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Achievements of the ARIADNE Initiative for Archaeological Data Sharing and Research

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The overall objective of the ARIADNE initiative is to help archaeological research and data management communities in Europe and beyond to more effectively share and use data that are dispersed across many institutions and projects. The initiative developed Research Infrastructure services that enable aggregation, integration, search and visualisation of data records that describe and link to data collections and items available in the providers' repositories and databases.

Funded under the Research Infrastructures strand of the European Union's Framework Programme for Research and Innovation, the ARIADNE projects implemented and enhanced the ARIADNE Research Infrastructure and mobilised a growing community of institutions and collaborative projects interested in sharing data through the e-Infrastructure. In the [ARIADNEplus](#) project almost 4 million data records were integrated in the ARIADNE Portal.

Following a brief introduction to the ARIADNE initiative, this article presents selected achievements of the initiative with the ARIADNEplus project. It addresses the extension and support of the ARIADNE community, the activities promoting FAIR data in archaeology, and the standardisation of datasets based on the [CIDOC CRM](#) and the domain vocabularies [Getty AAT](#) and [PeriodO](#). It considers the [ARIADNE Portal](#) as an effective data access and research tool, and the development of Virtual Research Environments as a new innovative approach.

The final remarks highlight the ability of the ARIADNE initiative to provide incentives for institutions and projects to share their data and make it useful through the ARIADNE Portal, which leverages the value of the providers' repositories and databases. Furthermore, ways in which ARIADNE fosters cross-disciplinary fertilisation are noted, for example, between scholars and technological developers of research services.



1. The ARIADNE Initiative in Brief

The overall objective of the ARIADNE initiative is to help archaeological research and data management communities in Europe and beyond to more effectively share and use data that are dispersed across many institutions and projects and often difficult to discover and access. The ARIADNE initiative set out to overcome the high level of fragmentation of archaeological data resources by providing a digital infrastructure that supports the sharing and use of existing data across national, institutional as well as domain boundaries.

For this purpose ARIADNE developed services and processes that enable aggregation, integration, search and visualisation of data records that describe and link to data collections and items available in the providers' repositories and databases. Thus, ARIADNE does not replace their digital infrastructures but provides services additional to them, e.g., search across the integrated data resources.

The original ARIADNE project implemented the first data infrastructure services for this (Aloia *et al.* [2017](#)), ARIADNEplus enhanced these services and developed additional ones. The whole e-infrastructure has been moved to the Cloud-based platform [D4Science](#), provided by the Institute of Information Science and Technologies (ISTI) in Pisa, an institute of the Italian National Research Council (CNR).

With the new e-infrastructure, data records from more archaeological fields of research have been aggregated and integrated for cross-searching, visualisation of results, and access to relevant data. ARIADNE aggregated mainly data records of monument and site inventories, excavation archives, fieldwork reports, and artefact databases, with fewer headings for specialist topics in archaeology. ARIADNEplus extended the range of sub-domains and resource types including, among others, palaeoanthropology, mortuary archaeology, inscriptions and rock art, scientific analyses and dating of material remains.

All this could be achieved thanks to funding of the [ARIADNE](#) (2/2013–1/2017) and [ARIADNEplus](#) (1/2019–12/2022) projects under the Research Infrastructures strand of the European Union's Framework Programme for Research and Innovation (Seventh Framework Programme and Horizon Europe 2020). Funded as so-called 'Integrating Activities', the projects could mobilise a growing community of institutions and large collaborative projects interested in sharing data through the ARIADNE infrastructure, portal and other services.

The original ARIADNE project consortium had 23 partners while ARIADNEplus had 41 partners, including the United States, Argentina, Israel and Japan. Furthermore, the ARIADNE network currently has 17 associate partners, and many other informal collaborations. Indeed, the on-going work of the ARIADNE initiative is based on a great sense of shared purpose.

Regarding data aggregation and integration, at present there are almost 4 million records searchable on the [ARIADNE Portal](#). The inclusion of data from the



international partners in the portal demonstrates that the ARIADNE initiative has the objective and capacity to expand the data pool beyond Europe.

The data pool includes many records from associate partners and other providers not funded through ARIADNEplus, who have been enthusiastic about integrating their rich data in the ARIADNE portal, cross-searchable and accessible, together with related data from other providers from around Europe and beyond. All aggregated data records have been transformed to Linked Data, which enables novel ways to search, explore and use the data. Indeed, the ARIADNE Portal has been turned into an effective research tool.

