

# 1. OPEN-ACCESS EPIGRAPHY

## Electronic Dissemination of 3D-digitized Archaeological Material

*Eleni Bozia<sup>1</sup>, Angelos Barmpoutis<sup>2</sup>, Robert S. Wagman<sup>1</sup>*

*Department of Classics, University of Florida<sup>1</sup>,*

*Digital Worlds Institute, University of Florida<sup>2</sup>*

*Emails: bozia@ufl.edu, angelos@digitalworlds.ufl.edu, rsw@ufl.edu*

### **Abstract**

Preservation and dissemination of archaeological material has always been an issue of concern for the academic research community. On the one hand, the fragility of the material limits their study. On the other hand, such material is housed in museums, libraries, and institutions worldwide, something that significantly thwarts their accessibility. Technology, high resolution 2D pictures, and electronic databases have attempted to overcome the aforementioned limitations. However, lack of contact with the physical object as a tridimensional structure still significantly obstructs research. In this paper we present the latest advances of the *Digital Epigraphy Toolbox*, a novel project that focuses on the digitization in 3D of ancient inscriptions from ektypa, the multi-modal visualization of their 3D models, the facilitation of interlinked 3D digitized records, and the easy and effective electronic dissemination of archaeological material. This project offers options for cost-effective shape-from-shading 3D digitization of ektypa, using a flatbed scanner, and various visualization modes, such as photorealistic 3D views and informative fingerprint map and depth map that assist scholars understand the structural characteristics of the artifacts. Finally, the project facilitates the dissemination of the 3D digitized objects by providing the users with an embeddable 3D viewer which can be easily imported in third-party databases, collections, and personal websites.

### **Keywords**

3D reconstruction, digital preservation, open-access, dissemination, visualization.

## 1.1. Introduction

Any usage of the term Digital in relation to the Humanities, such as the designations "Digital Classics" [Crane 2004, 46-55], "Digital Epigraphy," "Digital Archaeology," has been highly charged and extensively discussed. Issues, such as what the above terms mean and are meant to encompass, the possibilities and difficulties of interdisciplinary collaboration, and the place of Digital Humanities in academia and academic curricula have instigated scholarly discussions, aiming at redefining and reinventing the Humanities with the assistance, enhancement, and collaboration of computers (for discussions of the issue see [Bantz 1990, Berry 2012, Deegan and McCarty 2012, Denley 1990, Gold 2012, Hirsch 2012, Hockey 2004, Jones 2013, McCarty 2005, McCarty 2010]). Project development, relevant publications, cross-disciplinary collaborations, and applications seeking financial support clearly indicate the co-existence of five types of scholars-adopters who have motivated and promoted the espousal of technology, computer-enhanced humanities, and their application on real data, as well as the posing of problematic questions: innovators, early adopters, early majority, late majority, and laggards [Rogers 1962, 150]. Innovators consist of those scholars who first envision a better future for their field. In our case, this refers to two types of scholars: the humanist, who wishes to forgo the current limitations of research and promote the humanities by means of a diametrically different field such as computing, and the computer engineer, who repurposes his technical knowledge to advance the academic community. The early adopters include those who are proponents of technology, the enthusiasts that have wholeheartedly accepted new media, sometimes failing to question their purpose, or even regulate their usage. Early and late majority consist of the scholars who, albeit initially hesitant or unaware of the technology, are eventually willing to adopt new methods and methodologies and slowly integrate them into their academic routine. The last category describes those who are defensive and fear that digital media will vitiate the integrity of scholarship. The main reason for the aforementioned dissensions lies in that the introduction of technology has caught some by surprise; thus, they have failed to ask the right question: "what do-should we expect from technology?" On the one hand, innovators occasionally lack focus and proceed with the technology for the sake of technology. On the other hand, traditionalists refuse to reconsider the original research-study paradigm and have not yet

dealt with the coexistence of humanities and computers and their synchronous evolution that can also result in simultaneous progress of both areas.

