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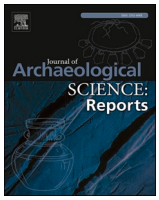

Innovative archiving of raw materials: Advancing archaeometric databases at the Austrian Archaeological Institute/Austrian Academy of Sciences☆

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ABSTRACT

Archaeometry unfolds at the intersection between natural sciences and archaeology, shedding light on the life cycle of ancient artefacts and structures. The systematic archiving of archaeometric data not only empowers intra-institute research but also allows international scholars to access organised sets of information. This archival approach facilitates collaborative research, encourages data sharing, and promotes a deeper understanding of cultural heritage.

The archaeometric collection curated by the Austrian Archaeological Institute (OeAI) encompasses a diverse array of artefacts and materials spanning multiple periods and regions. This includes thin sections of ceramics, pottery sherds, test briquettes, clay samples, plasters, mortars, glasses, metals, pigments and stones. Notably, the OeAI proudly hosts the most extensive archaeometric collections of Roman marble and pottery from Greece and Asia Minor, further enriching its repository of invaluable historical and scientific resources. Alongside these physical artefacts, the collection is complemented by a wealth of petrographic, geochemical, and mineralogical data. Recognising the significance of these records, encompassing information, materials, data, and documentation, we underscore their pivotal role in safeguarding and comprehending our cultural heritage.

These collections will be made available via a web application that provides downloadable open-format data and metadata, as well as Linked Open Data, where a controlled vocabulary is linked with online authority databases. Designed as a long-term sustainable solution, the database is intended to not only present the marble collections for which it was originally designed but to also be adaptable for archaeometric collections of varying types, such as the OeAI ceramics collection.

1. Introduction

The archaeometric collection of the Austrian Archaeological Institute (OeAI) of the Austrian Academy of Sciences (OeAW) contains a wide variety of materials and objects from a diverse assortment of locations and time periods. Such materials include thin sections of ceramics, pottery sherds, test briquettes, clay samples, various types of stones (e.g. chert, limestone, and serpentinite) as well as glass, metals, plasters, mortars and pigments. However, particular focus is made here on its extensive assemblage of white marble samples and its ceramic reference collection. Making these collections easily available to researchers is a high priority of the OeAI, particularly regarding the digital documentation of these samples and their analyses.

The initiative for developing an advanced open-access archaeometric database began with the *Fingerprinting White Marbles* project (FWM), funded by the Austrian Science Fund (FWF, project number P33042), which provided resources to establish an online database for managing project materials and analyses (Anevlavi et al., 2025). This initial database supports a substantial marble collection of approximately 9,000 geological samples and 5,000 marble artefacts. Recognizing the potential for a broader scientific resource, the decision was made to expand the database to incorporate the ceramic collection and provide a

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framework for integrating future collections, with 4,000 ceramic and geological clay samples to be included in the next step of database expansion (see Fig. 1). Thus, a small, specialized marble analysis database evolved into what is now known as oeai.METRIX — a comprehensive, open-access database supporting multi-disciplinary research in archaeology and materials science.

The following will give an overview of these two OeAI collections and provide a preview of oeai.METRIX that will hopefully give rise to discussion about the respective needs of the users – both "producers" and "consumers" of the data.

2. Collections

2.1. Marble provenance research

The OeAI holds one of the most extensive archaeometric collections of Roman marble and pottery from Greece and Asia Minor, consisting of approximately 9,000 geological samples and 5,000 marble artefacts. These materials derive from decades of research and fieldwork, as well as from donations by leading scholars, including Walter Prochaska, Donato Attanasio, and Luc Moens. The collection encompasses a wide variety of white and whitish marbles sourced from ancient quarries across the Eastern Mediterranean and the Balkans, including regions such as Paros, Prokonnesos, Dokimeion, Thasos, Penteli, Carrara, and Ephesos (Prochaska, 2021; Prochaska & Attanasio, 2021; 2022; Prochaska et al., 2024).

Samples within the collection are complemented by comprehensive analytical datasets, including petrographic thin sections, stable isotope analyses, trace element concentrations, and spectroscopy data. These are documented with associated metadata regarding archaeological context, provenance hypotheses, and sampling history. The collection serves as a key resource for comparative studies, enabling the identification of unknown artefact origins through cross-referencing with known quarry samples.