Thus the ARIADNE initiative has achieved its goal to enable effective sharing and use of archaeological data across national, institutional as well as domain boundaries. Fostering a culture of data sharing and joint capacity building will also be crucial for the further development of the initiative.

The development is being managed by the ARIADNE Research Infrastructure AISBL, a not-for-profit association, registered under Belgian law, but operating internationally. The association coordinates the acquisition of additional funds to maintain and extend the ARIADNE services and integrate new data resources.

2. Achievements with the ARIADNEplus Project

The ARIADNE projects had to provide reports on their innovative results and impacts (ARIADNE [2017](#); ARIADNEplus [2022b](#)). ARIADNEplus built on the substantial, indeed pathbreaking, achievements of the original ARIADNE project, and opened a new chapter of innovation and impact, referring to *The ARIADNE Impact* book (Richards and Niccolucci [2019](#)), in which partners, both established and new, describe perceived benefits of engaging in the ARIADNE initiative.

This article presents selected achievements of the initiative with the ARIADNEplus project, described in greater detail and with many references within sections of its impact report (ARIADNEplus [2022b](#)). The sections are organised according to the several expected impacts of 'Integrating Activities' by the EU Research Infrastructures programme, while this article highlights and details some achievements related to the overall focus of the special issue on how institutions and collaborative projects contribute to ARIADNE as data providers.

Topics addressed include the extension of the ARIADNE community, results of activities aimed to support community needs, promotion of FAIR (Findable, Accessible, Interoperable, Reuseable) data in archaeology (Wilkinson *et al.* [2016](#); Nicholson *et al.* [2023](#)), standardisation of archaeological data by ARIADNE, access to the integrated data resources, and Virtual Research Environments (VREs) as a new approach in addition to the ARIADNE Portal.



2.1 Extension and support of the ARIADNE community

2.1.1 Growing the ARIADNE network of partners

The ARIADNEplus project started in January 2019 with a consortium of 41 partners, up from 23 of the original ARIADNE project. Partners include cultural heritage agencies and museums, archaeological research institutes, repository and other data service providers, and technological centres with expertise in applications for cultural heritage and archaeology.

With ARIADNEplus the ARIADNE initiative has been active with 37 consortium partners across 23 European countries, and one partner each in the United States, Argentina, Israel and Japan. These are the Arizona State University (Center for Digital Antiquity, tDAR repository) in the United States, the Instituto de Antropología de Córdoba (CONICET-IDACOR) in Argentina, the Israel Antiquities Authority, and the National Research Institute for Cultural Properties (NARA), Japan.

The 23 European countries with partners in ARIADNEplus are Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Netherlands, Norway, Portugal, Romania, Slovenia, Spain, Sweden, and the United Kingdom.

Thus, the ARIADNE initiative has become stronger across Europe and expanded to other world regions. The inclusion of data from the four international partners in the ARIADNE Portal demonstrates that the initiative has the objective and capacity to expand its data pool beyond Europe.

Most of the archaeological members of ARIADNE also participate in the closely related COST Action [SEADDA](#), Saving European Archaeology from a Digital Dark Age, a partnership with representation from 31 European countries and six internationally (Argentina, Canada, USA, Japan, Israel, Turkey).

SEADDA and ARIADNE have complementary objectives. One main objective of SEADDA is a more sustainable future for digital archaeological resources through the creation of better and new repositories, where the community lacks an appropriate repository, while ARIADNE supports finding and accessing data that is being shared through existing and new repositories. In this approach ARIADNE also provides the prospect for new repositories of data aggregation and integration in the European and international pool of shared archaeological data.

ARIADNE increasingly receives requests by organisations to join the network as associate partners based on a cooperation agreement: 17 European organisations have already joined the network, including heritage authorities, archaeological institutes and collaborative projects, as well as domain data and technology expertise centres. These associates have further strengthened ARIADNE in Austria, Bulgaria, Croatia, Greece, Germany, Italy, Portugal and the United Kingdom, and expanded it to include North Macedonia, Serbia, Slovakia and Turkey.



