Linked Open Greek Pottery: Kerameikos.org

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1.0. PROJECT SUMMARY

Linked Open Greek Pottery: Kerameikos.org is a collaborative project dedicated to defining the intellectual concepts of Archaic and Classical Greek pottery following the methodologies of Linked Open Data (LOD). These concepts include categories such as shapes, artists, techniques, time periods, and production places. When linked externally to other LOD thesauri, such as the Getty Art & Architecture Thesaurus (AAT), Kerameikos.org allows for the normalization and aggregation of disparate museum and archaeological datasets into an information system that facilitates broader public access (e.g., Pelagios Commons). Beyond the definition of pottery concepts, following open web standards, Kerameikos.org standardizes and documents an ontology and model for exchanging pottery data, provides easy-to-use interfaces to visualize geographic and quantitative distributions of Greek pottery, and publishes a series of data manipulation web services enabling archaeologists and museum professionals to contribute data to this ecosystem. By the conclusion of the project, thousands of objects from several institutions that adhere to Open Data principles will be available for analysis by museums, archaeologists, and Greek pottery students and specialists.

With the aid of a National Endowment for the Humanities Level II Digital Humanities Advancement Grant in Fall 2018, Kerameikos.org was able to enhance the scope of Linked Open Greek Pottery to encompass the concepts of Archaic and Classical Greek vase-painting and build a more comprehensive platform for research. Initially intended to be undertaken in an 18-month time frame, with the advent of the COVID-19 pandemic in early 2020, the project's Principal Investigator, Dr. Tyler Jo Smith (University of Virginia), applied for and received an extension to disburse our budget at a later date. Ultimately, our NEH-funded phase has concluded as a three-year project with our results presented virtually at the Computer Applications and Quantitative Methods in Archeology conference (CAA) held in Limassol, Cyprus in June 2021.

Under the supervision of Dr. Smith, Dr. Renee Gondek, and Ethan Gruber, the Kerameikos.org project had the following aims:

1. To publish the intellectual concepts of Archaic and Classical Athenian pottery following the principles of Linked Open Data. These concepts include categories such as techniques, vessel shapes, production places, time periods, and artists (groups or individuals of painters and/or potters).
2. Software development to improve the reusability of these concepts in external projects by making machine-readable data easily accessible to technical audiences.
3. To develop a standardized data model for representing vases in order to test the aggregation of objects from several museum collections and develop interfaces for query and visualization, thus illustrating the utility of LOD methodologies applied to this material. This public user interface includes the following features about each concept URI:
    a. Maps showing the distribution of production places and findspots;
    b. Photographic examples of vases corresponding to techniques, shapes, artists, etc. defined in Kerameikos.org;

c. Intuitive interfaces for creating distribution queries, e.g., to compare the shapes created by two different potters, represented as charts generated nearly instantaneously.

2.0. PROJECT ORIGINS AND GOALS

2.1. Origins and Motivations

The indestructible nature of terracotta pottery from ancient Greece, and indeed from across the world, has left an abundant amount of material in the archaeological record. Formed into a variety of shapes and sizes, these artifacts have the ability to enhance our understanding of historical, economic, social, and cultural processes. For example, ancient vessels often inform modern scholars about their possible function within a given ancient culture (e.g., domestic, ritual), as well as the technical expertise required for manufacture. More broadly, pottery enables researchers to date archaeological sites, reconstruct the nature of these sites, and reveal trade and interaction between groups of people. Furthermore, a large quantity of ancient Greek pottery is figure-decorated, reflecting the artistic style of a certain period, the visual language of a region, and narrative scenes that pertain to religion, daily life, literature, or contemporary events. Sometimes termed 'vases' and numbering in the several hundreds of thousands, these often beautiful and elaborately decorated objects demonstrate the advanced abilities of their artists (both potters and painters). For well over a century, they have been a vital part of the traditional Classics curriculum of civilization, language, mythology, and drama; they have proved foundational to surveys of the history of Western art; and they have long played a role in Studio art and architectural practice as a result of their sophisticated construction, firing techniques, composition, and design.

Considering the importance of Greek figure-decorated pottery for researchers in the fields of Classics, archaeology, art history, and history, there exist a variety of accessible databases within both museum collections and digital archives, among them the Beazley Archive Pottery Database. While the basic ideas underlying the classification of ancient Mediterranean pottery are shared across languages (e.g., shape, production place, painter, potter, iconography, etc.), there are no firm standards for describing, representing, and publishing pottery datasets on the web. Additionally, due to the wide variation in the native languages of these databases (and lack of consistent, controlled vocabulary even among databases of the same languages), it is difficult to conduct research across multiple systems. Kerameikos.org is a thesaurus that seeks to define the intellectual concepts of Greek pottery according to open web standards. Rather than relying on textual strings as controlled vocabulary (the painter, Exekias, in most Western scholarship is transliterated to 埃克塞基亚斯 in Chinese), concepts are represented by HTTP URIs, following the definition of Linked Open Data (LOD) by Tim Berners-Lee: https://www.w3.org/DesignIssues/LinkedData.html. These URIs, when dereferenced, may offer both human-readable HTML or machine-readable RDF or JSON-LD, following standard ontologies. By definition these concepts link to identical concepts in other information systems.

Kerameikos.org aims to provide a pathway to normalisation for many pottery databases, enabling the large-scale data aggregation and subsequent analyses that are not currently possible within the discipline.

2.2. Past Work

Kerameikos.org was inspired by the success of the application of Linked Open Data principles to the study of coinage through the Nomisma.org project and other American Numismatic Society (ANS) projects built on the Hellenistic Royal Coinages project and Nomisma-Online Coins of the Roman Empire (http://numismatics.org/ocre/) and the (both funded by the NEH). Looking to Nomisma.org as a guide, Gruber and Smith began the Kerameikos.org project in Fall 2013 while Gruber participated in a Greek Vase-Painting graduate seminar taught by Smith at the University of Virginia. Like numismatics, Greek pottery is a discipline with a similar, rigorous classification system, and so the project was started by creating identifiers for about 60 different concepts in a small range of categories: production places, artists, shapes, styles, time periods, materials, and several others. Many of these categories of concepts conform to classes in existing, standard LOD ontologies, such as Friend of a Friend (FOAF: an ontology for people and organizations) and CIDOC-CRM (published by the International Council of Museums), though new classes have been defined for shapes and techniques in a pottery-specific ontology published by Kerameikos.org that fill semantic gaps in existing ontologies and extend the CIDOC-CRM.