The focus of both the inventors and the adopters has mostly turned to the collection of data, the creation of databases, automatic metadata analysis, and the digital publishing of those results. As many Humanities fields are language and text based, as are Linguistics and Classics, for instance, the capabilities of the computer indubitably provide an unprecedented assistance—the computer constitutes not only a storage space, but it can also be used as a search engine that provides easy access to a large amount of data.<sup>1</sup> Also, it can perform etymological comparisons and confirm the authorships of texts (see discussion about the Oxford Text Searching System in [Hockey et al. 1990]). The keyword that describes the above processes is "facilitation." According to Unsworth's presentation of primitives, "a useful tool-building enterprise in humanities computing" should assist and enhance the following: Discovering, Annotating, Comparing, Referring, Sampling, Illustrating, and Representing [Unsworth 2000]. Any library of texts with basic Text Encoding Initiative (TEI) features [Cayless et al. 2009, Renear 2004, Simons 1996] can satisfy almost all the above except for "Illustrating" and some profound aspects of "Discovering," which are indispensable to the study of epigraphy and archaeology (see [Bodel 2012] for a history of digital epigraphy). Starting with "Illustrating," current epigraphic databases include 2D still images of the inscription and/or the ektypon (an impression of an inscription formed by pressing wet paper onto the surface and peeling off when dry).<sup>2</sup> The quality of the picture can be significantly compromised due to lighting conditions, and a 2D picture cannot convey all the information that one would acquire had they had the original ektypon (for other imaging techniques see [Barmpoutis et al. 2010]). Therefore, most of the databases include the inscribed text, following the conventions of Leiden [Hunt 1932, van Groningen 1932, Woodhead 1981] and Epidoc [Cayless 2003].<sup>3</sup> Digital access to those texts significantly facilitates and promotes study and re-

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<sup>1</sup> The Perseus Project, <http://www.perseus.tufts.edu/>

<sup>2</sup> The US Epigraphy Project, <http://usepigraphy.brown.edu/>; Epigraphische Datenbank Heidelberg, <http://www.epigraphische-datenbank-heidelberg.de/>; *Inscriptions of Aphrodisias*, <http://insaph.kcl.ac.uk/>; *Inscriptions of Roman Cyrenaica*, <http://ircyr.kcl.ac.uk/>; Pleiades Project, <http://pleiades.stoa.org/>; Electronic Archive of Greek and Latin Epigraphy, <http://www.eagle-eagle.it/>; Center for the Study of Ancient Documents, <http://asp.classics.ox.ac.uk/research/projects/csad3.asp>. See also [Pasqualis 2005, Crowther 2002].

<sup>3</sup> For information on Epidoc, see The EpiDoc Collaborative for Epigraphic Documents in TEI XML, <http://epidoc.sourceforge.net/>.

search. However, two aspects that have yet to be considered are: the improvement of the illustrations of the artifacts and the enhancement of discovery.

### 1.1.1. From 2D to 3D open-access epigraphy

Jameson eulogizes the inclusion of images of manuscripts in digital databases and states that, "the images dramatically increase access to source materials, reduce the power of the scholar as 'gatekeeper,' expose the scholar's judgments to wider scrutiny, and make it more likely that readers or users will actually collaborate in the work of perfecting the state of scholarship." In [Jameson 2004] she discusses the issue of open-access scholarship, presenting projects that provide images of manuscripts. The point she makes, though, is espoused by the *Digital Epigraphy and Archaeology Project*<sup>4</sup> (DEA) project that intends to not only create repositories of artifacts, but also publicize them and invite new interpretations. The *DEA Project* has espoused this "democratization of knowledge," as it was eloquently called by Jameson. More specifically, the *Digital Epigraphy Toolbox*<sup>5</sup> (Fig. 1.1) aims at filling the two aforementioned gaps in research and study of ancient inscriptions and other archaeological artifacts. First, the implementation of the *DEA* shape-from-shading algorithm onto ektypa automatically produces their 3D model [Barmpoutis et al. 2010], which can then be rotated, zoomed in, and re-lighted. Thus, the user can better visualize the object of his study and reexamine weathered parts of the ektypon by manipulating the perspective and the lighting. Furthermore, the *DEA* database includes all the relevant (contextual) metadata, that currently consist of more than 50 fields of information about the inscription. The metadata for the physical object follow the Heidelberg Epigraphic Database protocol, and the user has the option to add any field from a drop-down menu list. Being in the position to have a collective record of the ektypon and the inscription, the researcher has the opportunity to pose new questions or old questions on a new basis. So, instead of a simple hyperlink that addresses the user to other resources and has been described by Bodel as crude contextualization [Bodel 2012, 280], one can comprehensively study the artifact, the text, and take advantage of every available resource. The existence of such records also facilitates comparative studies of large numbers of inscriptions. Furthermore, we

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<sup>4</sup> The Digital Epigraphy and Archaeology Project (DEA), <http://www.digitalepigraphy.org>

<sup>5</sup> Digital Epigraphy Toolbox, <http://www.digitalepigraphy.org/toolbox>