Through associates the ARIADNE network also expands thematically, for example, through the [ROCEEH](#) project in the field of palaeoanthropology in regions of Africa, the Levant, Eurasia and Europe (Kandel *et al.* [2023](#)), and through the research environment [dataARC](#) of the North Atlantic Biocultural Organization (NABO) in the field of long-term human ecodynamics (Opitz *et al.* [2021](#)). Furthermore, significant contributions to data types in the ARIADNE Portal are foreseen, e.g., bioarchaeological isotope data from the [IsoArch](#) database (Plomp *et al.* [2022](#)).



Figure 1: Extension of the ARIADNE network of partners in European and other countries. Map created with mapchart.net. Green: countries with ARIADNE and ARIADNEplus consortium members and associate partner institutions. Yellow: countries not yet with associate partners. Not represented: United States, Argentina, Japan and Israel, with consortium members in ARIADNEplus, and associate projects with international partners.

2.1.2 Benefits perceived by associate partners

As the European infrastructure for archaeological data aggregation and access, ARIADNE provides orientation and a focus for institutions and projects in Europe and beyond, aiming to make their data available for research and other purposes, enabled by the portal.

Associate partners, like formal consortium partners of ARIADNE and ARIADNEplus, perceived favourable effects on institutional policy formation and capacity building for



data sharing, particularly in countries where there has been little previous tradition of open access to research data in archaeology and heritage (e.g., countries in central and south-eastern Europe).

European schools abroad, including French and British schools based in Athens and Ankara, have been keen to participate. These schools often lack IT resources but sit on massive archaeological legacy archives. Therefore, they appreciate ARIADNE as an opportunity for their own digital capacity building with a view to sharing their data.

Associate partners have not been funded from the ARIADNEplus project, but have invested significant time and staff resources in their contributions, particularly those who prepared data for aggregation and integration in the ARIADNE portal (e.g., the [ROCEEH](#) and [THANADOS](#) projects). This has also been done by other providers who have not joined as associate partners, including several institutions in the United Kingdom, for example the British Museum provided data from the [Portable Antiquities Scheme](#) of many archaeological finds by non-professionals.

It is estimated that, through unpaid effort, ARIADNEplus has leveraged at least an additional 24 person months of work on data provision. That many organisations have wanted to join ARIADNE and been willing to commit time and resources to contribute, clearly bodes well for the sustainability of the initiative.

2.1.3 Recognition by major archaeological institutions

The value and impact of the ARIADNE initiative is confirmed by its growth and the recognition by the main institutions for archaeology in Europe. The initiative is recognised by the European Archaeological Council (EAC) and the European Association of Archaeologists (EAA) as the leading integrator of archaeological data resources in Europe and beyond. Former and current presidents of both institutions have been members of the ARIADNEplus Scientific Advisory Board, ensuring regular dialogue with both organisations.

ARIADNEplus supports vital interests of these and other sector institutions in increasing access to archaeological data through provision of data management guidance and tools, conference sessions with a focus on FAIR and Open data, promotion of appropriate digital repositories (together with SEADDA), and of course ARIADNE's capability to aggregate data shared through repositories and collaborative databases.

It is noteworthy that as early as 2015, after the first two years of the original ARIADNE project, the European Archaeological Council (EAC) recognised the project's potential and strongly encouraged participation. In their Amersfoort Agenda, setting the agenda for the future of archaeological heritage management in Europe, the Council emphasised

'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).

2.1.4 Understanding and serving community needs

The development of the ARIADNE research infrastructure, portal and other services is based on a solid understanding of the community needs captured in surveys, focus groups, and studies (e.g., a study on the impact of COVID-19).

The ARIADNE surveys in 2013 and 2019, with 692 and 484 completed questionnaires included in the analyses, are the largest existing surveys on data practices and related needs of archaeologists in Europe (ARIADNE [2014](#); ARIADNEplus [2019](#)). Consequently, results are often referenced by researchers to explain developments in digital archaeology and underpin arguments. The joint ARIADNE–SEADDA survey of archaeological repositories in 2021 (Geser *et al.* [2022](#)), with participation by 60 repositories of research centres and heritage agencies, is the largest survey on current policies and practices of repositories supporting a single discipline.

The survey provides an evaluation of the extent to which the repositories conform to ideals of FAIR and open access data. The recommendations given on how to promote further progress in this regard can inform related measures by major bodies such as the EAC, national heritage agencies, as well as research institutions. Importantly, the survey found that what would help the repositories most to support open data access and reuse policies are regulations and clear guidelines from heritage authorities and supporting agencies in this regard.