The initial 2014 prototype featured several hundred vases aggregated from the J. Paul Getty Museum and the British Museum. Objects from each institution were mapped into an RDF model conforming to the CIDOC-CRM ontology, linking to typological URIs within their own LOD thesauri. These data were imported into a 'triplestore' with an open query interface conforming to the World Wide Web Consortium's SPARQL protocol. Using Kerameikos.org URIs as a bridge between the British Museum and Getty thesaurus URIs, queries were constructed to visualize geographic and quantitative distributions of the vases from these collections together, as well as display thumbnail photographs of vases related to the concept URI within the public-facing HTML page. The software framework middleware underlying Nomisma.org is open source, developed by Gruber, and was adapted for Greek pottery for the Kerameikos.org project (https://github.com/kerameikos/framework), and all other server applications are also open source. The Kerameikos.org framework from its inception included a back-end for creating and validating new LOD concepts and a front-end public user interface with the features listed above.

This prototype was the topic of a paper presented at the April 2014 Computer Applications and Quantitative Methods in Archaeology (CAA) conference in Paris (see Sections ***6.1-2***). The following year, Gruber and Gondek organized a Greek Pottery Linked Data roundtable at the CAA conference in Siena, Italy. This roundtable was well-attended and featured vigorous discussion about the future of the discipline as pertaining to Semantic Web principles.

Development progressed steadily from 2015 to 2016. In 2016, the chart visualization Javascript library was migrated to d3js, and the maps were migrated from OpenLayers to Leaflet, with geographic data represented by the open standard of GeoJSON instead of Google's KML. The import RDF model for vases was extended to support images published via International Image

Interoperability Framework (IIIF: http://iiif.io/) APIs by adopting specifications from the Europeana Data Model. In the Spring of 2017, URIs to 3D models of Greek vases published by the Ure Museum (University of Reading) to Sketchfab or through the University of Virginia's own system have been incorporated into the underlying vase RDF and are available for view in the Kerameikos.org public user interface. In the Fall of 2017 and in collaboration with Greg Parker (Beazley Archive, Oxford University), the OpenRefine (an open source application designed for cleaning data) workflow for creating concepts derived from the Beazley Archive Pottery Database was established. In Fall 2017, OpenRefine APIs for the reconciliation of spreadsheet data to Kerameikos.org URIs were implemented.

Following the reception of the Digital Humanities Advancement Grant, the Kerameikos.org platform was migrated from Gruber's personal Rackspace cloud server to a server managed by the The Institute for Advanced Technology in the Humanities at the University of Virginia for long-term sustainability. Aspects of the website are still undergoing redesign to improve the transparency of the process of participating in the project.

2.3. Intended Audience

Although we have not yet conducted a survey on how Kerameikos.org is currently being used, we have begun to see its use outside of our own technical environment, including in other digital projects and some scholarly publications. The audience for the project falls into three broad categories: 1) Scholars and Researchers using Kerameikos.org data or methodologies to conduct original research; 2) Museums and Cultural Institutions; 3) Pedagogical Environments and the General Public interested in the ancient world; and 4) Technical Users relying on Kerameikos.org as part of their infrastructure or to provide more historical context for their own collections or research data.

2.3.1. Scholars, and Researchers

Kerameikos.org is largely intended for use by Classical archaeologists and other Classical scholars and advanced students engaged in the study of ancient Greek figure-decorated ceramic vessels. While the large online database known as the Beazley Archive Pottery Database remains a valuable resource for searching individual objects or the works of an individual painter, as it is currently configured, it lacks the ability to link with data in a relational way. For example, one can search for the 'Berlin Painter' within the database, and the results will display a list of individual vessels attributed to that painter. Within Kerameikos.org, however, searching the 'Berlin Painter' will result in a map, a list of vases aggregated from multiple museum collections (e.g, British Museum and Harvard Art Museums), provide a definition of the artist, and a summary of the artist's output.

2.3.2. Museums and Cultural Institutions

The concepts of Kerameikos.org are authoritative, having been produced and edited by subject specialists. Therefore, they are useful as a controlled vocabulary system for collections cataloging, whether museum collections or archaeological datasets. We have engaged in discussions with archaeologists, who are keen to use Kerameikos.org URIs within their own information systems. Presently, ceramics in the Oxford I.Sicily project of inscriptions of ancient

Sicily are cataloged with Kerameikos.org URIs for shapes (see section ***5.0***), and we are aware of two other institutions looking at Kerameikos.org as a cataloging resource.

Beyond cataloging use-cases, Kerameikos.org has generated interest from both large and small museum collections as a means by which materials can be made more broadly accessible to students and scholars of Greek pottery. Among these has been Branko van Oppen, the Curatorial Consultant for Ancient Art at the Tampa Museum of Art, Dan Pett at the Fitzwilliam Museum of Cambridge University, and the LOD technologists at the J. Paul Getty Museum, David Newbury and Brenda Podemski.

2.3.3. Pedagogical Environments and the General Public

In addition to Kerameikos.org benefitting scholars, researchers, and cultural institutions, its potential impact on pedagogical environments and the general public should not be ignored. One can easily see how the interface will be helpful for K-12 instructors designing lesson plans covering ancient history and civilizations. For instance, perhaps one lesson may focus on mythology and the Trojan War and another may delve into the dining and drinking practices of the ancient Athenians and how Greek vases both demonstrated and enhanced those experiences.

Due to the broad appeal of the images on vases and the widespread distribution of these vessels around the world, individuals outside structured learning environments (schools, universities) could utilize Kerameikos.org in a myriad of ways. For instance, a volunteer docent may need to prepare a tour in a local, regional, or university museum that houses a small collection of Greek vases or other ancient artifacts. Or perhaps a volunteer lecturer at a senior care facility is presenting an introductory talk on ancient Greek religion and mythology. Importantly, regional museums and cultural centers in the Greek-speaking world (Greece, Cyprus, diaspora communities) will be able to use Kerameikos.org to showcase cultural heritage events for children and adults alike, as will institutions and foundations engaged in Classical outreach throughout the English-speaking world (e.g., Australia, UK).

2.3.4. Technical Users

There are various categories of technical users that benefit from Kerameikos.org. Software developers working on museum or archaeological database systems are able to build cataloging tools or user interface features directly on stable APIs provided by Kerameikos.org. The OpenRefine API that Gruber developed can be adapted directly in other software frameworks to autosuggest search terms, for example, when cataloging a vase, a curator may type ‘kot’ into a search box. The Kerameikos.org API responds with ‘kotyle,’ a name for a type of cup, and the preferred labels and URIs from Kerameikos.org can be incorporated into those collections management systems.

Museum interfaces can extract machine-readable data directly from Kerameikos.org through well-established HTTP content negotiation methods. A collection management system could extract the geographic coordinates for a production place from Kerameikos.org to display a map or parse the definition in English or other languages to provide individual users of those museum databases further descriptive context of the concept.

3.0. DATA MODEL

3.1. Software Architecture

Kerameikos.org's software architecture is nearly identical to that of Nomisma.org, due to Gruber's software development and data science roles at the American Numismatic Society. Kerameikos.org is an open source middleware application that handles the front-end user interface and back-end administrative functions. The framework is available on Github at https://github.com/kerameikos/framework. This collection of scripts - predominantly XSLT, XForms (and supporting standards), and Javascript - binds together open source server applications that run in Java, specifically in Apache Tomcat.

