatio-temporal boundaries of cultural periods and contributed one of the largest collections of nearly 900 periods from prehistory to modern times (including time-ranges) for 24 European countries and regions. From the associated project ROCEEH 134 periods common in paleoanthropology are included, also covering regions of Africa, the Levant and Eurasia. Through the PeriodO system other institutions and projects can also use the contributed periods, enabling interlinking of data referring to the same periods.
- *Getty Art & Architecture Thesaurus (AAT):* ARIADNEplus promotes the mapping of terms data providers use for the subjects of their datasets to concepts of the large and multilingual AAT, which enables Linked Data based searches across the provided datasets. In ARIADNEplus, such mappings at present amount to 15,700 from 22 partners, up from over 6,400 from 12 partners in the original ARIADNE project.

- *Tool for vocabulary mapping:* For the mentioned mappings the ARIADNE initiative also provides the interactive Vocabulary Matching Tool on the D4Science platform. Other data interoperability initiatives where providers use different vocabularies can benefit from using this service.

Further activities within and beyond the project

- *Supporting data providers:* Support data providers in applying the ARIADNE approach and tools for the standardisation and integration of their datasets.
- *Beyond the project:* Promote further the adoption of the ARIADNE approach and tools for standardising archaeological datasets.

4.3 Integration of datasets from more domains and at deeper level

4.3.1 Project datasets integration strategy

Archaeology is a multi-disciplinary field in which researchers need knowledge and data from different domains. The initial ARIADNE project had a focus on monument and site inventories, excavation archives, fieldwork reports and artefact databases. ARIADNEplus increases the pool of integrated research data through incorporation of datasets from more archaeological domains of research and, where possible, the depth of data integration for item-level access.

ARIADNEplus aims for the high quality integration of datasets from the wide range of archaeological domains based on the ISO standard CIDOC Conceptual Reference Model (ontology) and domain-specific extensions. This integration requires data providers to produce standardised descriptions of records of different types of data according to CRM-based Application Profiles, which must be jointly developed by domain researchers, data managers and vocabulary experts.

The Application Profiles allow mapping of the schemas used in domain databases to the common CIDOC-CRM and extensions (e.g., CRMarcheo for archaeological excavation) and concepts of vocabularies used by the databases. For the mapping work ARIADNEplus also provides the required tools. Based on the mappings the data records of the providers can be aggregated and integrated in the ARIADNE portal for data search across the different providers, visualisation and access.

This data integration is based on using the Linked Data approach in which ARIADNEplus is among the forerunners and promoters in the archaeological sector.

4.3.2 Background and developments

The initial ARIADNE project incorporated mainly monument and site inventories, excavation archives, fieldwork reports, and artefact databases. ARIADNEplus mobilises data from a wider range of archaeological domains of research, including palaeo-anthropology, bio-archaeology, environmental archaeology, maritime and underwater archaeology, standing structures (e.g. ancient buildings), inscriptions (epigraphy, rock carvings), burial archaeology, inorganic materials study and dating.

Data records are registered in the CIDOC-CRM-based ARIADNE catalogue, which has been enhanced in ARIADNEplus so that it allows greater flexibility and detail for representing data collections as well as individual items. This enables item-level access of some resources such as fieldwork reports or artefact images, while for others more domain-specific CIDOC-CRM based Application Profiles are being prepared. These allow the exploitation of more fine-grained ARIADNEplus Linked Data for advanced exploration of relations among the integrated data.

Enhancement of the ARIADNE catalogue model

The original ARIADNE Catalogue Data Model (ACDM) has been developed using a subset of classes and properties of the CIDOC-CRM to map the metadata schemas of data resources to this model, which allows aggregation and integration of the metadata into the data catalogue. In the ARIADNE project the data resources were mainly monument and site inventories, artefact databases, fieldwork reports and archives. ARIADNEplus now mobilizes a wider range of data types from different archaeological domains of research, and aims to integrate them as far as possible at item level.

The ARIADNE Catalogue Data Model (ACDM) initiated the CRM-based standardisation of data catalogues in archaeology, cultural heritage and related fields of the humanities. In the PARTHENOS

project[47], led by ARIADNE coordinator PIN and involving other partners, a more sophisticated data catalogue model has been developed. The PARTHENOS CRMpe model[48], created for social sciences, humanities and heritage catalogues, covers actors, activities, procedures, datasets and software (Frosini et al. 2018). The CRMpe model has been taken up by ARIADNEplus to create the new AO-Cat (ARIADNE Object Catalogue) model (ARIADNEplus 2020b), which allows greater flexibility and detail for representing data collections as well as single data items.