The ARIADNE research infrastructure clearly supports community needs for services enabling data discovery, access and reuse. The results of the ARIADNEplus community survey in 2019 confirmed high appreciation of data services already implemented in the portal by the original ARIADNE project and planned new services of the portal and services in addition to it (ARIADNEplus [2019](#) 107-14).

Results of the study on the impact of the COVID-19 restrictions on archaeology and cultural heritage (Geser [2021](#)) indicated increased interest by archaeological researchers to exploit existing fieldwork reports and data. The repositories survey confirmed this, as 24 of the 27 repositories that monitor user access reported an increase ranging from 5% to over 100%, covering a variety of purposes. Researchers who wish to extract information from fieldwork reports and datasets for studies, or data managers for metadata generation, could benefit from Natural Language Processing (NLP) tools and expertise developed by ARIADNE partners (Binding *et al.* [2019](#); ARIADNEplus [2022a](#) 30-42).

The COVID-19 crisis also showed that many cultural heritage institutions need to extend their online offer with attractive and engaging content. Here the ARIADNE Visual Media Service ([VMS](#)) for 3D models and Reflectance Transformation Imaging (RTI) could allow the exploration of archaeological and other heritage sites and objects in engaging ways. The VMS is part of the ARIADNE development of Cloud-based Virtual Research Environment (VRE) services (see Section 2.5). The interest and requirements of heritage organisations using it have also been explored. Among



the perceived 'selling points' of the VMS are that it can be used for content development in collaborative or closed mode, supports high-resolution interactive media, and allows narrative text and links to additional content, such as educational material, to be added to highlighted parts of 3D models.

2.1.5 Training, events and publications

Briefly summarised, some results of the ARIADNEplus training and dissemination activities are:

Training workshops and Training Hub

Training workshops (most provided online) and visits to ARIADNE competence centres involved 510 researchers. The main topics were open access publications and data, the FAIR data principles, data management plans, data sharing and interoperability, and use of respective ARIADNE services. Unfortunately, due to the COVID-19 crisis, only 34 researchers and data managers could visit ARIADNE competence centres for individual studies or summer schools of the Transnational Access programme.

The [Training Hub](#), launched in January 2021, brings together selected training and self-learning resources on vital data-related topics in different formats by ARIADNE partners and other providers. Until the end of 2022 it attracted around 4000 visitors, with a remarkable percentage of return visitors of 27.3%.

Conferences and other events

The ARIADNEplus partners and associates reported 88 conference sessions and other events (not including training) that they have (co-)organised (42) or attended to give ARIADNE-related presentations and network with participants. The total number of attendees is estimated as being 4077; 61 events had international and 27 national participants. Due to the COVID-19 crisis most events were held online.

Publications

In the period January 2019 to December 2022, partners and associates published 53 ARIADNE-related articles in journals, conference proceedings and books. Of these, 45 have been published open access or a preprint version is available in an open access repository.

Two data papers deserve a special mention: 'An Aegean history and archaeology written through radiocarbon dates' by Katsianis *et al.* ([2020](#)) in the *Journal of Open Archaeology Data* describes an open access published dataset of radiocarbon dates for Aegean history and archaeology, a total of 3159 radiocarbon samples from 353 sites. It is the largest collection so far of such data for Greece. A data [record](#) of this collection is included in the ARIADNE Portal. 'Deep data example: Zbiva, Early medieval data set for the Eastern Alps research' by Štular and Belak ([2022](#)) in the *Research Data Journal for the Humanities and Social Sciences* describes the



Zbiva open access research database, the product of four decades of data collection and curation. The ARIADNE Portal includes 8775 [records](#) from the database.

2.2. Fostering FAIR data in archaeology

2.2.1 Promoting the FAIR data agenda in archaeology

ARIADNE is committed to promoting the FAIR data agenda in the European archaeological sector, in line with general policies of the European Commission and EU member states on open access to publicly funded research data. Related requirements set by funding agencies often include a Data Management Plan (DMP), usually referring to FAIR data as the goal, and deposition in an appropriate repository with the data 'as open as possible, as closed as necessary', for example, in case of sensitive data.

The ARIADNEplus community survey in 2019 included a question on current training needs of archaeologists regarding data management and processing. Asked how helpful eight suggested training options would be for the work of respondents (N=328-330), how to apply open/FAIR data principles in archaeology was appreciated most (94.6% very helpful or helpful); next came depositing project datasets in a digital repository (92.4%), and defining and implementing a Data Management Plan was also seen as important (89%) (ARIADNEplus [2019](#) 122-24).