The web application architecture is based on XRX (XForms, REST, and XQuery), though XQuery has been substituted for the combination of SPARQL and Apache Lucene/Solr. Kerameikos.org identifiers are stored in the filesystem as RDF/XML files, maintained in a Github repository (https://github.com/kerameikos/data), which enhances access in addition to providing version control (see Section ***7.3***). Apache Solr is the *de facto* standard search index in the cultural heritage sector, prevalent in repository applications, like Fedora, or content aggregators, like Europeana. XForms, a W3C standard schema for advanced web form functionality, is the backbone of Kerameikos.org, handling the editing and publication process of ceramic concepts in addition to processing RDF data dumps from contributors (World Wide Web Consortium 2009). XForms enables the publication of data into the project's internal Solr index and RDF triplestore (open source Apache Fuseki is currently implemented in Kerameikos.org), but also supports REST interactions with a variety of external Linked Open Data services. The XForms processor used by Kerameikos.org is Orbeon (http://orbeon.com). Orbeon provides an array of processors that serialise the canonical RDF/XML concepts, Solr and SPARQL query results, and various APIs into all of the content types required to power the user interface—from human-readable HTML to machine-readable JSON-LD, Turtle/RDF, and GeoJSON for mapping.

Kerameikos.org's architecture is modularized. With minor modifications, the Github/filesystem -based storage could be replaced with any number of off-the-shelf graph database solutions. Fuseki could be substituted with any SPARQL 1.1-compliant RDF triplestore, Solr could be replaced with any search index software that supports REST, and Orbeon could be swapped with other XForms processors, such as XSLTForms or betterFORM. While the Kerameikos.org framework does include code fragments which are specific to this project, we aim to make this application more generalisable and adaptable for publishing other types of LOD thesauri.

3.2 Ontologies and Data Models

In order to promote reusability, we opted to incorporate classes and properties from other RDF ontologies when possible. Several classes from the cultural heritage standard, CIDOC-CRM, were adopted: E4_Period, E53_Place, and E57_Material. While the CRM provides an Actor class, we adopted Person and Organization from Friend of a Friend (FOAF) to designate painters, potters, and workshops. Most identifiers are simultaneously designated as concepts, as defined by the Simple Knowledge Organization System (SKOS). Accordingly, since a production place, e.g.,

Athens, is reckoned to be a concept, but also has a geographic component, we have chosen to implement SpatialThing from the World Wide Web Consortium (W3C) geographic vocabulary (World Wide Web Consortium 2004) to encapsulate coordinates in the form of simple points (with geo:lat and geo:long) or more complex polygons that represent regions, encoded in GeoJSON (see **Figure 2**, below).

Some classes—such as shape, ware, or technique—are particular to the discipline and have no equivalent in other ontologies. The British Museum and J. Paul Getty Museum thesauri are intended to be applied to a diverse array of object types found in museums, and so their applications are more general. For example, in the British Museum thesauri, vessel shapes such as lekythos and amphora are considered object types (rather than forms or shapes). As a result, we endeavored to create an ontology, identified by http://kerameikos.org/ontology# (prefix: 'kon'), for pottery-specific classes and properties that would fill in these gaps. Therefore, http://kerameikos.org/id/lekythos and http://kerameikos.org/id/amphora are defined by the kon:Shape class; http://kerameikos.org/id/black_figure is a kon:Technique. These are subclasses extending the generic E55_Type in CIDOC CRM.

As mentioned previously, the most vital aspects of any concept defined in Kerameikos.org are the multilingual labels and links to related concepts in other LOD systems. SKOS provides a clear avenue for encoding labels with skos:prefLabel (preferred label) and skos:altLabel (alternative label) and linking external concepts with skos:exactMatch and skos:relatedMatch. The Exact Match property is used when linking to the Getty Art & Architecture Thesaurus (AAT), the British Museum Object Names Thesaurus, Virtual International Authority File (VIAF), Lexicon of Greek Personal Names, and most other systems. All IDs require an English definition (denoted by the skos:definition property), but definitions in other languages may be used. SKOS scope notes may be included to define rules governing the semantic application of a concept.

The other essential linking property incorporated from the SKOS ontology is skos:broader, used to connect concepts hierarchically. Logically, this would apply to production places: Athens is in Attica, which is in Greece. Techniques, shapes, and periods may also be linked together with skos:broader, following the traditional organizational structure of Greek pottery. Bell kraters and volute kraters are specific renditions of the krater shape. The black-figue technique, by definition, comprises both silhouette and incision. Applying the SKOS ontology to these concepts makes it possible for Kerameikos.org identifiers to reflect the current methods of Athenian pottery classification.

3.3. Server Infrastructure

Kerameikos.org currently resides on a virtual machine with 4 GB of memory hosted by the The Institute for Advanced Technology in the Humanities at the University of Virginia. Gruber's experience in managing Nomisma.org suggests these resources are more than sufficient for managing a server load of up to several hundred thousand SPARQL queries per day. This ceiling is considerably higher than our current load, but the resources of this virtual machine can be expanded in the future, as necessary.

4.0 THE TEAM AND ITS WORK

4.1. Individuals and Collaborations

4.1.1. Core Team Members

Tyler Jo Smith (PI), Professor, University of Virginia

AB, Classics, cum laude, Davidson College, 1989. M.Phil., Classical Archaeology, Oxford University, 1992. D.Phil., Classical Archaeology, Oxford University, 1997. Tyler Jo Smith is Professor of Classical Art and Archaeology in the McIntire Department of Art at the University of Virginia, where she also serves as Director of the Interdisciplinary Archaeology Program. A specialist in ancient Greek vase-painting, she is the author of *Komast Dancers in Archaic Greek Art* (Oxford, 2010), co-editor (with D. Plantzos) of *A Companion to Greek Art* (Wiley-Blackwell, 2012), and author of *Religion in the Art of Archaic and Classical Greece* (2021). She has published numerous articles and book chapters on various aspects of Greek and Roman iconography, and her research focuses on the connections between ancient art, performance, and religion. As a field archaeologist she has studied and published pottery from Berezan, an ancient Greek colony on the north coast of the Black Sea, and also the Archaic pottery collections of the British School at Athens, which includes excavated material from Naukratis (Egypt), Sparta, and Athens. She is an editor for the *Corpus Vasorum Antiquorum* in North America and a founding member of Kerameikos.org, for which she provides specialist knowledge of Greek pottery and vase-painting terminology. She has presented at archaeology conferences and given Digital Humanities seminars relevant to Greek vases, including the scanning and printing of ancient objects in 3D.

Ethan Gruber, Director of Data Science, American Numismatic Society

BA, History, The Pennsylvania State University, 2006. MA, Art and Architectural History (Classical Art and Archaeology), University of Virginia, 2013. Ethan Gruber is the Director of Data Science for the American Numismatic Society. With more than ten years of experience in digital humanities projects, Gruber specializes in Linked Open Data technology, digital archives, data modeling, and information architecture. He is a member of the Nomisma.org scientific committee and a founding member of the Kerameikos.org project, and has advised on knowledge representation, ontologies, and has undertaken all of the software development for the project. In 2012-13, he was a faculty member of the NEH-funded Linked Ancient World Data Institute. He has presented at a wide variety of conferences, relevant to both cultural heritage and the semantic web industry.