Still this model is intended for a common level of semantic description of data resources, while more domain-specific descriptions require richer CRM-based Application Profiles, particularly when the goal is to achieve item-level integration and linking of data items. Basically such Application Profiles specify further the AO-Cat ontology by including specific classes and properties to better describe the domain data.

Collection-level versus item-level access

The difference between collection-level and item-level integration of data resources in the Data Portal can be briefly described as follows: Collection-level means that a record describes the data collection which, for example, can be a collection of artefact images, a database of scientific data, or an excavation archive containing items of different types of data. In such cases the record includes a link to the site of the provider where users can explore the collection, which can contain hundreds or thousands of items, usually with more detailed description. Item-level integration means that each of the items can be found and accessed directly within the Data Portal. Via semantic relations of the underlying knowledge base also similar or related items can be found, for example to compare artefacts of the same type.

In practice the technical setup and heterogeneity of some data collections makes it difficult to provide records of individual items. In other cases it is preferable to provide access at a higher level, e.g., the description of a database or group of items in a repository, rather than individual items without contextual information. Therefore, in ARIADNEplus for each new data collection the best integration approach is defined through taking account of the technical setup and appropriate granularity of data access.

Domain-specific application profiles

Deeper integration of domain-specific datasets has been progressed in ARIADNEplus through the creation of CIDOC-CRM based Application Profiles. These allow mapping of the schemas used in the datasets to the AO-Cat model, additional classes and properties of the common CIDOC-CRM and appropriate extensions, e.g., CRMarcheo for archaeological excavation or CRMsci for scientific observations.[49] For the mapping work ARIADNEplus partners provide the required tools, the Mapping Memory Manager (3M)[50] for mapping databases to the CIDOC-CRM and extensions, and the Vocabulary Matching Tool[51] for mapping "local" to common domain vocabularies.

[47] PARTHENOS (H2020, 5/2015-10/2019), http://www.parthenos-project.eu

[48] CRMpe stands for CIDOC Conceptual Reference Model (CRM) – Parthenos entities (pe).

[49] CIDOC Conceptual Reference Model: Compatible models & Collaborations, http://www.cidoc-crm.org/collaborations

[50] Mapping Memory Manager - 3M (Institute of Computer Science, Foundation for Research and Technology – Hellas), http://www.ics.forth.gr/isl/3M

[51] Vocabulary Matching Tool (Hypermedia Research Group, University of South-Wales), http://heritagedata.org/vocabularyMatchingTool/

Meanwhile several domain-specific Application Profiles, completed and tested or advanced drafts, have come out of this exercise (ARIADNEplus 2020c; ARIADNEplus 2022b). Importantly, once established, the domain-specific Application Profiles can be used by new ARIADNEplus data providers as well as other projects with a focus on data of the respective domains of archaeological research.

Already completed and tested profiles include those for Heritage Science (e.g., materials studies and dating), Ancient DNA (aDNA studies), Inscriptions, Marks and Graffiti (e.g., study of texts on ancient objects) and Mortuary Archaeology. Other profiles are currently being revised and finalised, e.g., the profiles for Fieldwork and Remote Sensing. In the exercise it was also found that not all thematic sub-groups needed to develop their own profile as the AO-Cat model, use of the Heritage Science profile or another approach turned out to be sufficient for core aspects of their datasets. These sub-groups for example include Palaeoanthropology, Metal Detector Surveys (artefacts) and Maritime and Underwater Archaeology.

Applying Linked Data

Based on the new AO-Cat model or more specific Application Profiles the data records from the different providers can be aggregated and integrated in the ARIADNE data catalogue and provided to the search portal. In the process, the records are transformed into Linked Data, which support searching and visualising results within the Data Portal.

The Linked Data knowledge graph also allows the use of semantic search functionality, i.e. SPARQL queries (W3C 2013) to discover and retrieve data resources based on semantically defined relations between them. The semantic relations are defined by the CRM ontology and extensions and the vocabularies used for the data records (e.g. the Getty Art & Architecture Thesaurus for subjects). These relations provide the potential to explore the knowledge graph for specific research questions.