The EAA Board endorsed the FAIR principles and proposed a collaboration with ARIADNE for their implementation in archaeology. The EAC works with SEADDA on progressing data 'FAIRness' in the sector. ARIADNE promoted FAIR data in various ways, including dissemination of guidelines, a FAIR data management plan (DMP) tool and templates for archaeologists, FAIR as part of training activities and resources, and sessions and presentations at domain conferences.

2.2.2 FAIR guidance and DMP tool

Researchers and data managers in archaeology look for practical guidance on what is meant by FAIR data and how to create and make it available. For broad dissemination in the sector ARIADNE adopted the [PARTHENOS](#) FAIRify guide (Hollander *et al.* [2018](#)), to which institutions active in ARIADNE also contributed. The guide offers twenty guidelines, aligning the efforts of the research data producers and archivists to make the data as reusable as possible based upon the FAIR principles; each guideline has recommendations for both in this regard.

The guide is available in nine language versions, downloadable from [Zenodo](#), since December 2018 in English, since the second half of 2019 in French, German, Greek, Hungarian, Italian, and from July 2020 in Czech, Portuguese and Turkish, the latter three translated by ARIADNE and SEADDA partners. On 12 October 2023 the downloads of the guide in the different language versions stood at 4273.

ARIADNE promotes the standardisation of Data Management Plans (DMPs) and appropriate data practices for archaeological projects, taking account of requirements and standards for archaeological datasets. The ARIADNE DMP



templates and online tool, which conform to European Commission and Science Europe guidelines, have been developed specifically for archaeologists (Doorn and Ronzino [2022 online](#)). By using them archaeological researchers can better understand the requirements for FAIR data and more easily draw up a fit for purpose DMP.

Interest in using the templates and online tool appears to exist; for example, an online workshop on them in March 2022 was attended by 89 participants. Users of the DMP templates and tool so far prepared over 100 DMPs, presumably academic archaeologists applying for or already having a research grant.

A recent survey by the EAC Working Group for Archaeological Archives on the situation of digital archiving in the area of heritage management, answered by experts from 27 countries (30 regions), found that in this area DMPs are not widely applied. In 20% of the countries DMPs are legally required related to fieldwork reports, and in two countries for fieldwork data. In some countries DMPs are recommended only for specific types of data (Novák *et al.* [2023](#)).

2.3. Standardisation of archaeological datasets

2.3.1 Standardisation based on CIDOC CRM

ARIADNE promotes standardisation and integration of archaeological datasets based on the CIDOC Conceptual Reference Model ([CIDOC CRM](#)) through mapping datasets to the CIDOC CRM and domain extensions of the ontology. Importantly, the ARIADNE initiative also provides the [X3ML Toolkit](#) (Marketakis *et al.* [2017](#)), which is the most advanced environment for mapping datasets to the core or extended CRM versions. The X3ML Toolkit has been developed at the Institute of Computer Science of the Foundation for Research and Technology (FORTH) in Greece and is included in the ARIADNE data aggregation services on the D4Science platform.

Work on the CIDOC CRM-based standardisation and integration of archaeological datasets included CRM extensions and application profiles. Domain-specific extensions of the CRM allow better modelling of data for particular fields of research, for example, the extensions (co)created by ARIADNE experts: CRMarcheo for excavations, CRMba for heritage buildings, and CRMtex for inscriptions, marks and graffiti. These CRM extensions are increasingly being adopted for research projects and databases, especially CRMarchaeo (for examples see ARIADNEplus [2022b](#) 45-46; Katsianis *et al.* [2023](#)).

Application profiles of the CIDOC CRM are more geared towards its use in IT systems. In ARIADNE the core application profile is the ARIADNE data catalogue model (AO-Cat), derived from the CRM-based ARIADNE Ontology (AO) (Felicetti *et al.* [2023](#)). This model in particular enables the search system of the data portal to provide results for the 'What', 'When' and 'Where' user queries across the aggregated and semantically integrated datasets (Richards [2023a](#)).