Fig. 1. Photo of the physical marble and ceramics collection room of the OeAI © N. Gail – OeAI/OeAW.

In preparation for inclusion in oeai.METRIX, each sample is being digitally recorded with structured attributes that allow for granular searches by sample type, quarry group, analytical technique, geographic source, and associated artefact or project. This makes the collection not only a physical reference archive but also a digitally accessible resource for provenance research,[1] authentication studies, and interdisciplinary collaboration. With its breadth, analytical depth, and digital integration, the marble collection forms the backbone of the oeai.METRIX platform.

2.2. Ceramics research

In addition to OeAI marble collection, the OeAI's ceramics collection includes around 4,000 ceramic and geological clay samples in the form of both processed and unprocessed materials and artefacts. As one of the most significant research tools for the newly established ceramic lab within the OeAI Unit for Archaeological Sciences, the ceramic reference collection, alongside advanced laboratory facilities, enables cross-cultural and diachronic analysis of exchange and trade networks as well as production modes. These analyses allow researchers to contextualize ceramic material evidence within broader cultural, socio-economic, and political frameworks. Current flagship projects within the ceramic lab focus on the connections between craft organization and phenomena of mobility, acculturation, centralization, urbanization, and state formation.

The core of the ceramic reference collection lies in its vast array of materials and data, primarily from the ancient city of Ephesos in modern-day Western Turkey. Since the 1990s, archaeologist Sabine Ladstätter and geologist Roman Sauer have led systematic and integrated archaeometric studies, uncovering crucial insights into production modes and trade networks. Spanning from the Archaic to Late Antique periods, the collection encompasses everything from unprocessed ceramic sherds to meticulously prepared powdered, epoxied, and thin-sectioned samples, alongside several clay specimens. This collection's unique value stems from its in-depth chemical, petrographic, and mineralogical analyses, which not only illuminate the history of Ephesos but also extend to other key sites in Asia Minor, such as Priene, Pergamon, and Milet. What began with Ephesos has grown into a vast repository of materials from across Central and Eastern Europe, the Central and Eastern Mediterranean, Egypt, and Southwest Asia. Covering a timeline from prehistory to historic eras, the collection offers an unparalleled resource for comparative ceramic studies, serving as a crucial tool for researchers around the globe.

3. The database

3.1. oeai.METRIX

Having a fine collection of materials and data, we now have the problem of how to appropriately share and present that data. A decision was made to create an online application that would take the guidelines of the FAIR Principles (Findable, Accessible, Interoperable, Reuseable) into consideration (Wilkinson et al., 2016). Thus, during the development of oeai.METRIX, care was taken to incorporate FAIR elements such as descriptive metadata, the incorporation of standard and open technologies and formats (including for download), open access

[1] Over several decades, researchers have investigated marble to determine its provenance and authenticate its use in historical artefacts and monuments (Rapp, 1985). This helps reveal societal connections, economic importance, and the use of expensive marble to signify elites (Maniatis, 2003). Archaeologists and art historians gain insights into marble's material and chronological significance (Taelman, 2022). Studying ancient quarries also sheds light on technological advances (Maniatis, 2003). Additionally, research into trade routes and the exchange of marble materials provides valuable archaeological insights (Herz & Doumas, 1991; Maniatis, 2004; Anevlavi & Prochaska, 2021).

vocabularies that are linked to authority databases, and the release of the platform under an open-source license (more details will be given below). This was intended to increase the useability and access of the archaeometric data and analyses. However, there is always an inherent risk of smaller applications with an extremely narrow focus ending up in the dreaded database graveyard where expensive, overly specialized and ultimately unused databases are left to rot. Despite the initial funding as mentioned above, the narrow focus of this project posed a risk of limited long-term use for the database, potentially rendering it obsolete. Additionally, this approach did not align with the OeAI's current database strategy, which emphasizes sustainability and broader applicability to ensure ongoing relevance and utility (overview of the OeAI data structure being prepared for publication in the forthcoming proceedings of the 2022 Archaeo-Informatics conference of the DAI Deutsches Archäologisches Institut and the ODTÜ METU Middle Eastern Technical University, Schwaiger et al., 2022).