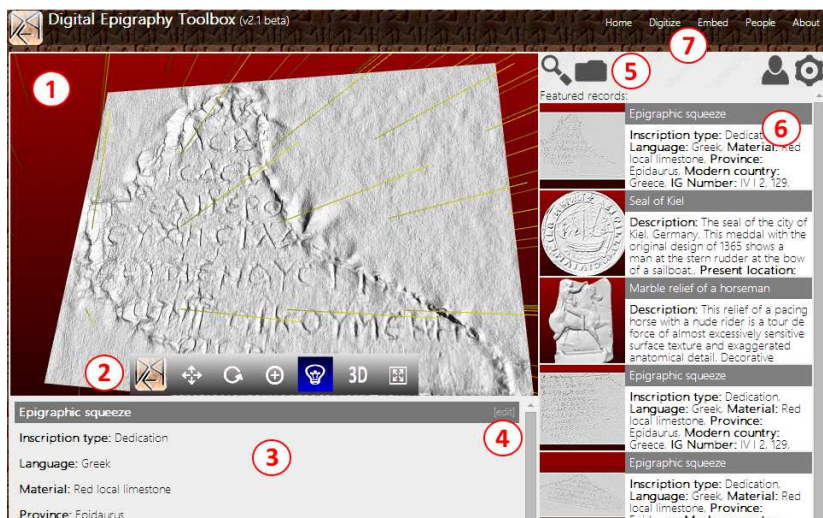
should not forgo the case of the Classicist who ventures into the study of archaeological artifacts to perform an all-encompassing study of a particular historical era. The possibility of such comparative studies has been impeded mainly by the difficulty to access information in a new research area. The *DEA* Virtual Museum<sup>6</sup> provides a user-friendly interface that purports to ease the exposure to new information and is meant to be used by scholars of all fields.

With regards to "Discovery," today there are several online collections of inscriptions which intend to enhance scholarship by facilitating access to epigraphic texts for scholars and students. What needs to be considered, though, is that most of these databases only provide access to textual information assembled from previous printed editions, not to the original artifacts— a fact that limits the potential for original research, as the scholar is reduced to studying the information from someone else's perspective. The *DEA* project aims at providing a space where scholars can re-quantify results, pose new questions, provide different answers based on new available resources, and ultimately reconsider their research. The *DEA* is not only meant to be another database that also includes alternative visual representations; instead the *DEA* explores and adopts new state-of-the-art technologies, creating a truly "Open-Access Epigraphy."

Another issue that relates to the dissemination of knowledge and the democratization of academic research is the need for interlinked epigraphic databases. The existence of digital databases does not in itself guarantee the accessibility or the comprehensive accumulation of all the information necessary for well-founded research and valid results. This concern has been posed by Álvarez, Gómez-Pantoja, and García-Barriocanal in [Álvarez et al. 2010] who have created a system on Hispania Epigraphica where epigraphic data are shared as linked data, recommending the adoption of a similar strategy for other digital libraries (for linking epigraphic data, see also [Cayless et al. 2009]). The *DEA* project gives users the option to add hyperlinks to other digital libraries and online data that are incorporated into the record of the artifact. Thus, the project intends to facilitate the retrieval of information by minimizing the search time and providing comprehensive metadata about the entries. Moreover, users have the option to save the records of their work on their devices, thus creating their own libraries of artifacts, their 3D models, and the accompanying metadata.

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<sup>6</sup> The *DEA* Virtual Museum, <http://www.digitalepigraphy.org/museum>



**Fig. 1.1.** A screenshot of the *Digital Epigraphy Toolbox v2.1*. Several key features are marked: 1) 3D embeddable viewer, 2) 3D toolbar with several options to move, rotate, zoom, relight, view in full screen, and change visualization mode such as 3D view, depth-map, and finger-print-map, 3) meta-data viewer, 4) open-access record editor, 5) search toolbar with options to search by keywords, or browse by collection, 6) comprehensive list of search results with color-coded keywords and automatically generated outline of each record based on your keywords, 7) shape-from-shading 3D digitization tool, using flatbed scanner.

The *DEA* project also focuses on the 3D representation of other archaeological artifacts, such as statues, vases, coins, medals, and seals (Fig. 1.1). The importance of having access to the object and being able to examine details by zooming, moving, and relighting cannot be overstated. As Tupman emphasizes in her chapter on the effect of digital technologies on the study of funerary monuments, the study of a cemetery, for instance, requires the collaboration of a number of specialists who can study the funerary *stèle*, the inscribed text, and the funerary dedications, among other artifacts [Tupman 2010, 73-86]. Tupman stresses the significance of digital 3D representations of the findings and ultimately of the site in its entirety. Also, Eiteljorg states the significance of 3D imagery for archaeologists and suggests that "these processes provide unprecedented access to objects without risk of damage." [Eiteljorg 2004, 27]. Paoletti et al. examine the teaching and research possibilities that a virtual museum can offer [Paoletti et al. 2004]. Therefore, there seems to be a scholarly demand for exploring new ways in which technology can further archaeological research. The *DEA* project has set the ground for the creation of an online dynamic library of 3D artifacts. The user is given digital access, the ability to manipulate them (rotate, move, zoom,

relight), and organize them comparatively for analysis (several of these features are depicted in Fig. 1.1 that shows the interface of the *Digital Epigraphy Toolbox*).