It is worth noting that the data catalogue model of the original ARIADNE project initiated the CRM-based standardisation of data catalogues in the field of cultural heritage and related humanities. Building on jointly developed expertise, e.g., in the PARTHENOS project (Frosini *et al.* [2018](#)), the new ARIADNE catalogue model (AO-Cat) provides greater flexibility and detail to describe data collections and individual items.

More specialised application profiles have been created by ARIADNEplus working groups in view of more granular semantic integration of data items of certain thematic domains - mortuary archaeology (Aspöck *et al.* [2023](#)), for instance. Such domain application profiles can also use extensions of the core CRM such as CRMtex for epigraphical information (Vassallo *et al.* [2023](#)).

The purpose of profiles for thematic domains in archaeology is to allow searches of the ARIADNE semantic database (RDF triple store) and visualisation of results for research questions. Tests conducted with representative ARIADNE datasets and relevant mappings for item-level data integration proved that the approach is feasible, but it also became clear that specialised interfaces and tools need to be designed to support domain-specific research questions. For the tests an experimental interface built on [ResearchSpace](#) has been used, a free and open-source system developed at the British Museum with a focus on projects using the CIDOC CRM.

2.3.2 Applying core domain vocabularies

A major part of the standardisation work of the ARIADNE initiative in the field of archaeology is demonstrating the power of using common vocabularies for data integration. The core examples here are the Getty Art & Architecture Thesaurus (AAT) and the PeriodO gazetteer for cultural period definitions.

For the subjects of their data resources providers of ARIADNE make semantic mappings of terms of their local vocabularies (thesauri, term lists) in different languages to concepts of the large and multilingual Getty AAT. This enables subject-based searches on the ARIADNE Data Portal across the integrated data collections and records. The total number of mappings to the AAT at present amounts to 22,100 from 42 data publishers, up from around 6400 from 16 publishers in the original ARIADNE project.

For the mapping, ARIADNE provides the browser-based interactive Vocabulary Matching Tool ([VMT](#)), developed by the Hypermedia Research Group at the University of South Wales, and included in the data aggregation services on the D4Science platform.

The [PeriodO](#) gazetteer system provides unique identifiers (URIs) for named periods, with time-ranges, that allow stable linking of archaeological, ancient world and historical data resources that refer to the same period. In 2015, ARIADNE partners contributed a collection of 663 periods from 24 European countries to PeriodO (ARIADNE Consortium [2015 collection](#)). For the PeriodO project, started in 2014,



this was the *'first major step'* of growing the PeriodO dataset and user community (Rabinowitz *et al.* [2016](#) 53-54).

ARIADNEplus partners and associates extended the contribution to 2298 named periods, including more detailed sets of periods and sets for further European countries and territories of the international partners. As a different example, the associate project ROCEEH contributed a set of 145 named periods from their Out of Africa Database. These are being used in palaeoanthropology and 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 and ARIADNEplus, enabling wider interlinking of data in Linked Open Data (LOD) initiatives. Sets of named periods provided to PeriodO in ARIADNEplus are not included in the initial ARIADNE collection. These have other PeriodO authorities, the ARIADNEplus partners or associates or other sources that have prepared periods for inclusion in PeriodO.

2.3.3 Using and sharing Linked Open Data

Data records aggregated in the ARIADNE Data Catalogue are transformed to Linked Data standards, which support searching and visualising results on the portal. The Linked Open Data (LOD) knowledge graph of the semantic database (GraphDB) can also be explored programmatically, using SPARQL queries. It can be accessed by researchers and developers through the ARIADNEplus_Lab, which provides a user guide and a set of tools for exploring the LOD and possibly link it with data from other projects (see Section 2.5).

2.3.4 Making archaeological data more FAIR

The data standardisation promoted by ARIADNE increases the overall 'FAIRness' of archaeological data. The FAIR principles include as requirements that (meta)data should meet domain relevant community standards (i.e., CIDOC CRM), be described with accurate and relevant attributes (i.e., Getty AAT terms), and encoded using a formal, shared and broadly applicable language for knowledge representation (i.e., W3C RDF for Linked Data). The FAIR principles also state that the (meta)data should be registered in a searchable resource, i.e., the ARIADNE Portal.

2.4. Access to integrated knowledge-based resources

2.4.1 Data records searchable on the Data Portal

The ARIADNE Portal exploits the integration of knowledge-based data resources, i.e., data records described with the CIDOC CRM-based data catalogue model (AO-Cat) and vocabularies of the domain of knowledge, the Getty AAT and named cultural periods with time-ranges from PeriodO.