We therefore decided to transform what would be a small, specialized database with a small user base into an adaptable and more inclusive model that could regularly include new data from new projects. The focus would be archaeometric data and analyses that would complement the already existing database structure at the OeAI. And thus, the Fingerprinting White Marbles project was used as a basis to create oeai.METRIX (https://oeaimetrix.oeaw.ac.at/).

oeai.METRIX complements the database structure of the OeAI, where separate databases are made interoperable through linked data in order to reduce redundancy. The OeAI core services consist of oeai.DAM and oeai.MAC (see Fig. 2). oeai.DAM (which stands for Digital Asset Management) is responsible for all images, PDFs and 3D-data and allows for both open and internal-only access for images in its collections (https://oeaidam.oeaw.ac.at/search). oeai.MAC (which stands for Magazines, Archives and Collections) is the physical object management system at the OeAI (https://www.oeaw.ac.at/oeai/oeaidigital/core-services/oeaimac). It is responsible for a general overview of physical objects and their storage locations, such as archaeometric samples, artefacts, books, maps, the Helmut Brückner Archive of core samples, as well as the OeAI digital holdings. Additional separate applications can be easily linked to these core services via URL or API, allowing for easy incorporation into the OeAI database structure. This can be seen in projects such as oeai.COIN (https://oeaicoin.oeaw.ac.at/), the OeAI Roman coin database, as well as the main subject of this paper, the materials and archaeometric analyses database, oeai.METRIX.

oeai.METRIX (see Fig. 3) is a web-based application developed using the Django framework (https://www.djangoproject.com/), primarily designed for the visualization of archaeometric research data and related visual materials of archaeological artifacts. The data structure can be seen in Fig. 4. The system is built on a PostgreSQL (https://www.postgresql.org/) relational database enhanced with the PostGIS spatial extension, which allows for the storage and management of geographic coordinates, such as excavation sites and find locations. This geospatial functionality supports the integration of archaeological data into interactive visual interfaces, enabling users to explore spatial relationships and contextual information directly. Geoinformation is made accessible and visualized through the Leaflet JavaScript library (https://leafletjs.com/) in combination with OpenStreetMap (https://www.openstreetmap.org/), allowing for dynamic mapping and intuitive geographic exploration within the application (see Fig. 5). Visualization of archaeometric analyses can be displayed with an interactive network diagram which can also be made available for download. The underlying data model of oeai.METRIX has been designed with a modular and extensible architecture, allowing for the seamless integration of future research projects. The original research data and analyses can be downloaded in FAIR-friendly open CSV or JSON formats, and an integrated rights management system enables both open access to publicly available datasets and restricted access to sensitive or unpublished data, which can only be viewed via authenticated login. Access to certain restricted data can be requested by contacting the responsible researcher and oeai.METRIX technical support. Partial access to certain data and analyses can also be arranged, allowing open sharing of data whenever possible while at the same time protecting publication rights of the researcher. The archaeometric data are also published in peer-reviewed journals, along with all related information, which is simultaneously added to the database.

The hosting infrastructure and collaborative software development for the application are provided by the Austrian Centre for Digital Humanities and Cultural Heritage (ACDH-CH) of the Austrian Academy of Sciences (https://www.oeaw.ac.at/acdh/acdh-ch-home). Visual resources are dynamically retrieved via an API connection to oeai.DAM, the OeAI's central image repository, and rendered directly within the application interface. Object samples may be linked to corresponding entries in oeai.MAC, the institutional object database, via persistent identifiers, ensuring access to up-to-date contextual information such as current storage location or loan status. Relevant literature can be explored in relation to archaeometric samples through integration with the Zotero reference management system (https://www.zotero.org/), which allows for direct linking to associated publications. Furthermore, the database incorporates a controlled vocabulary framework, enabling the semantic enrichment of data and facilitating connections to external authority files to support standardized searching and interpretation,