Renee Gondek, Research Affiliate in Archaeology, University of Virginia

B.Phil. Classics, History of Art and Architecture, summa cum laude, University of Pittsburgh, 2005. M.A., Classical Art and Archaeology Program, University of Virginia, 2007. Ph.D., Classical Art and Archaeology Program, University of Virginia, 2013. Formerly based at the University of Mary Washington, and an affiliate of the Interdisciplinary Archaeology Program at the University of Virginia, Renee M. Gondek taught courses in the Department of Classics, Philosophy, and Religion. Her area of specialization is the art and archaeology of the Archaic and

Classical Greek world, with an emphasis on vase representations of gender and iconographic expressions of rituals and rites of passage. Co-editor of *The Ancient Art of Transformation* (2019), she has published on the identity and dress of brides on Athenian vases, and contributed introductory articles on Greek art and Greek vase-painting to Khan Academy, an educational website. As an early steering committee member of Kerameikos.org, Gondek participated in the initial phases of the project, providing specialist knowledge of pottery shapes and definitions.

4.1.2. Scientific Committee

Vladimir Alexiev works on Data and Ontology Management at Ontotext AD, a graph database solutions company based in Sofia, Bulgaria. He is a member of the DBpedia and Europeana quality committees and a frequent speaker at these conferences and events. His favorite topics are Linked Open Data and its application in cultural heritage and digital humanities, advising the British Museum and the J. Paul Getty Museum on their LOD endeavors. As a scientific committee member for Kerameikos.org since its inception, Alexiev has frequently provided semantic modeling advice.

Thomas Mannack is Reader in Classical Iconography in the Faculty of Classics at Oxford University and Director of the Beazley Archive Pottery Database housed in the Classical Art Research Centre at Oxford. An expert on Athenian painted pottery, he is the author of numerous publications on Greek vases, including: *The Late Mannerists in Athenian Vase-Painting* (Oxford, 2001); *Haspels Addenda* (Oxford, 2006); and *Griechische Vasenmalerei: eine Einführung* (Darmstadt, 2002). He has co-authored multiple volumes of the *Corpus Vasorum Antiquorum* (*CVA*) and serves as editor of the *CVA* for the United Kingdom and Canada.

Anne-Violaine Szabados is a researcher and specialist in Semantic Web applications at the Centre National de la Recherche Scientifique (CNRS), Archéologies et sciences de l'Antiquité (ArScAn) Department in Paris, France. With experience on the CLAROS project at Oxford University and modeling the *Lexicon Iconographicum Mythologiae Classicae* (*LIMC*; a thesaurus of Classical mythological motifs) into Linked Open Data, Szabados provides Kerameikos.org with additional LOD skills and expertise in ancient Greek cultural heritage management.

4.1.3. Graduate and Undergraduate Assistants

Abigail Bradford, graduate student, Mediterranean Art and Archaeology, University of Virginia
Caroline Carter, graduate student, Mediterranean Art and Archaeology, University of Virginia
Savhannah Long, undergraduate Archaeology major, University of Virginia
Delaney Mitchell, undergraduate Archaeology major/Interdisciplinary Archaeology Program assistant, University of Virginia
Najee Olya, graduate student, Mediterranean Art and Archaeology, University of Virginia
Caroline Stratos, Federal WorkStudy undergraduate student

4.1.4. Content Translators and Editors (not funded directly by NEH)

Nicholas Harokopos, University of Athens (Modern Greek)
Nicole High-Steskal, Österreichisches Archäologisches Institut (German)
Laura Rembart, Österreichisches Archäologisches Institut (German)

4.1.5. Institutional Collaborators

The Classical Art Research Centre, Oxford University
The Institute for Advanced Technology in the Humanities, University of Virginia

4.2. Preliminary Work

In preparation to begin working with student assistants, it was important to familiarize each of them with the history of the study of Athenian vases as well as the ways that these objects are studied and analyzed today in a variety of settings (e.g, excavations, research, museum exhibitions). Because each student was based at the University of Virginia, each one was required to enroll in or audit Smith's lecture course on Greek Vase-Painting. In addition to the regular assigned readings for the course, the assistants were given extra material to read about the production and distribution of Greek vases, and familiarized with the major resources, such as Sir John Beazleys' 'lists' of Athenian black- and red-figure painters and Sir John Boardman's series of Thames and Husdon (World of Art) handbooks. Students were also instructed by Gondek on the use and functionality of the Beazley Archive Pottery Database as a research tool for creating site content and term definitions. Finally, Smith held workshops on pottery illustration and recording, and on 3D scanning and printing using material in the University of Virginia Art Museum.

4.3. Workflow

4.3.1 Creating Pottery Concept LOD

The most comprehensive vocabulary of Athenian Archaic and Classical pottery taxonomies is published by the Beazley Archive Pottery Database at the University of Oxford. However, these are not represented as stable URIs that can be reused as standard identifiers in a database system. Our first step, completed by Gruber, was to extract these vocabularies in a number of conceptual categories (artists, shapes, techniques, production places, etc.) and load them into an open source software application designed for data cleaning called OpenRefine (https://openrefine.org/). After some basic normalization, such as standardizing spelling and capitalization, these terms were reconciled to URIs in other LOD vocabulary systems, such as those published by the J. Paul Getty Museum, the British Museum, the Pleiades Gazetteer of Ancient Places, and Wikidata.org, the data back-end of Wikipedia. The resulting list of terms was then vetted by Smith and Gondek, who removed any terms that were not relevant to our cultural scope.

Once these lists of concepts were created, Smith and Gondek reviewed and approved the terms. Since the current project focuses on Athenian vase-painting during the Archaic and Classical periods, concepts that defined vessels outside of this purview were eliminated (e.g., the Iliupersis Painter, a South Italian painter, is not Athenian and therefore lies outside of the scope of the project). Because the list of artists was very lengthy, it was subdivided into technique (i.e., black-figure artists, red-figure artists) and then further subdivided into period (i.e., Archaic red-figure artists, Classical red-figure artists). Moreover, since there are many artists listed in the Beazley Archive Pottery Database (1300), some with only one vessel attributed to their hand, the artist lists were reduced to be representative of the more familiar names and most famous artists. In order to do this, one of the students (Stratos) compiled a list of around 200 painters using John Boardman's three handbooks on Athenian vases. At a point in the future, the lists of artists will expand and reflect the entire corpus of artistic personalities currently listed in the Beazley Archive Pottery Database.