At the close of the original ARIADNE project in January 2017, 16 data publishers had provided around 1.9 million data records to the portal. Meanwhile the new portal provides access to almost 4 million (3,980,906) records from 44 publishers, representing a much larger volume of data items as there are many records of fieldwork archives (at the time of writing 117,035), and other sources containing numerous items of different kinds of archaeological data.

2.4.2 Data Portal access

The portal can be accessed openly and freely by anybody; there are no restrictions or charges to use it, and also Web Content Accessibility Guidelines (WCAG) have been followed. Access statistics for the new portal start from January 2021: in that year there were 7165 visitors to the portal, by December 2022, with ever more data included, this had increased to 32,000 visitors, an increase of 350%. The top ten countries from which visitors came to the portal were the United Kingdom, United States, France, Bulgaria, Italy, Germany, Netherlands, Hungary, Cyprus, and Australia.

2.4.3 Advanced search and access facilities

In ARIADNEplus the Data Portal has been enhanced in several ways to offer advanced data search, visualisation and exploration facilities. The portal provides multi-lingual and granular subjects search, which builds on the mapping of local vocabulary terms from data providers to the Getty AAT.

The Map-based search facility offers many new features, including different layer types, heat maps and cluster points for results, polygon support for areas of interest, but also bounding boxes to mask precise location. Various options for filtering data records can be applied to results of both the Map-search and Timeline-search facility. Furthermore, where available, images of artefacts are included in served data records. Results of the community needs survey in 2019 have been duly considered - for example, with the extra effort invested on the Map-search facility to support users' high interest in location-based search of data resources.

2.4.4 The portal as an effective research tool, also including contributions by citizen scientists

In ARIADNEplus the portal has been turned into an effective research tool. Use of different search filters allows new types of research, for example, to explore and compare patterns of sites and artefacts found in different regions and relating to different cultural periods. Richards ([2023b](#)) presents examples for this research capability regarding artefacts. It was not possible to achieve such research so effectively before. It reduces researchers' effort to discover, combine and analyse data for exploratory research.

Importantly, the examples are for searches combining archaeological data records (i.e., sites, monuments, grey literature) and records of artefacts found by metal detectorists and other members of the public in England, registered in the Portable



Antiquities Scheme (PAS). Thereby researchers can investigate how clusters of such finds may relate to known archaeological sites or indicate the presence of hitherto undiscovered sites.

The ARIADNE portal also integrates records of finds by metal-detectorists (and others) in other countries where this is permitted, and registration of finds in national databases has been enabled. These databases, supported by ARIADNE partners, are Digital Metal Detector Finds in Denmark (ARIADNE partner Aarhus University), FindSampo in Finland (University of Helsinki for the Finnish Heritage Agency), and Portable Antiquities of the Netherlands (Data Archiving and Networked Services - KNAW-DANS).

By bringing records from the finds databases into the ARIADNE Data Portal, placed alongside knowledge created by professional archaeologists, contributions of 'citizen scientists' (Wessman *et al.* [2023](#)) to archaeology become visible at the European level and usable for comparing finds from different countries. Thereby the portal supports ideals formulated in the *European Framework Convention on the Value of Cultural Heritage for Society* (Council of Europe [2005](#)), promoting the participation of citizens thus leading to a wider understanding of heritage and its relationship to communities and society.

2.5. Development of virtual research environments

Providing Virtual Research Environments (VREs) is one of the most ambitious innovation goals of the ARIADNE initiative in the field of archaeological research. VREs tailor and combine online tools for research tasks and data from research communities.

While the ARIADNE Portal is already an effective research tool, such VREs on the D4Science platform are intended to support research in addition to filtering, visualising and exploring the integrated data records for research questions.

Furthermore, research tools that are available as a service in a Cloud-based environment avoid researchers investing effort to acquire, implement, maintain and upgrade them. Instead of dealing with IT issues the researchers can focus on their research questions and collaboration.

In the ARIADNEplus project some ARIADNE services have been enhanced or newly developed, with a view to becoming part of a VRE or a VRE in their own right. Functionalities provided by such services include, for example, semantic annotation of images of archaeological objects that contain textual or symbolic information, annotation of terms detected in archaeological texts with different subject vocabularies using Named Entity Recognition (NER) techniques, and visualisation in 3D of excavation layers or buildings with linked documentation (ARIADNEplus [2022a](#)).