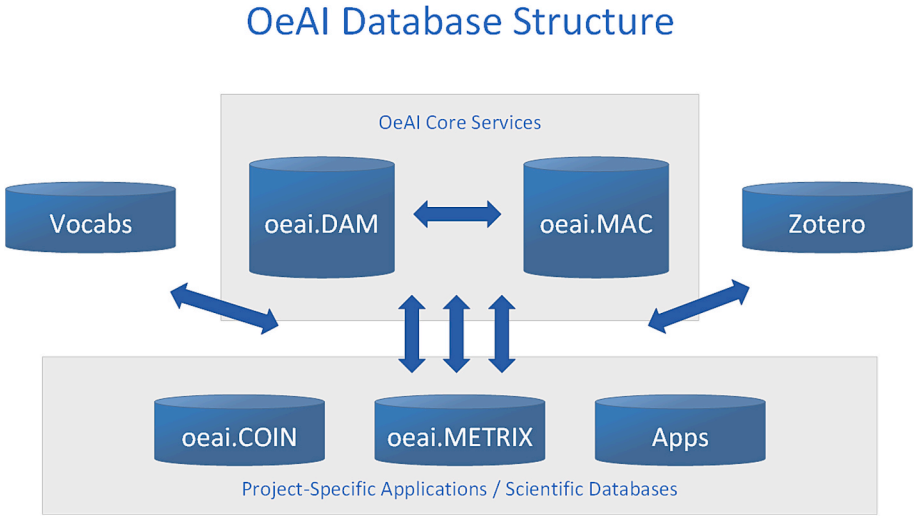

Fig. 2. OeAI database structure overview © OeAI/OeAW.

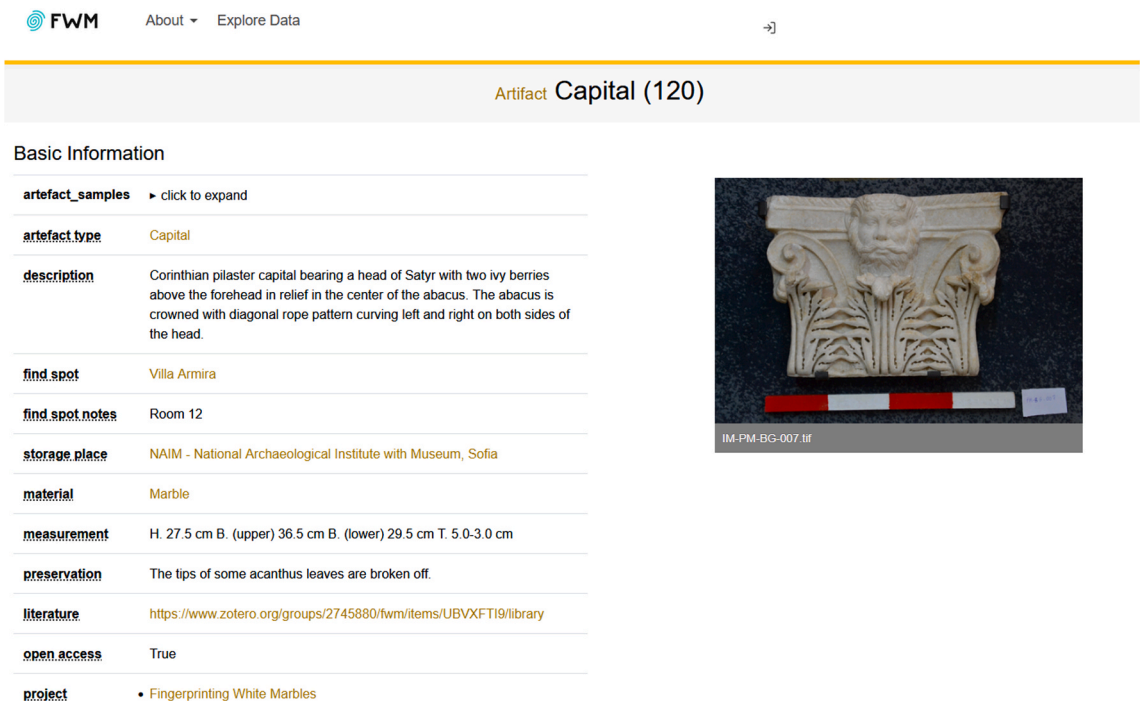

Fig. 3. Screenshot of oeai.METRIX displaying artefact data with clickable links and oeai.DAM image interface © OeAI/OeAW.