## 1.2. Dissemination of 3D epigraphic content

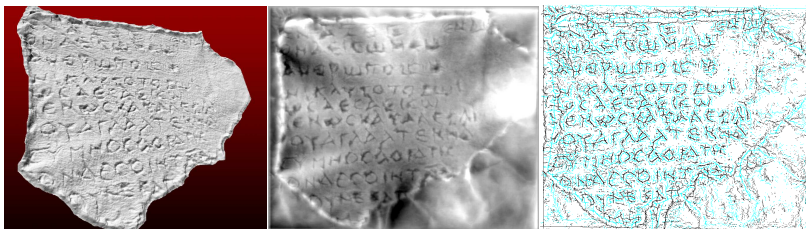
In order to facilitate the dissemination of any type of digitized content through the internet, an on-line database or dissemination mechanism should provide solutions to several technological challenges including the following: a) identify and support widely-used open file formats, b) ensure that the file size is optimal for on-line delivery, c) minimize hardware and software requirements in order to provide access to the widest possible audience, and d) facilitate interoperability across databases.

In the case of text or image-based epigraphic content, the first three of the aforementioned problems are now automatically solved internally by the web-browsers; therefore, any of the text or image epigraphic databases do not have to face such technological challenges. More specifically, the file formats for digitally storing texts and images have been standardized and are now supported across browsers and operating systems. In the case of textual content, UNICODE is widely supported and adopted by TEI as the preferred digital format. Similarly, in the case of images, PNG or JPG formats can store 2D visual content in a compressed way and are universally supported across systems. Hence, 2D images can be efficiently disseminated to the widest possible audience with the smallest possible computational cost.

In the case of 3D content, however, all of these problems and technological challenges exist. One of the goals of the *DEA* project is to provide solutions to these problems and set the standards for open-access dissemination of 3D epigraphic content.

### 1.2.1. Accessibility and visualization of 3D content

Several file formats have been established for storing 3D objects or 3D environments that have been either digitized by scanning a physical object or designed using a software for computer-assisted design. OBJ and STL are two examples of 3D file formats that are supported by special purpose software for 3D design and can open and render their content on the screen. Besides these special purpose software packages, 3D file formats are not supported by default in web-browsers or computer operating systems. Therefore, even if a 3D epigraphic database provides access to files of 3D



**Fig. 1.2.** The *Digital Epigraphy Toolbox* offers different visualizations of the same 3D digitized inscription. Left: 3D visualization, Center: depth-map (deeper inscribed areas appear darker), Right: fingerprint-map (visualizes local peaks and valleys in cyan and black respectively).

digital objects, these files can only be handled and viewed by users who use appropriate third party software. This hinders significantly the dissemination of 3D epigraphic material to the general scholarly community.

To overcome this issue, the *Digital Epigraphy Toolbox* provides a web-based 3D viewer along with the 3D epigraphic content. The viewer is based on the new canvas capabilities of HTML5 and WebGL, which can render 3D graphics on websites. The 3D viewer of the *Digital Epigraphy Toolbox* can be used without requiring additional software or plugins, since WebGL is already included in the majority of the popular desktop and mobile web-browsers. Furthermore, the 3D viewer offers advanced features for visualizing the model of the digitized inscription, using photorealistic 3D graphics, as well as other 2D visualization modalities that help the users study the structure and variations of the digitized artifacts (Fig. 1.2). The 2D visualizations include the depth-map of the inscription (Fig. 1.2 center), which is a grayscale image, whose intensities are proportional to the depth of each pixel, and the fingerprint-map (Fig. 1.2 right), which highlights the peaks and valleys of the surface to help the user understand the changes of curvature. These 2D visualizations are also ideal for publishing an inscription in print as they depict better their 3D structure compared to a photograph.

### 1.2.2. File size compression for 3D epigraphic content

The size of digital files with text or 2D images is in general considered small either due to the simplicity of the digital information stored in these two modalities, or because it can be effectively compressed. This facilitates notably the dissemination of textual or image-based information, because such files can be instantly transferred through the network and presented in a browser-based database; they can be downloaded or attached in emails and stored as an entire database locally in personal computers.