Experts agree that use of Linked Data complies with most of the FAIR data principles[52], and the project takes care to build the ARIADNE Linked Data and knowledge graph following these principles. Linked Data based ontologies and vocabularies that are already in the Linked Open Data Cloud[53] form hubs for linking data across providers, and ARIADNEplus uses such vocabularies (e.g. Art & Architecture Thesaurus, PeriodO Period Gazetteer). Thus, ARIADNEplus Linked Data can also link to data from other Linked Data providers, and vice versa. Therefore ARIADNEplus will make its Linked Data accessible to external developers to use and interlink data.

ARIADNEplus is one of the forerunners in using Linked Data, e.g., for the operation of the data catalogue and search portal. In recent years there have been more adopters of the Linked Data approach in archaeology and related disciplines, but the use of Linked Data is still far from mainstream. Therefore ARIADNEplus also includes a research group, one of the “task forces” within the Innovation WP, that investigates benefits of Linked Open Data (LOD) usage and how barriers to a wider take-up for data integration in archaeology could be overcome.

4.3.3 Innovation activities and results

The innovation activities in brief

- Integrate data from a wider range of archaeological research domains than the original ARIADNE project, e.g., palaeoanthropology, bioarchaeology, environmental archaeology, marine and

[52] For example, see Cox & Yu (2018), Hasnain & Rebholz-Schuhmann (2018), GO-FAIR: FAIRification Process, https://www.go-fair.org/fair-principles/fairification-process/

[53] Linked Open Data Cloud, https://lod-cloud.net

underwater archaeology, mortuary archaeology, built structures, inscriptions (epigraphy, rock carvings), scientific analyses of materials and dataing.

- Enhance the CIDOC-CRM based ARIADNE data catalogue model and create CRM-based Application Profiles to cover datasets as well as individual items from the extended range of archaeological domains.
- Apply Linked Data methods and technology for data integration and discovery and access on the ARIADNE data portal. Provide also programmatic access to the knowledge graph of the Linked Data to explore semantic relations between data for research questions as well as to reuse and interlink ARIADNE data with other datasets.

Selected highlights of results

- *Enhanced ARIADNE data catalogue model:* The CIDOC-CRM-based data catalogue model (AO-Cat) has been enhanced to provide greater flexibility and detail for describing data collections as well as individual items.
- *Creation of domain-specific Application Profiles:* Deeper item-level integration of datasets is enabled by CRM-based Application Profiles for different archaeological domains present in ARIADNEplus such as scientific analysis of materials and dating, ancient DNA studies, mortuary archaeology, epigraphy, among others. These can be used by ARIADNEplus data providers as well as other projects that want to employ the CIDOC-CRM for domain datasets.
- *Enhanced data aggregation:* The ARIADNE data pipeline has been enhanced, including a dashboard that allows monitoring and managing the progress of data aggregation and integration in the data catalogue and portal. A helpdesk and manual for data providers are available.
- *Linked Data based data integration:* ARIADNEplus integrates datasets into the data catalogue and portal using Linked Data standards and technology. The new CIDOC-CRM based catalogue model and domain Application Profiles support deeper integration and linking of domain data for advanced discovery and access on the data portal.

Further activities within and beyond the project

- *Provide programmatic access to ARIADNE Linked Data:* Such access to the Linked Data knowledge graph, i.e. using SPARQL queries, will allow advanced exploration of semantic relations between data for research questions as well as reuse and interlinking of ARIADNE data with other datasets.
- *Organise Linked Data hackathons:* Enable technology experts and archaeologists to explore the knowledge graph of the ARIADNE Linked Data and showcase interlinking of datasets.
- *Investigate barriers to wider take-up of the Linked Data approach:* Identify and analyse impediments to take-up by archaeological institutions and projects and how these could be overcome.
- *Beyond the project:* Investigate how more data of certain types could be mobilised, for instance, 3D models of sites and artefacts from research projects and museums, remote sensing data from projects such as EAMENA[54], and other particularly relevant data resources.

[54] EAMENA - Endangered Archaeology of the Middle East and North Africa, https://eamena.arch.ox.ac.uk

4.4 Extending the portfolio of services for digital archaeology

4.4.1 Project service portfolio strategy

ARIADNEplus extends the ARIADNE service portfolio with new and enhanced services that are provided within the Cloud-based D4Science platform[55]. The goal is to enable innovative and effective ways of carrying out data-based archaeological research (digital archaeology), going beyond the data discovery, visualisation and access provided by the ARIADNE data portal.