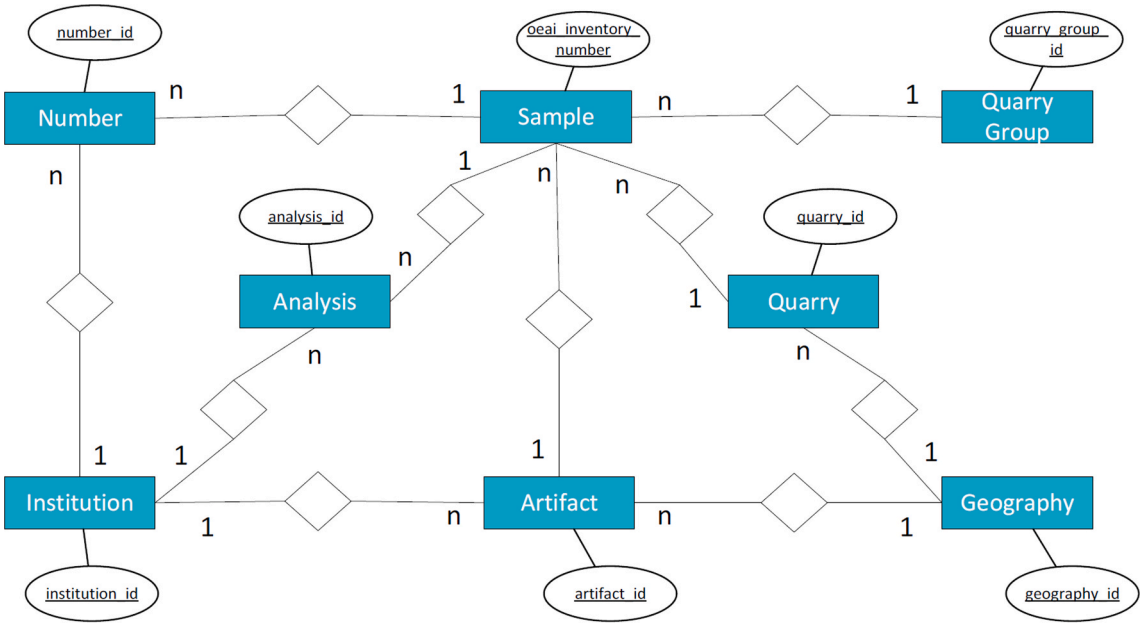

Fig. 4. oeai.METRIX database structure © OeAI/OeAW.

enabling consistent terminology, improved data interoperability, and alignment with external authority standards. This flexibility ensures long-term scalability and adaptability to evolving research needs in the field of archaeometry in a FAIR-friendly environment.

3.2. *Flexibility*

The application was designed from the beginning to be flexible, displaying data in a simple table format with searchable attributes. As required by the FWM project, archaeometric samples of marble can currently be searched by various characteristics, such as analysis type, artefact, institution, project, sample number, geographic location etc., which can be easily filtered (see Fig. 6). These features are broad enough to easily incorporate other projects and material types – the OeAI ceramics collection can comfortably use the same features. The data model itself also allows for project-specific characteristics to be included, such as those created as part of the original marble database plan, where samples can be searched via marble quarry or via quarry group which refers to clusters of quarries or marble sources that exhibit similar traits based on geographic proximity (quarries located near one another) or a combination of geographic and geochemical features (e.g. nearby locations sharing comparable geochemical properties). The ceramics collection, when uploaded, could also have personalized categories as attributes – such as typology, style, manufacturing procedures or