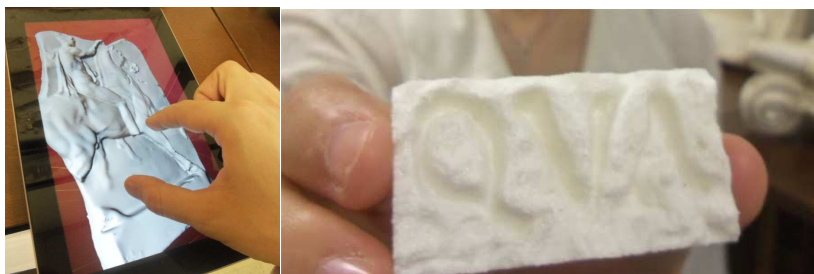
However, in the case of 3D digitized objects the file size is significantly larger as they contain the information of the 3D location of every point in these models as well as the information regarding their triangulated mesh, which in general corresponds to 5 numbers per 3D point (or equivalently 20 bytes) for a uniform grid of triangular strips. This results in inconveniently large files that cannot be easily disseminated and cannot be instantly loaded in a web-browser. In the *Digital Epigraphy Toolbox* we have developed a novel method for storing the 3D structure of an inscription that uses only 1 byte per 3D point, which effectively compresses the overall 3D model by a factor of 20. Our technique stores the depth of the inscription's anaglyph captured as an orthographic projection of the inscription. This method produces a 2D depth-map image stored in PNG format (Fig. 1.2 center) which contains all the information needed to effectively transmit and visualize the original 3D model of the inscription (Fig. 1.2 left). The proposed compression technique can be used in any anaglyph, inscribed, or embossed surface and can encode the depth of each pixel with very high precision up to 9.76 micrometers (which is derived by dividing the depth range  $\sim 0.5\text{cm}$  by  $256 \times 2$ ). As a result, the 3D inscriptions of the *DEA* database can be effectively loaded and visualized, using any desktop or mobile web-browser.

### 1.2.3. Embeddable 3D viewer to facilitate interoperability

The *Digital Epigraphy Toolbox* provides an easy-to-embed viewer that facilitates the interoperability of various epigraphic and archaeological projects, which is a significant step towards the unification of digital epigraphic databases. Scholars can easily embed the 3D objects of the *DEA* database into their own web-sites, blogs, or personal databases, using this embeddable viewer. Each virtual exhibit has an HTML tag that can be found in the archaeological metadata record of the exhibit. Users can copy and paste the corresponding HTML tag into their own web-sites:

```
<iframe src="http://www.digitalepigraphy.org/view?heightmap=
d1a7a25fdaf3010f" width="600px" height="400px" frameborder="0"
scrolling="no"></iframe>
```

The width and height can be customized according to the design of the user's website by changing the corresponding parameters in the above HTML tag. Multiple objects can be added to the same website by using this tag with the corresponding identification number of the archaeological arti-



**Fig. 1.3.** Dissemination of 3D digitized artifacts using the touch-based natural user interface of the *Digital Epigraphy Toolbox* (left), and tangible 3D printed replicas of the inscriptions (right).

fact from the *DEA* database, which can be accessed through the interface of the *Digital Epigraphy Toolbox*.

#### 1.2.4. Dissemination of tangible 3D content

Although the importance of 3D digitized archaeological artifacts or sites is evident [Eiteljorg 2004, Paoletti et al. 2004, Tupman 2010], the interaction of the users-scholars with the virtual objects could be problematic. More specifically, the manipulation of 3D virtual objects and the navigation in virtual spaces are actions that should imitate the way that humans interact with physical objects and real-world spaces. The conventional keyboard or mouse interaction is far from natural since multiple key strokes and/or mouse movements are required in order to move, rotate, and in general manipulate in multiple degrees of freedom 3D virtual objects.

To overcome the above limitations the *Digital Epigraphy Toolbox* provides the users with two different options for natural interaction with 3D digitized inscriptions: a) touch-based natural user interaction, which enhances the dissemination of the digitized inscriptions by providing a natural experience that resembles the interaction with physical objects (Fig. 1.3 left), and b) 3D printing of the objects in the *DEA* database, which allows the study of physical replicas of the original inscriptions and can be used as a valuable educational or research tool. Figure 1.3 (right) shows one of our experimental samples of 3D printed inscriptions from the *DEA* database printed in life-size dimensions using Replicator II.

In conclusion, the *DEA* project is the first on-line 3D epigraphic library and has set several standards for effective open-access dissemination of 3D epigraphic content as presented in detail in this paper.

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