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To cite this article: M Limongello *et al* 2022 *J. Phys.: Conf. Ser.* **2204** 012014

Digital survey and reconstruction for enhancing epigraphic readings with erode surface

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Abstract. The contribution illustrates the applied procedure of the digital survey and documentation of a funerary epigraph written in Greek but dating back to the Roman period (dimensions of about 31 cm x 20 cm). It comes from Velia (Salerno), a Greek and then Roman city in southern Italy. It was found in 1967 and currently represents the only Greek funerary inscription of the Roman period coming, most probably, from the necropolis of Porta Marina Sud. The inscription presents many gaps and preserves only part of the upper right and lower margins. The surface is highly eroded, maybe due to the exposure to atmospheric agents, making the text interpretation extremely difficult. The implemented image-based and range-based techniques contributed to reading the inscriptions, letting to recover much information that was invisible to the naked eye. The 3D survey system choice has to be consistent with the work aims and the physical object characteristics. A high degree of geometric detail was essential for our case study. Therefore, a triangulation laser scanner performed the first digital capturing, subsequently integrated with a structured light system (Artec Eva and Leo) and finally, a close-range photogrammetric acquisition to produce a high-resolution orthophoto.

1. Introduction

Thanks to the development of increasingly innovative and powerful systems in 3D surveying and graphic representation, we are witnessing a new and real need for digital cataloguing, preservation, and enhancement as a methodology for revitalizing Cultural Heritage. Archaeological disciplines are increasingly interested in using emerging digital technologies (often related to the geomatics field) that allows a rigorous geometric and radiometric description of archaeological remains and their contexts [1]. Besides, digitizing a cultural asset allows its remote sharing for interdisciplinary research (e.g., with physically distant experts). Furthermore, it offers the possibility of generating an extensive information storage system that can be modified, queried, and implemented over time and reached at any time. Finally, digital technology could also offer non-experts the possibility to enjoy cultural heritage through a virtual interaction experience [2], a very effective solution in the current pandemic situation. Even though archaeometry investigations have been widely used, so much that this type of analysis can be considered consolidated, the same cannot be said about digital survey and graphic restitution technologies [3]. Although numerous cases of three-dimensional survey techniques have been applied, it is impossible to find in the literature a unitary and organic attempt to systematically deal with both the data acquisition procedures and the final documentation production. Indeed, techniques and methodologies change according to the object size and the results extracted from the digital model [4-5].

This contribution illustrates the applied procedure of the survey and digital restitution of a funerary epigraph written in Greek but dating back to the Roman period (figure 1). Most of the stone surface is very damaged. It preserves only faint traces of letters, making the decipherment of the text complex even employing well-established techniques such as grazing light and/or UV fluorescence imaging. The implemented techniques, based on the integration of range-based and image-based systems, strongly contributed to reading the inscriptions, recovering much information that was invisible to the naked eye.

Figure 1. The funerary epigraph written in Greek but dating back to the Roman period.

2. Case Study description

The epigraph comes from Velia (Salerno), a Greek and then Roman city on the Tyrrhenian coast of southern Italy. Preserved in the deposits of the Archaeological Area, it is temporarily located, for needs of study and documentation, at the Department of Sciences of Cultural Heritage of the University of Salerno. The city original name was *Hyele*, becoming *Elea* in classical times and Velia in Roman times. It was founded around 540 BC by a group of Greeks from Focea (Asia Minor) that had abandoned their homeland after the Persian conquest. It was the home of the philosophers Parmenides and Zeno, born and lived in the city in the fifth century BC, founders of an important philosophical school. In the Hellenistic period, Velia was particularly active in maritime trade, the source of its wealth, and soon became a faithful ally of Rome.
In Roman times the city retained its cultural Greek character, as evidenced by the persistence of still using the Greek language in the imperial age.
The inscription under study belongs to this historical context, it is indeed written in Greek but can be traced back to the Roman period. It is possible to date it to the second century AD based on the presence of the ivy leaf (*hedera distinguens*) used as a sign of separation for the words. The epigraph, found in 1967 in the Porta Marina Sud area, is engraved on a sugar marble slab, probably of insular origin, and it unfortunately presents many gaps. It only partially preserves the upper right and lower margins (maximum height 31 cm, width 20 cm, thickness 3.5 cm). The surface is highly corroded, maybe due to the prolonged exposure to atmospheric agents, making the interpretation of the text extremely difficult. Given the premises, it felt necessary to verify if digital survey techniques could improve the reading of the engravings.
The acquisitions were conducted by the Model Laboratory of the Department of Civil Engineering (DICIV) of the University of Salerno.