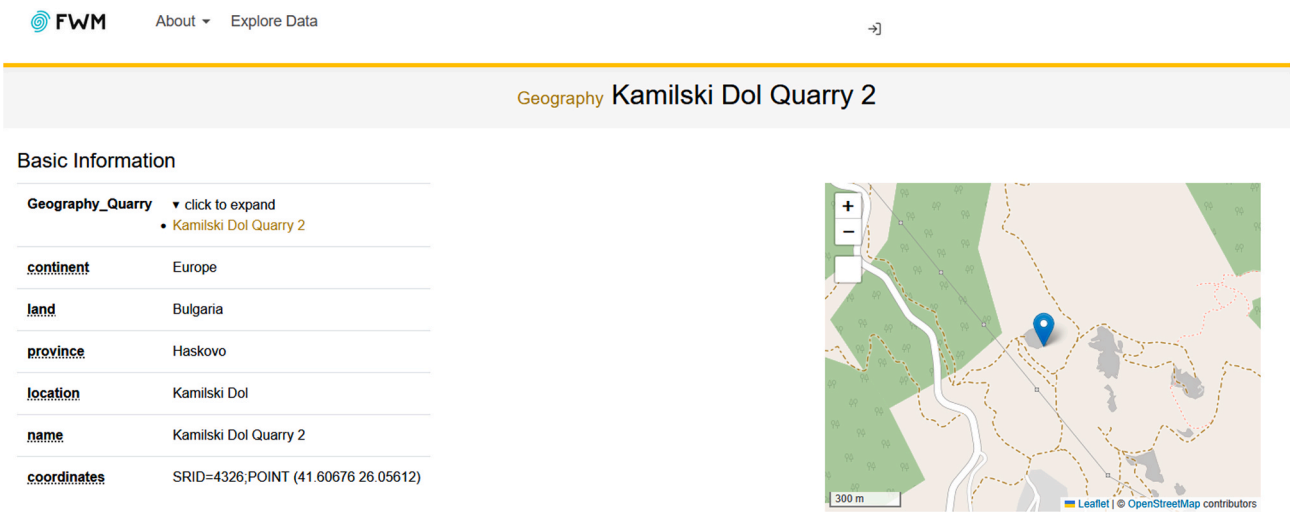

Fig. 5. Screenshot of oeai.METRIX displaying geographic attributes © OeAI/OeAW.

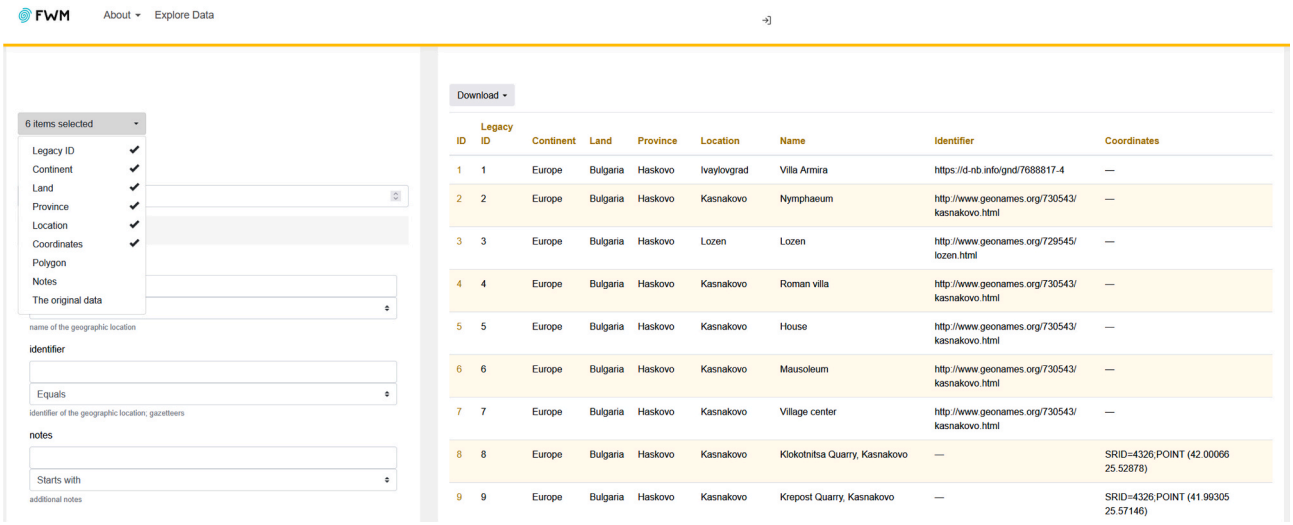

Fig. 6. Screenshot of oeai.METRIX displaying adaptability of attributes © OeAI/OeAW.

morpho-functional shapes. They can be added as search bars with additional features displayed in a table format.