Upon completion of these tailored lists of concepts, it was then time to research and create definitions. The students, both graduate and undergraduate, were responsible for drafting preliminary definitions for shapes, artists, and techniques. Originally, the students worked independently, only coming together to review each others' definitions. But, as the team and the lists of terms expanded, the division of labor changed and the writing process became more collaborative. For example, the artist concepts numbered in the hundreds, so the students divided the list and then worked in pairs to perform research, fill in knowledge gaps, and check information. Each team would then proofread another team's definitions before turning them over to Smith and Gondek for editing, adding, and reformatting.

While the initial definitions created by the students were good on their own, they were not standardized. Therefore, Smith and Gondek reassessed the terms and created templates for each type of concept. Such standardization was especially critical for the artist biographies since each entry needed to reflect the same type of data, and some biographies even cross-referenced with each other. Of course, a template of this nature would have been useful for the students, but Smith and Gondek designed the templates organically as they moved through the concept lists. After editing a few entries at a time, it often became clear that something vital was missing or the wording was inconsistent, and it was then necessary to go back to fill in the gaps or rewrite a portion. For the artist concepts, Smith and Gondek had to examine and edit several dozen painters before a working template was formed.

The resources utilized to create the definitions included: reference books, like Beazley's *Attic Black Figure Vase Painters;* published excavation data, like those from the Athenian Agora; books concerning Greek vase-painting, like John Boardman's handbooks referenced above and R.M. Cook's *Greek Painted Pottery*; and the online database for Greek vase-painting known as the Beazley Archive Pottery Database. With these materials, we were looking to understand a variety of parameters, which changed depending on the type of concept. For instance, for artists we needed to know: the date of activity for the painter; the origin of the painter's name; the shapes the painter often decorated; the subjects the artist often painted; and the findspots of pottery associated with the painter.

Once the definitions were reformatted and edited by Smith and Gondek, they were reviewed by a final editor (Mitchell) to identify any lingering inconsistencies or problems. Following the final revision of the definitions for each category of concept, these definitions were inserted into Google Spreadsheets. In order to expand the reach of Kerameikos.org, several external project collaborators worked to translate the definitions into German and Modern Greek. A similar process was completed for shapes (edited by Mitchell) and for techniques (edited by Mitchell and Long). Additional metadata were inserted as needed: Greek plural forms of shapes, alternative labels, parent concept URIs (for example, that the subclass 'squat lekythos' links to the parent shape of 'lekythos', http://kerameikos.org/id/lekythos), and bibliographic reference URIs published by Zenon, the library catalog of the German Archaeological Institute (https://zenon.dainst.org/).

Once the Google Spreadsheets were ready for publication, Gruber logged into the Kerameikos.org back-end to conduct a spreadsheet import through a simple web-based interface to map columns to RDF ontology properties, such as those from the World Wide Consortium's (W3C) Simple Knowledge Organization Scheme (SKOS: https://www.w3.org/TR/skos-reference/). After initiating the import process, the concepts were mapped into RDF and published online. At this point, the URIs were active and stable and could be used for cataloging. The LOD are ingested into Kerameikos.org's internal graph database and SPARQL endpoint, which is a protocol for querying RDF.

At this point of this process, metadata *about* the SKOS concepts were incorporated into the RDF with the W3C's Provenance Ontology (https://www.w3.org/TR/prov-o/). The provenance metadata link these concepts to the spreadsheet from which they were derived, and these spreadsheets, in turn, were linked to one or more editors that contributed to their intellectual development. Each project director, student, and external translator is represented by a URI that also links to their profile on ORCID (https://orcid.org/). Through the University of Virginia Library's subscription to the DataCite service, we minted DOIs that represent the full intellectual contribution of each editor to the project (as a dataset), which is a novel approach to formalizing credit in Digital Humanities projects.

At least once per month, the team came together for regular team meetings to report on progress. Often the focus of these meetings was on the entry of concept definitions, bibliographic references, and linking concepts together hierarchically. Also discussed at these team meetings was past or upcoming conferences, presentations, and other dissemination activities.

4.3.2 Harvesting Open Vase Data

After the minting of a significant number of concept URIs in Kerameikos.org, we have sought to harvest data from several major and minor collections of Athenian pottery in order to develop an interface that enhances the research value of each concept URI. By aggregating vases that are linked to these concepts, we are able to display images of example objects in museum or archaeological collections, generate a map showing the geographic distribution of the concept, and formulate some basic distribution analyses that are represented as charts.

At the outset of the project, we determined that we would model vases into the CIDOC-CRM ontology published by the International Council of Museums (http://www.cidoc-crm.org/). This is a common RDF ontology used throughout the cultural heritage informatics community. One of its advantages is that it can be used to represent the knowledge graph of any sort of object. That is also one of its disadvantages: one museum may use the ontology to create a model for vases that differs from the model of another museum. Even though both museums may use Kerameikos.org URIs for their vocabularies, discrepancies in the underlying model make interoperability difficult. Early in this NEH-funded phase of Kerameikos.org, another community-oriented project emerged: Linked Art (https://linked.art/), for which Gruber serves on the scientific committee. Linked Art is a standard profile of CIDOC-CRM (represented in JSON-LD, a more accessible syntax to software developers) that has growing support among museum technologists. Kerameikos.org then adopted Linked Art as its profile when ingesting vase data into its SPARQL endpoint.

The Indianapolis Museum of Art at Newfields became a test case for building a Linked Art data importer directly into Kerameikos.org (presented at a Linked Art workshop in the UK in 2019; see Section ***6.1***). The collection is small, but the prototype was successful. The J. Paul Getty Museum provided access to its test API of Linked Art vase data, which Gruber harvested and reconciled to Kerameikos.org URIs in OpenRefine, using an API that Gruber built into the Kerameikos.org framework in 2018. Other collections, whether large or small, provided CSV exports that were also reconciled to Kerameikos.org URIs in OpenRefine and exported directly into Linked Art-compliant RDF using OpenRefine's export templates. These templates have been published openly on GitHub and can be reused by anyone else:
(https://gist.github.com/ewg118/c474d751790c4c0d086fdce738bb74c6.)
So far, Gruber has used the APIs he has written himself to clean vase data for integration into Kerameikos.org, but these tools can be used by researchers or museum curators to normalize their own data and prepare it for publication in a format that facilitates optimal reuse.

Whenever possible, the findspot (or the first event in an object's provenance) was normalized from these museums' export data to geographic place URIs in Wikidata.org, in addition to the full geographic hierarchy extracted from Wikidata. This enables queries to discover all vases found in Sicily, for example, by means of linking individual towns to their parent districts. The findspot data model was incorporated into Linked Art from ARIADNE, which is a European Union-funded archaeological data infrastructure project:
(https://github.com/linked-art/linked.art/issues/285).

With the integration of nearly 8,000 objects from a handful of museums, including the J. Paul Getty Museum and the British Museum, we were able to improve the interface in Kerameikos.org to provide users with additional context about individual concepts. Furthermore, most of our partners implement the International Image Interoperability Framework (IIIF), enabling the display and annotation of high resolution, zoomable images through a standard API (see **Figure 1**).