The new and enhanced Cloud-based services, for example, include services for publication and exploration of enhanced images (e.g. Reflectance Transformation Imaging - RTI) and high-quality 3D models of buildings and artefacts, annotation of texts and images (e.g. fieldwork reports, artefact or laboratory images), and natural language processing (NLP) of documents to find and extract specific information.

The provision of Cloud-based services reduces costs of technology management as it avoids scholars investing effort to acquire, implement, maintain and upgrade software for research. Instead of dealing with IT issues they can focus on their research tasks. This allows cost-savings for the research community while at the same time opportunities for research groups to jointly use services in dedicated virtual research environments (VREs) for addressing research questions (see *Section 4.5*).

4.4.2 Background and developments

ARIADNEplus already offers the advanced ARIADNE data portal as an effective research tool. Going beyond the data exploration enabled by the data portal, ARIADNEplus will provide a range of new and enhanced services for digital research on the Cloud-based D4Science platform.

The portal as an effective research tool

The core achievement of the original ARIADNE project was the implementation of a fully functional pipeline to harvest, integrate and make searchable records from repositories and databases of institutions located in different countries within a data portal. The pipeline aggregates the data records into the ARIADNE catalogue and feeds the search portal with records that are integrated based on common standards.

In ARIADNEplus the data portal has been enhanced in several ways. Firstly, the technical setup has been reworked and the data pipeline, catalogue and portal are now being hosted on the Cloud-based D4Science platform. Secondly, following many enhancements, the newly released data portal[56] offers advanced data search, visualisation and exploration facilities.

Important enhancements from the user perspective, for example, concern the Map-based search facility, e.g. six different layer types are now available (Open Street Map, Open Topology and four Google layers, e.g. satellite-view), use enabled for polygon-shaped areas of interest as well as other geometric structures, direct links to identified resources of interest, etc.; Timeline-search based on time-spans as well as archaeological/cultural time periods; new and improved filters such as the enlarged list of resource types, subjects of the Getty Art & Architecture Thesaurus covered, etc., and all filters can be applied to the results from both the Map and Timeline search facilities. Furthermore the resource landing pages have been improved with more features to find similar resources directly from these page, and the pages now also provide a preview of visual content.

[55] D4Science (CNR-ISTI, Pisa, Italy), https://www.d4science.org

[56] ARIADNEplus data portal, https://portal.ariadne-infrastructure.eu

It is worth noting that the extra effort invested in the map search facility has been informed by results of the ARIADNEplus user community needs survey, which showed a particularly high interest from researchers in location-based search of available data resources (see *Section 4.1.2*).

Indeed, ARIADNEplus has turned the original data portal into an effective research tool. Use of different search filters allows new types of research, for example comparison of patterns of settlement or artefacts found in different regions relating to different cultural periods (ARIADNEplus 2021a, 2021b). Such research was not possible to achieve so effectively before, and with the ingest of datasets from providers of different countries the potential to exploit this will increase ever more.

New and enhanced research data services

ARIADNEplus extends the ARIADNE portfolio of research services with new and enhanced services. Use of these services is generally intended to be via the CNR-ISTI D4Science platform. This section gives a brief overview of the services, not including the dataset and vocabulary mapping tools already described in *Section 4.2.2*. Some of the new and advanced services will be used in ARIADNEplus Pilots to demonstrate to the archaeological research community and other user groups innovative applications of the services and available datasets.

Overview of new and advanced research services

Cloud-based Geoserver: The CNR-ISTI Cloud-based Geoserver provides common geospatial/GIS functionality, for example, buffer definition, layer selection, proximity, viewshed analysis and so on. The Geoserver has already been employed for a small Cloud-based demonstrator in D4Science of the Istituto Centrale per l'Archeologia (ICA) for location and other information on shipwrecks. A larger ARIADNEplus Pilot of ICA will focus on the historical development of a part of ancient Rome.

Space-time query services: The space-time query services are implemented and can be used on the Data Portal. They allow users apply powerful searches and filters on the integrated data enabling them to explore research question.

Archaeological image annotation: An annotation tool specialised for annotation of archaeological objects which contain written/symbolic information has been developed by the Archaeological Museum of Zagreb (AMZ) and the CNR-ISTI Visual Computing Lab. Among other functionalities the Digital Autoptic Process (DAP) tool[57] allows annotation in a CIDOC-CRM compliant way images of such objects.