In ARIADNEplus, provision of Cloud-based VREs on the D4Science platform has been explored and achieved according to researcher needs. To kick-start the VRE development, three use-case workshops were organised, focused on thematic domains represented in ARIADNE, including Geospatial, Environmental, Mortuary and ancient DNA data and research. Among the external participants were developers of the [dataARC](#) and [THANADOS](#) projects, which thereafter became associate partners of ARIADNE. In the workshops some needs of researchers were identified and addressed by developing or enhancing VRE services.

The [ARIADNEplus Lab VRE](#) now offers researchers a set of tools to process, visualise and analyse the ARIADNE Knowledge Base as well as their own data (Pagano [2022](#)). The tools include JupyterHub (pre-installed and ready to use), RStudio and the DataMiner analytics engine to specify and execute data computing tasks on the D4Science Cloud-based infrastructure. The virtual research lab also provides researchers with access to the ARIADNEplus Linked Open Data (LOD) in the semantic graph database (GraphDB) as well as tools for exploring the LOD with an available web GUI or programmatically, using SPARQL queries.

A need was identified for interdisciplinary research projects to annotate archaeological texts with terms drawn from different subject vocabularies. Therefore, a service for such annotations has been developed and added to the ARIADNEplus_Lab VRE.

In the original ARIADNE project the Visual Media Service ([VMS](#)) 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 (Ponchio *et al.* [2016](#)). In ARIADNEplus the VMS has been enhanced in several respects, the most important advance being that users, guided by a visual wizard, can annotate selected parts of a 3D model and add interactive links to research documentation (ARIADNEplus [2022a](#) 15-18). In this way the VMS has been turned into an effective research environment. The environment can also be used by cultural heritage institutions to provide information on sites and objects in engaging ways, adding to 3D models narrative texts and links to related heritage objects, further information and educational material.

3. Final Remarks

The ARIADNE initiative achieved its core objective to help the archaeological research and data management communities in Europe (and beyond) to share and use data more effectively, even those that are dispersed across many institutions and projects.

The implemented services of the ARIADNE 'data pipeline' allow large-scale aggregation of records of different data resources, filtering and visualising their 'What', 'When' and 'Where' information in order to address specific research questions, and accessing relevant data in the providers' repositories and databases. The ARIADNE data infrastructure does not replace them, it leverages their value for the archaeological community.



The ARIADNE initiative mobilised a growing number of institutions and collaborative projects interested in sharing their data and making it useful through the ARIADNE Portal. The community portal provides incentives for institutions and projects to build capacity for sharing FAIR data the ARIADNE way, to contribute to common goals, and to gain visibility and recognition for doing so. Semantic integration and effective use of the shared data is enabled through standardisation based on essential domain standards (i.e., CIDOC CRM, Getty AAT, PeriodO) and Linked Open Data standards and technologies.

It is also noteworthy that one of the impacts expected by the EU Research Infrastructures Programme from 'Integrating Activities', such the ARIADNEplus project, is cross-disciplinary fertilisation. In the ARIADNE initiative this is being promoted by the participation of communities and integration of datasets from different domains of archaeological research.

For instance, the work on domain-specific CIDOC CRM application profiles has contributed to building related knowledge and cross-fertilisation. Different and common aspects of domain datasets became clearer in the process, as well as interfaces and tools required to support more domain-specific research questions than with the key parameters 'What', 'When' and 'Where' of the portal search interface. Creation of such interfaces and tools is one aspect of the roadmap for the further development of the ARIADNE research infrastructure.

Cross-fertilisation has also been fostered between scholars and developers of e-research services in workshops on use cases of ARIADNE Virtual Research Environments. VREs must be co-designed by scholars and technical experts. In the process service developers learn about the requirements of scholars' projects, and scholars learn how VREs can support their research tasks. Moreover, collaboration and cross-fertilisation with other data sharing initiatives is enabled by the ARIADNE Linked Open Data (LOD). ARIADNE did not build another 'data silo', the LOD can be used for linkage from and to other online resources, for example in interdisciplinary projects. Building additional environments for virtual archaeological research and promoting such projects are, of course, other items of the ARIADNE development roadmap.

Finally, the ARIADNE Research Infrastructure AISBL offers associate members the opportunity to contribute to the roadmap and the services and data resources of the community research infrastructure.

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