Figure 1: J. Paul Getty Museum 71.AE.441 as displayed in a IIIF viewer with four associated photographs.

Many of the findspots of these objects (when available), particularly from the J. Paul Getty Museum and British Museum, have been normalized to geographic identifiers from Wikidata.org. This facilitates the visualization of geographic distribution of the concepts associated with these vases, for example, artists or shapes (see **Figure 2**).

Other visualizations in the form of charts can be generated dynamically based on vase data to display the distribution of a particular category of information for a specific concept, or to compare concepts together. These distribution charts are based on data currently aggregated in the Kerameikos.org Linked Open Data ecosystem, and therefore do not yet represent a cohesive picture of pottery production, as the results are heavily weighted by the collecting practices of the British Museum and the J. Paul Getty Museum.

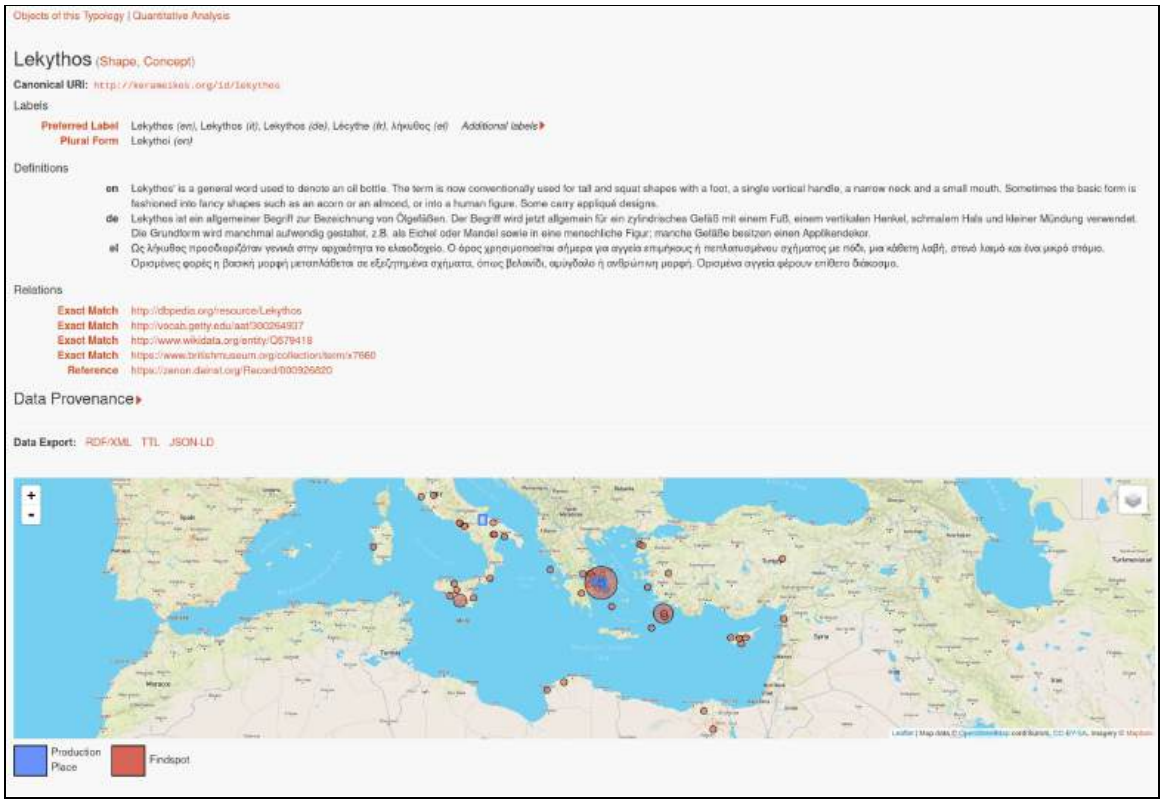

Figure 2: The geographic distribution of production and finds of the 'lekythos' shape (http://kerameikos.org/id/lekythos), illustrating a distribution across the Mediterranean.

5.0. ACCOMPLISHMENTS AND OUTCOMES

More than 400 Greek pottery concepts were defined and published by the Kerameikos.org team. These concepts fall under the categories of Archaic black- and red-figure artists (and groups/workshops of artists), techniques, materials, historical periods, and vase shapes. Definitions include citations to relevant bibliographic references. Labels and definitions for shapes have been translated into German by Nicole High-Steskal and Laura Rembart at the Austrian Archaeological Institute (ÖAW) and into Modern Greek by Nicholas Harokopos at the University of Athens, hopefully facilitating their reuse in German or Greek collections or archaeological databases. Work remains to edit the major Classical red-figure artist definitions and prepare them for final publication, which will continue into the near future.

We have aggregated about 8,000 vases from 7 museum collections: Harvard Art Museums, The Fralin Museum of Art (University of Virginia), Tampa Museum of Art, Fitzwilliam Museum (Cambridge University), Indianapolis Museum of Art (Newfields), J. Paul Getty Museum, Ure Museum of Greek Archaeology (University of Reading, UK), and the British Museum. The contributions of the British Museum, Getty, Tampa, and Fitzwilliam represent nearly the entire body of Athenian pottery in these collections. The Fralin and Ure Museum vases were a proof of concept in the integration of 3D scanned pottery through the Kerameikos.org.org user interface.

The broader our coverage of pottery concepts and the more vase data we aggregate from collections and archaeological databases, the more accurate and complete the query results are. Although they have not used Kerameikos.org directly to answer research questions applying Social Network Analysis to the Athenian pottery industry within our own time period of focus, Drs. Eleni Hasaki and Diane Cline have extracted data from the same source, the Beazley Archive Pottery Database, in order to drive their analyses, citing Kerameikos.org's influence on their own methodologies (see Section ***7.1***).

So far, we are aware of one project integrating Kerameikos.org URIs for vessel shapes: the University of Oxford I.Sicily (http://sicily.classics.ox.ac.uk/inscription/ISic020014), a project of Sicilian inscriptions. The implementation of these URIs into I.Sicily may enable us to integrate these objects from Sicily back into our own environment for further query and visualization among other collaborators.

Early in the project, we were approached by Nicole High-Steskal and Laura Rembart at the Austrian Archaeological Institute (ÖAW) to translate Kerameikos.org concepts into German for the eventual integration of these URIs into the institute's archaeological databases in order to facilitate the optimal reusability of their own data in other systems, for example, in Kerameikos.org itself or other ancient world linked data projects, such as Nomisma.org or Pelagios Commons. In a similar vein, in 2019, a test set of Greek vases integrated into Kerameikos.org were published through its own APIs into the Pelagios Linked Open Data model and made accessible in the Peripleo application, uniting these objects with other materials from the ancient world, such as coins, epigraphy, and literary works (https://medium.com/pelagios/new-treasures-added-7014f3a52985), making our partners' objects broadly accessible to the public through research portals they never anticipated nor (in many cases) have the technical expertise into which they are able to directly contribute. Making these objects accessible in Pelagios was one of our major goals in this project.