Text and image annotation: A more broadly useable annotation tool is being developed by University of South-Wales' Hypermedia Research Group to enable semi-automatic semantic annotation of text and image items with terms of different vocabularies (e.g. fieldwork reports, artefact or laboratory images).

Advanced natural language processing (NLP) services: General Architecture for Text Engineering (GATE) NLP framework-based tools have been developed in ARIADNE by University of South-Wales' Hypermedia Research Group, and experimented with on documents in English, Dutch and Swedish (Binding et al. 2018; Vlachidis & Tudhope 2016). The GATE NLP-based approach has been enhanced by partners in an EOSCpilot demonstrator (Textcrowd[58]), with documents in Italian (Felicetti et al. 2018). The EOSCpilot tools have already been implemented on the D4Science platform. Further development in ARIADNEplus particularly focuses on making the user interface and tools easy to use by archaeological data managers and researchers. Furthermore, the NLP and semantic annotation system

[57] Digital Autoptic Process (DAP) tool, http://tss.isti.cnr.it/dap

[58] TEXTCROWD (EOSCpilot demonstrator): https://eoscpilot.eu/science-demos/textcrowd

INCEpTION[59] has been implemented as an additional solution. A large demonstration pilot using INCEpTION is being planned by the Institut National des Recherches Archéologiques Préventives (INRAP) using reports in French from their preventive archaeology work.

***3D documentation of an archaeological excavation**:* The EpHEMERA[60] system of The Cyprus Institute's Science and Technology in Archaeology Research Center (STARC) allows documentation of archaeological excavations in 3D, specifically of the excavation layers and related documentation; how to bring it on the D4Science platform is currently being investigated.

***Visual Media Service (VMS)**:* The original ARIADNE VMS[61] already allowed users effective publication, rendering and exploration of enhanced images (e.g. Reflectance Transformation Imaging - RTI) and high-quality 3D models of buildings and artefacts. In ARIADNEplus the CNR-IST VCLab has enhanced the VMS in several respects of which the most important advance is enabling users to link information to selected parts of a 3D model of a monument or artefact. Thereby the VMS has become a virtual research environment. An ongoing development aims to make the VMS ready to effectively handle LiDAR data. When completed this new service will be employed in an ARIADNEplus Pilot by the Institut of Archaeology of the Scientific Research Centre of the Slovenian Academy of Sciences and Arts (ZRC-SAZU).

ARIADNEplus includes a research group, one of the "task forces" of the Innovation WP, that investigates the potential use of services by businesses from other sectors than archaeology. The group selected cultural and creative industries, particularly businesses which create products for heritage tourism, museums and visitor centres of monuments and sites, and the Cloud-based Visual Media Service (VMS)[62] as the most relevant service offer. The study on the impact of COVID-19 confirmed that the service is relevant to cultural heritage institutions as many needed to extend their online offer with engaging visual content such as 3D models (see *Section 4.1.2*). The CNR-ISTI Visual Computing Lab and the Central Institute for the Union Catalogue of Italian Libraries (ICCU) have presented the advanced VMS in a webinar to businesses and heritage institutions and collected their interest and requirements for using the service.

4.4.3 Innovation activities and results

The innovation activities in brief

- Offer Cloud-based data and research services to avoid scholars investing effort to implement and maintain information technology and software for research.
- Enhance the search facilities of the Cloud-based data portal to provide an effective research tool, e.g., explore patterns in integrated data and compare results for different regions and cultural periods.
- Provide a range of new and enhanced services for data-based archaeological research beyond what the data portal allows, e.g., analysing many data objects (e.g. Natural Language Processing of documents) as well as studying single objects (e.g. 3D models).

Selected highlights of results

- *The Data Portal as a research tool:* The portal currently provides access to nearly 2 million data records from 19 publishers and with forthcoming additions the volume of records will increase to

[59] INCEpTION, https://inception-project.github.io

[60] EpHEMERA, http://ephemera.cyi.ac.cy

[61] Visual Media Service https://visual.ariadne-infrastructure.eu

[62] Visual Media Services (CNR-ISTI, Visual Computing Lab), https://visual.ariadne-infrastructure.eu

over 2.5 million. Many improvements have turned the data portal into an innovative and effective research tool, e.g., use of different search filters allows exploring research questions based on patterns identified in the data.