This flexibility can also be seen in the controlled vocabulary which the OeAI has created for use across its database components. It consists of a hierarchically sorted list of terms originating from the earliest oeai.DAM database that have been expanded into a SKOS-based (https://www.w3.org/TR/skos-primer/) format. This allows for alternative labels, multilingual translations, and self-created definitions or links to authority databases, such as PeriodO (https://perio.do/en/, ChronOntology (https://chronontology.dainst.org/), Getty's AAT (https://www.getty.edu/research/tools/vocabularies/aat/), Wikidata (https://www.wikidata.org/) etc., that can be regularly added to or expanded upon as new terminology is included into the various database components. The FWM collection is currently linked to authority databases such as Geonames (https://www.geonames.org/) and the iDAI Gazetteer of the Deutsches Archäologisches Institut (https://gazetteer.dainst.org/) for geographical vocabulary, as well as the Virtual International Authority File (https://viaf.org/) for the identification of institutions. Material types will be linked to the OeAI Materials database that was created using Vocabs (https://vocabs.acdh.oeaw.ac.at/oeai-materials_browse/en/), a collaborative vocabulary creation service provided by the previously mentioned ACDH-CH. While the service allows for linking to authority databases, it is also possible to create specialized definitions for materials and objects that are not found in other authority databases, allowing for the creation and curation of an OeAI-Institute-specific vocabulary collection. Researchers from the FWM project were able to be directly involved in defining the marble types in the OeAI Materials Thesaurus, a benefit which researchers from the OeAI ceramics lab has also received regarding glass types.

Regarding specialized literature, the FWM project was able to link directly to a project-specific Zotero library (https://www.zotero.org/groups/2745880/fwm/library) and the ceramics lab will also be able to link their own ceramics-specific literature to their own archaeometric samples and analyses.

These are just a few examples of the personalizations that new projects can include when added to this flexible database. The marbles of the FWM project and the OeAI ceramic collections are just the first of hopefully many future archaeometric collections and project data that will be added to oeai.METRIX.

3.3. *Comparative applications*

While oeai.METRIX was originally developed within the context of the Fingerprinting White Marbles project (Andreeva et al., 2022), it is

explicitly designed to be a flexible, open-access, and reusable infrastructure that extends well beyond a single collection. Unlike platforms such as GeoRoC (Geochemistry of Rocks of the Oceans Consortium) (Sarbas, 2008) and EarthChem (Earth Chemistry Data Consortium) (Niu et al., 2011), which focus on geochemical data in the geosciences, or the Levantine Ceramics Project (LCP) (Berlin, 2014), which centers on ceramic typologies and descriptive metadata, oeai.METRIX offers a modular architecture that integrates archaeometric analytical data, object metadata, and controlled vocabularies within a single environment tailored to cultural heritage research. The platform is open source and released under the MIT License, with the codebase freely accessible on GitHub (https://github.com/acdh-oeaw/fwm), allowing other institutions with comparable collections to adopt or adapt the system. This reusability is further supported by the use of standard technologies (Django, PostgreSQL), open formats (CSV, JSON), and the integration of linked authority files (e.g., GeoNames, iDAI Gazetteer, VIAF). Moreover, oeai.METRIX is designed to align with ongoing European digital infrastructure efforts such as EOSC (European Open Science Cloud) (David et al., 2023) and ARIADNE (Advanced Research Infrastructure for Archaeological Dataset Networking in Europe) (Niccolucci & Richards, 2013), with future implementation of metadata standards like CIDOC-CRM and persistent identifiers (e.g., handles or URIs) planned to support interoperability and integration into broader Linked Open Data (LOD) frameworks (Bauer & Kaltenböck, 2011). By explicitly embracing these standards and collaborative principles, oeai.METRIX positions itself not only as a sustainable internal resource but also as a platform capable of contributing to and benefiting from pan-European research infrastructures.