6.0. DISSEMINATION OF PROGRESS

6.1. Papers and Presentations of Kerameikos.org

Bradford, Abigail, Renee Gondek, Ethan Gruber, and Tyler Jo Smith. "Linked Open Data Vocabularies and Recognizing Intellectual Contributions via ORCID", Computer Applications and Quantitative Methods in Archaeology (CAA), annual meeting, Limassol, Cyprus and virtual, 14-18 June 2021. DOI: 10.5281/zenodo.4956819.

Gruber, Ethan, Renee Gondek, and Tyler Jo Smith. "Linked Art for Archaeological Data Exchange", Computer Applications and Quantitative Methods in Archaeology (CAA), annual meeting, Limassol, Cyprus and virtual, 14-18 June 2021. DOI: 10.5281/zenodo.4956819.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “Kerameikos.org: 2020 Current Work and Future Plans” (poster), Linked Pasts 6 (virtual conference), 2-16 December 2020.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “Kerameikos.org: Pottery and Linked Open Data”, (lighting talk), Annual Meeting of the Archaeological Institute of America, Washington D.C., 2-5 January, 2020.

Gruber, Ethan, “Linked Open Greek Pottery: Kerameikos.org and Linked Art”, presented at the Linked Art workshop at the Victoria and Albert Museum, September 2019.
DOI: 10.5281/zenodo.3463596.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “Kerameikos.org: A Linked Open Greek Pottery Project”, Fédération internationale de associations d'études classiques and the Classical Association (FIEC / CA), annual conference, London, UK, 5-8 July 2019.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “Kerameikos.org: Linked Open Data for Greek Pottery” (poster), Computer Applications in Archaeology (CAA), annual meeting, Krakow, Poland, 23-27 April 2019. DOI: 10.5281/zenodo.3243539.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “Kerameikos.org: A Network Science Approach to the Study of Greek Pottery”, University of Virginia, Archaeology Brown Bag Workshop, Charlottesville, Virginia, 22 March 2019.

Gondek, Renee and Ethan Gruber. “Linked Open Greek Pottery: Kerameikos.org”, NEH Project Directors' meeting, Washington D.C., 18 March 2019.

Gondek, Renee, Ethan Gruber and Tyler Jo Smith. “LOD and 3D: A Corinthian Kotyle as Test-Case”, Linked Data Month, University of Virginia, SHANTI and DH@UVa, Charlottesville, Virginia, 15 March 2018.

Gruber, Ethan and Tyler Jo Smith. “Kerameikos.org: The Semantic Web Meets Greek Pottery”, University of Virginia, DH@UVa, Scholars’ Lab, Charlottesville, Virginia, 14 October 2016.

Gondek, Renee, Ethan Gruber, Tyler Jo Smith. “Linked Open Data for Ceramics”, Roundtable on databases and pottery, Computer Applications and Quantitative Methods in Archaeology (CAA), annual meeting, Siena, Italy, 1 April 2015:
(http://2015.caaconference.org/program/roundtables/rt3/).

Gruber, Ethan and Tyler Jo Smith. “Linked Open Greek Pottery”, presented at Computer Applications and Quantitative Methods in Archaeology (CAA), annual meeting, Paris, France, 24 April 2014.

6.2. Publications

Bradford, Abigail, Renee Gondek, Ethan Gruber, and Tyler Jo Smith. "Linked Open Data Vocabularies and Recognizing Intellectual Contributions via ORCID", *Computer Applications and Quantitative Methods in Archaeology (CAA) conference proceedings* (forthcoming).

Gruber, Ethan, Renee Gondek, and Tyler Jo Smith. "Linked Art for Archaeological Data Exchange", *Computer Applications and Quantitative Methods in Archaeology (CAA) conference proceedings* (forthcoming).

Gruber, Ethan and Tyler Jo Smith. 2014. "Linked Open Greek Pottery", in *21st Century Archaeology: Concepts, Methods and Tools. Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*, edited by G. Giligny *et al.*, 205-214. Oxford: Archaeopress. (https://caa2014.sciencesconf.org/46119/document)

7.0. IMPACTS

7.1. Citations of Kerameikos.org in other Publications

Although the project has stood as a proof of concept since 2014, it has been cited in several articles about standards and best practices for archaeological or museum data modeling and dissemination.

Hasaki, E. and Cline, D. 2020. "Social Network Analysis and Connoisseurship in the Study of Athenian Potters' Communities", in E. Hasaki and M. Bentz (eds), *Reconstructing Scales of Production in the Ancient Greek World: Producers, Processes, Products, People. Proceedings of the XIX Conference of Classical Archaeology, Archaeology and Economy in the Ancient World, Bonn 22–26 May 2018*, 59-80. DOI: 10.11588/propylaeum.639.c9977.

ARIADNE Infrastructure. 2017. "Report on the ARIADNE Linked Data Cloud". http://www.ariadne-infrastructure.eu/Resources/D15.2-Report-on-the-ARIADNE-Linked-Data-Cloud

Sikos, Leslie F. 2016. "Rich Semantics for Interactive 3D Models of Cultural Artifacts", in *Metadata and Semantics Research*, volume 672, edited by E. Garoufallou, E. Subirats, A. Stellato, J. Greeberg. https://link.springer.com/chapter/10.1007/978-3-319-49157-8_14

Atenas, J., L. Havemann, E. Priego. 2015. "Open Data as Open Educational Resources: Towards Transversal Skills and Global Citizenship". *Open Praxis* 7.4: 377-389.

Kansa, Eric. 2015. "Contextualizing Digital Data as Scholarship in Eastern Mediterranean Archaeology". *CHS Research Bulletin* 3.2.

7.2. Long Term Impact

It is difficult to evaluate the long term impact of Kerameikos.org, as it has not yet seen wider adoption in the Greek pottery specialist community or museum sector as a vital piece of research or cataloging infrastructure, unlike similar LOD-oriented specialist projects, such as Nomisma.org for numismatics or the Pleiades Gazetteer of Ancient Places. We hope the project evolves in this direction, and the expansion of scope into other cultures of pottery, particularly those that are underrepresented in the Getty Art & Architecture Thesaurus (AAT), will have an impact in those disciplines.

One of the most notable and immediate impacts is our approach to formalizing intellectual credit to participants in Kerameikos.org for their contributions to the definitions and translations they have written for the project. This is particularly relevant for the students who have worked with Smith and Gondek. Generating a DOI for each individual's contribution to Kerameikos.org, and linking this DOI to an ORCID iD is a means of generating a permanent record in their scholarly profile of having working on the project - that the contribution to Kerameikos.org as a *dataset* holds equal weight as more traditional publications, such as journal articles. Digital Humanities labor is often little more than a credit line on a project 'About' page or a brief mention on a CV. The feedback we received on this system at CAA 2021 indicates this is a novel approach to the recognition of DH labor, one that other project managers will seek to emulate well beyond the narrower field of Athenian pottery.