- *Responding to community needs:* Responding to the high interest of researchers in map-based search expressed in the community needs survey, this portal service has been enhanced with several new features. The Cloud-based Geoserver provides additional functionality that will be demonstrated in project pilots in which geospatial data play a major role.
- *Extended portfolio of services:* In addition to the data portal, other enhanced and new services are provided on the Cloud-based D4Science platform for digital archaeology. These include services for publication and exploration of visual media (e.g. 3D models, RTI images of artefacts), Natural Language Processing (NLP) of documents in different languages, annotation of texts and images, among others.
- *Promoting services to users beyond research:* The Visual Media Service has been demonstrated to creative businesses and heritage institutions and their interest and requirements for using the service collected. As identified in the study on the impact of COVID-19, many heritage institutions need to extend their online offer with engaging visual content such as 3D models.

Further activities within and beyond the project

- *Data Portal multi-lingual features:* Further development of the portal focuses on enhancing the multilingual search capabilities.
- *ARIADNEplus innovative pilots:* The pilots will demonstrate how ARIADNEplus services and data can be used in innovative ways. For example, one pilot will use the Cloud-based Geoserver and other services to show the historical development of a part of ancient Rome, another pilot will use one of the Cloud-based NLP services for analysing preventive archaeology reports.
- *Beyond the project:* Investigate how to further extend the portfolio of services with relevant candidates, for instance, machine learning on visual content, e.g., image recognition, classification, support of content-based retrieval.

4.5 Providing virtual research environments

4.5.1 Project VREs strategy

Providing Virtual Research Environments (VREs) is one of the most ambitious innovation goals of ARIADNEplus in the field of digital archaeological research. In addition to data discovery, visualisation and access on the ARIADNEplus Data Portal, such environments combine and tailor services for the specific research tasks and data types of research communities. The ARIADNEplus VREs will be implemented on the Cloud-based D4Science platform. But these must be co-designed by archaeologists and technical experts to ensure that relevant and fit for purpose research environments are being developed.

4.5.2 Background and developments

In the original ARIADNE project the state of digital archaeology in different fields of research, perceived difficulties, and requirements for progress towards innovative solutions have been investigated (ARIADNE 2017b). The study results suggested there is much potential for ARIADNE to provide VREs, with the proviso that the data infrastructures and services will have to take account of the multi-

disciplinarity of archaeological research, particularly different data standards and vocabularies being used by different research communities.

A VRE can generally be defined as an online working environment for a community of researchers that provides services and tools for various research tasks. The services could be two or more of those described in the previous section, adapted to the specific needs of researchers in a domain of archaeological research.

The envisaged ARIADNEplus VREs are intended to support data-related research tasks beyond what the Data Portal already allows. They will be implemented on the CNR-ISTI D4Science platform which provides "VREs-as-a-Service" to support open science practices (Assante et al. 2019). "VREs-as-a-Service" provide generic services (e.g. user authentication & authorization, communication, data storage, metadata, etc.) as well as more research-specific applications (e.g. Data Miner, R-Studio for statistical and other analysis).

Most archaeologists are not familiar with or even aware of VREs as envisaged by ARIADNEplus, and technological VRE developers with an archaeological background are rare as well. Therefore, "a bicycle made for two" approach (Pollard & Bray 2007) is necessary in which archaeologists and technology experts learn from each other in a process of co-designing relevant and fit for purpose VREs.

To promote such co-design a series of VRE use cases workshop is being held, in which discussion of general and domain-specific community requirements for services generates a basis for functional descriptions of VREs seen as relevant. Three workshops have already been held with in total 95 participants.

The first two workshops involved VRE experts and archaeological researchers in four thematic domains represented in ARIADNEplus: Geospatial and Mortuary Data and Research (28 January 2021), and Ancient DNA and Environmental Data and Research (6 May 2021). The presentations, discussion and conclusions of these workshops are summarised in the ARIADNEplus Final Report on Community Needs (ARIADNEplus 2021d: 52-67).

In the workshops existing VRE-like systems have also been presented, for example, Thanados[63] in the field of mortuary archaeology, dataARC[64], which supports interdisciplinary research on human-environment interactions in the North Atlantic region, and the Strategic Environmental Archaeology Database (SEAD)[65]. Rachel Opitz (University of Glasgow) in her presentation of dataARC addressed design principles of VREs and how to encourage use, noting that it is important to take account of concerns of researchers regarding data sharing and re-use in VRE.