A notable comparative example in the field of archaeometric database infrastructure is GlobaLID (Global Lead Isotope Database), a community-driven, open-access resource developed for the storage, analysis, and visualization of lead isotope data across archaeological and geological contexts. Technically, GlobaLID is structured around FAIR principles and is designed for extensibility and interoperability. It standardizes heterogeneous datasets by harmonizing eight lead isotope ratio formats and enriching entries with detailed metadata such as geographic coordinates (sourced or inferred via GIS methods), geological context, analytical techniques, and bibliographic references. The database is accessible via an interactive web application (https://globalid.dmt-lb.de), offering advanced features such as 1D–3D plotting, density estimation, and the capability to upload and compare external datasets directly within the interface (Klein et al., 2022; Westner et al., 2021).

4. Example of data treatment

Data input can be performed directly in the oeai.METRIX application. The import process can be shown using an example from the archive of the city of Roman Montana in present-day Bulgaria (Andreeva et al. 2024), detailing the procedures for handling these samples. Data entry starts in the SAMPLE entity, where each sample's unique Institute ID number is recorded, followed by relevant information populated across associated attributes. Data from the two analyses performed on the sample group, along with details of the laboratories where they were conducted, are entered in the ANALYSIS entity, with all information assigned to the appropriate fields. Subsequently, entries are made in the NUMBER entity, establishing a connection between SAMPLE and NUMBER through the oeai_inventory_number attribute, and all necessary codes and sample names are filled in. For Montana's archaeological samples, the project and laboratory numbers are identical, and a museum index number is added for any identified objects, specifying the institution responsible for each identifier. In the GEOGRAPHY entity, locations of the objects are recorded, including their placement in the archaeological museum, the Montana archaeological site, and the archaeological depot, with links to an external geographic database for further reference. The INSTITUTION entity lists the three sites associated with the sample group as well as the laboratories conducting the analyses, including a link to an authority database. Finally, the ARTIFACT entity connects to the SAMPLE entity via the artefact_id attribute, with detailed descriptions of the archaeological artefacts entered into the relevant fields, completing a comprehensive documentation of each sample and its contextual information.

The process for geological samples from marble quarries closely follows the procedure described above, with minor adjustments applied to the Bulgarian white marble quarry samples. Data were systematically entered into the SAMPLE, ANALYSIS (with Bulgarian sample groups including three analyses), NUMBER, INSTITUTION, and GEOGRAPHY entities. However, the Bulgarian samples uniquely include additional data in the QUARRY and QUARRY_GROUP entities, while no entries are made in the ARTIFACT entity, reflecting their distinct focus on quarry-specific data rather than artefact information. The resulting data will then be displayed in the application with the potential for future additions.

5. Conclusion

The Institute aims to systematically document all available archaeometric data regarding ancient materials, while planning future sampling and research missions across additional regions to comprehensively record ancient raw material sources and archaeological artefacts worldwide. The architectural framework of this database serves as a model for developing sub-databases for various other materials. Ultimately, this well-structured database transforms extensive datasets into an accessible, organized resource, delivering targeted information that supports and enhances users' research efficiently.

Beyond its utility as an internal research tool, oeai.METRIX demonstrates a forward-thinking approach to digital infrastructure in archaeometry. By adopting open-source technologies (Django, PostgreSQL), controlled vocabularies, and interoperable export formats (CSV, JSON), the platform supports both human and machine-readability. Its alignment with FAIR principles, coupled with the planned integration of persistent identifiers, Linked Open Data, and an open API, positions oeai.METRIX as a model for sustainable, collaborative data sharing. As new collections such as the OeAI ceramics reference archive are integrated, and alignment with European initiatives like those mentioned above, oeai.METRIX aims to play a central role in enabling cross-institutional archaeometric research.

CRediT authorship contribution statement

Micheline Welte: Writing – review & editing, Data curation, Writing – original draft. **Karl Burkhart:** Software, Data curation. **Helmut Schwaiger:** Writing – review & editing. **Vasiliki Anevlavi:** Writing – original draft, Investigation, Formal analysis. **Emmanouil Anevlavis:** Writing – original draft. **Pamela Fragnoli:** Writing – review & editing, Writing – original draft. **Walter Prochaska:** Resources, Investigation, Formal analysis.

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Data availability

Information is available in open access online database.

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