7.3. Data Access and Sustainability

The concept data are accessible at http://kerameikos.org/. Data dumps of all SKOS concepts are generated nightly in three standard LOD formats (RDF/XML, Turtle, and JSON-LD) and RDF files for individual concepts backed up to a public Github repository with an open license (https://github.com/kerameikos/data). These data will be deposited in the University of Virginia data repository (Dataverse) and third party vocabulary repositories, such as the Basic Register of Thesauri, Ontologies, and Classifications (BARTOC). See https://bartoc.org/en/node/18379, for example.

Datasets of vases from partner collections are openly licensed and can be reused according to the licenses expressed on the http://kerameikos.org/datasets page. All of these data are integrated and accessible through Kerameikos.org's graph database and SPARQL endpoint.

8.0. NEXT STEPS AND FUTURE GOALS

The next steps for the Kerameikos.org LOD project are both short-term and long-term in nature. The short-term goals can be completed without additional funding or support; the long-term goals will be dependent on partner collaborations and funding.

8.1. Short-term goals

1) Edit and upload the remaining artist definitions (Classical Athenian red-figure) and techniques onto the Kerameikos.org site. The completion of this task has been greatly delayed by COVID-19, which caused limitations on in-person meetings and reduced access to library resources. These aspects should be completed by the end of 2021.

2) Oversee the completion of the translation of all remaining current site content into German and Modern Greek.

3) Publish URIs for the remaining artists from the Archaic and Classical periods, whose work is prominent enough to warrant mention in a wide variety of scholarly publications. John Beazley identified approximately 1,000 distinct artists, although hundreds of these were attested by evaluating the artistic style of a small handful of vessels (or even a single one). As a result, these names exist only in the Beazley Archive Pottery Database and no other vocabulary system. We will create URIs for these eventually, but the definitions may be as simple as "Black-figure artist of the sixth century BCE", as virtually nothing else is known about them. Nevertheless, publishing URIs for these individuals provides a pathway for the Beazley database to evolve into a LOD system itself or to join these outlying objects with others from the same period or style in order to visualize new patterns that may not have been previously considered. Both the individuals and the funding are in place to complete these tasks.

8.2. Long-term Goals

1) Additional Translation into Languages other than English. Given the international interest in Kerameikos.org, it would be ideal to translate the site into widely-spoken languages, including Chinese and Spanish. We are already in conversations with experts on Greek vases who are native speakers of each. We noted above that the existing content is already being translated into German and Modern Greek.

2) 3D Models of Greek Vases. The second long-term goal will be to embed where possible 3D models of Greek vases such as those already laser scanned at the Fralin Museum of Art (http://archaeology.virginia.edu/3d-greek-vases.html). We have prototyped the publication of two different sources of 3D models: Sketchfab.com (an Ure Museum example) and an open standard PLY file format, which can be displayed in a variety of browser-based 3D viewer applications.

3) Expanding the Scope of Kerameikos.org. In the long-term, we aim to expand Kerameikos.org into other periods and cultures of ceramic production. Other interested scholars may join the Scientific Committee to move the project forward in its broader vision, but the most impactful organizational change we can make most immediately is to facilitate the creation of discipline-specific Working Groups. Our Scientific Committee includes specialists in Archaic and Classical Athenian pottery. It is well out of our purview to expand into Etruscan, South Italian, Bronze Age, Egyptian, Chinese, Indigenous North America, etc. ceramics. This work must be done by specialists in those

fields. The technical infrastructure for publishing these URIs has been built, but providing the content is the responsibility of those who have the expertise to create and manage it.

By creating Working Groups, we can open our project up to others. With some vetting and oversight from the Scientific Committee to ensure that new IDs conform to our data structure, Working Groups can operate with relative autonomy with some basic training in the semantics of our intellectual model and the user interfaces in the back-end for creating and editing URIs.

By involving more stakeholders in the project, particularly those with Digital Humanities experience, we can solidify the long-term sustainability of the project by soliciting help in software development and imbuing pottery specialists with a greater understanding of the Semantic Web models that underlie our technical infrastructure. The Kerameikos.org website is currently undergoing revision to make this new organizational structure transparent and provide a clear explanation about how potential collaborators may join the project.

4) Iconographic Modeling. After the completion of the core Athenian concepts, we are likely to turn our attention to iconographic annotation. There has been discussion throughout the Linked Ancient World Data community over the previous one to two years about assembling cultural heritage materials based on iconography, for example, to view depictions of a mythological motif, such as the Labors of Hercules, across many collections and types of media. In numismatics, Nomisma.org Scientific Committee members Ulrike Peter (Berlin-Brandenburg Academy of Sciences and Humanities) and Karsten Tolle (University of Frankfurt) have been working on Natural Language Processing to create a semantic model for the representation of deities and their attributes. Elsewhere, Scott Smith (University of New Hampshire) and Greta Hawes (Australian National University) have published MANTO (https://manto.unh.edu/), a thesaurus of URIs of mythological and legendary Greek characters and creatures and their relationships to each other, to places, and literary sources.

   Building on this work and using aggregated vases in Kerameikos.org that implement the IIIF standard, we will create a test-case for annotating iconography depicted on objects and linking them to MANTO URIs. The first step is thematically uniting Greek pottery in our own system as a demonstration of what might be done by applying IIIF annotation to other information systems, enabling depictions of Hercules on vases, coins, statues, temples, etc. This is a significant undertaking that requires further financial investment to complete, but a proof of concept is currently under development.

5) Development of Generalizable Linked Art Viewer. Since the vase data ingested into Kerameikos.org's SPARQL endpoint conform to the Linked Art specification (with some minor variations in shape classification) and Gruber is involved in Linked Art's advisory committee, we implemented an object that enables any vase imported into

Kerameikos.org to be displayed in a distinct interface that includes typological or physical metadata (interlinked with Kerameikos.org URIs), but also displays static and zoomable IIIF images and a dynamically generated map that includes a point for the production place and findspot, when applicable. Although translations of this interface have not yet been fully completed, the UI is multilingual, drawing preferred labels in other languages directly from Kerameikos.org LOD when requested by the user (see **Figure 3**).

Figure 3: British Museum 1836,0224.127, a black-figure amphora of Exekias, as represented partially translated in French in the Kerameikos.org viewer: http://kerameikos.org/object/?uri=https://www.britishmuseum.org/collection/object/G_1836-0224-127&lang=fr

Although purpose-built for the display of ceramics within the Kerameikos.org software framework, these design principles can be made into a more generalizable viewer for any sort of cultural heritage object encoded in the Linked Art CIDOC-CRM profile. A longer term goal of Kerameikos.org is to expand this view to include faceted search and browse interfaces that include a wide variety of data and geographic visualization features that enable unified query across the project's data contributors. This software infrastructure can be spun out into a stand-alone application and applied beyond Athenian vases to other types of objects.