In the discussion of the dataARC example of interdisciplinary research the need of a VRE service for annotation of research objects with different domain vocabularies was identified. In interdisciplinary research scholars often have different views of research objects and such annotations can support mutual understanding and collaboration between scholars of different research domains. A service for annotations with multiple vocabularies is being developed by the Hypermedia Research Group of ARIADNEplus partner University of South-Wales.

Philip Buckland (Umeå University) showed that the Strategic Environmental Archaeology Database (SEAD) allows powerful searches over varied datasets, but mentioned that it is not easy to (re-)define them when new data has been added, and it requires significant computing resources. Following the discussion of this issue, the D4Science team developed the ARIADNEplus_Lab VRE, which provides Jupyter Notebooks, RStudio and their Data Miner service to specify and execute data computing tasks

[63] Thanados - The Anthropological and Archaeological Database of Sepultures, https://thanados.net

[64] dataARC – Enabling Research on the Long-Term Human Ecodynamics of the North Atlantic, www.data-arc.org

[65] SEAD - Strategic Environmental Archaeology Database, www.sead.se

on the D4Science Cloud-based infrastructure. The VRE provides also access to the ARIADNEplus Linked Data in the semantic graph database (GraphDB), which can be explored with an available web GUI or programmatically with SPARQL queries (W3C 2013).

The third workshop focused on three of the planned seven ARIADNEplus innovative pilots in which geospatial data infrastructure and services for remote-sensing data (e.g. LiDAR), GIS and other data resouces play a major role (23 February 2022). The workshop had a Questions & Answers approach in which the pilot lead partners presented their concepts and discussed related open questions with D4Science VRE experts, e.g., use of the Cloud-based Geoserver and other geospatial services. This workshop helped define further the concepts of the pilots and their requirements for VRE services (ARIADNEplus 2022a).

VRE specialists and archaeologists now work closely together to ensure that the VRE services support user needs regarding new research capabilities. This is an iterative process in which archaeologists trial service prototypes and suggest improvements and additions to be implemented, so that archaeologists can generate new research insights with them.

4.5.3 Innovation activities and results

The innovation activities in brief

- Foster co-design of Virtual Research Environments (VREs) by archaeologists and technology experts
- Provide Cloud-based VREs that combine services as needed by archaeological researchers of different domains.
- Demonstrate innovative uses of VRE services and datasets in ARIADNEplus pilots.

Selected highlights of results

- *Co-design of Virtual Research Environments:* A VRE must be co-designed by archaeologists and technical experts to ensure a relevant and fit for purpose research environment is being developed. The co-design of VREs has been promoted with three workshops on use cases in geospatial, mortuary, ancient DNA and environmental archaeological research, and three of the innovative pilots of the project. VRE specialists and archaeologists now work closely together to ensure that the VRE services support user needs regarding new research capabilities.
- *Implemented ARIADNEplus_Lab VRE:* One of the VREs suggested in a use case workshop has already been implemented on the Cloud-based D4Science platform. The ARIADNEplus_Lab VRE provides Jupyter Notebooks, RStudio and the D4Science Data Miner service which enable users to specify and execute data computation tasks for research purposes. The VRE also allows exploration of the ARIADNEplus Linked Data in the semantic graph database (GraphDB).
- *Annotation of research objects with different domain vocabularies:* In interdisciplinary research scholars often have different views of research objects and could jointly benefit from semantic annotations of the objects with terms of different vocabularies. A VRE service for such annotations is being developed.
- *The Visual Media Service (VMS) has become a VRE:* The VMS now includes the capability to link information on a 3D model and selected parts of it for research documentation as well as other purposes, e.g., museum information about cultural artefacts.

Further activities within and beyond the project

- *Workshops on VRE use cases in Archaeological Sciences:* An additional workshop will focus on relevant VREs for scientific data domains present in ARIADNEplus, e.g., material studies, dating methods such as dendrology, bio-archaeology, paleo-archaeology.
- *Pilot demonstrations of the use of VREs:* VREs will be used in project pilots to demonstrate their innovative capabilities for archaeological research.
- *Beyond the project:* Maintain and promote the developed VREs and pilot demonstrations to increase the interest of researchers in using VREs for digital archaeology.

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