3. Data Acquisition and Data Processing

The choice of 3D survey technique must always be consistent with the work aims and the physical object characteristics. For our case study, it was essential to obtain a high degree of geometric detail in the digital model generation. For these reasons, as a first application, a triangulation laser scanner, the VIVID 910 Konica Minolta, was used. The device works in a range of distances from the object between 0.6 and 2.5 m and is equipped with a 640x480 pixel CCD sensor and three interchangeable lenses respectively corresponding to three different focal lengths: tele (f = 25.5 mm), middle (f = 14.5 mm) and wide (f = 8.0 mm). Working with the Tele lens at an average distance of about 50 cm, the model resolution corresponds to about 1.5 tenths of a millimeter. This estimated resolution allows reading most of the engravings on the marble slab. The digital capturing of the entire epigraph, which surface area is less than 620 cm^2, involved 19 scans with an estimated overlapping of approximately 80%. The considerable overlap among the single range-maps ensures a robust alignment between the surfaces and a complete geometric model, in order to obtain a polygonal model free of data gaps or shadow zones [6]. Indeed, potential subsequent invasive editing actions on the mesh surface (e.g., filling holes or smoothing to reduce instrumental noise) could 'falsify' the model and interfere with the interpretation of the engraved text. The software used to manage the data acquisition is the Polygon Editing Tool (PET), a Konica Minolta proprietary software. The main settings for the 3D measurements were the focus and the scanning quality, set to "fine" (in this way the laser beam strikes the object's surface three consecutive times with acquisition times of about 2.5 sec). PET also allows the processing of the acquired raw data. However, it was conducted with Geomagic Wrap (3D Systems), a more versatile reverse engineering software characterized by many utilities for mesh processing. The data elaboration workflow included the following steps: i) Data filtering and noise reduction; ii) Manual registration to align different scans using homologous points; iii) Global registration by automatic alignment optimization (Iterative Closest Point algorithm); iv) Merging different scans into a single polygonal model; v) Surface editing - manual and automatic - to correct possible errors and imperfections of the generated mesh (corrupted triangles, duplicate triangles, non-manifold edges, non-manifold vertices, etc.). Once the digital model was created, to further enhance the reading of the characters impressed on the surface, a best-fit plane was set at a 5 mm distance from the surface of the inscriptions. The best-fit plane was used as a reference to generate a DEM - Digital Elevation Model, which helped the reading and deciphering of part of the text.

Subsequent tests on the same epigraph were conducted with two structured light 3D measurement systems, the Artec Eva and Artec Leo scanners. The aim was to verify if the results could be integrated with the VIVID output to support and optimize the text interpretation.

The first one, the Artec EVA hand-held scanner, is ideal for making a quick, textured, and accurate 3D model of medium-sized objects: the linear field of view ranges from a minimum of 214x148 mm to a maximum of 536x371 mm. It scans quickly, capturing precise measurements in high resolution: the maximum resolution achievable is 0.5 mm, with an accuracy of 0.1 mm, acquiring up to 16 fps and the camera, available for the acquisition of colorimetric information, is 1.3 MP. EVA requires neither targets nor calibration to get started. The scanner uses a powerful hybrid geometry and texture tracking to reconstruct the 3D geometry. However, the data – collected by moving the instrumentation around the entire object with slow and uniform movements – can be monitored in real-time and displayed by the proprietary software on a computer or tablet only. This drawback is solved by the more recent Artec Leo scanner, used for further acquisitions to compare the different instruments offered on the market and understand which best highlights the inscriptions on the epigraph. Leo is the first 3D scanner to provide automatic onboard processing, with a 512 GB SSD internal hard drive, providing a very intuitive workflow, making 3D scanning as easy as taking a video. As the user scans the object, he sees the 3D replica building in real-time on the Leo touch panel screen. Leo has higher technical specifications: first, it is faster, with a reconstruction rate up to 80 fps and higher resolution, up to 0.2 mm; conversely, the accuracy remains at 0.1 mm. Its large field of view ranges from a minimum of 244×142 mm to a maximum of 838×488 mm. The practical step of epigraph digital capturing with these hand-held scanners was not particularly difficult but still suffered from the homogeneity of the object's texture and

its predominantly two-dimensional shape. Artec 3D scanners, since they employ the structured-light method of 3D reconstruction and capture 3D frames using optical technology, are quite influenced by the surface optical characteristics of objects. In addition, the scanner has a defined depth range. If it's too close to the object, it may fail to capture all or part of the object. On the other hand, if the scanner is too far away, various types of 3D "noise" will appear in the scene, complicating the postprocessing effort and affecting the results. Despite these challenging factors, the acquisitions phase kept few minutes with both instruments. The software used to manage the scans is Artec Studio 15 Professional, the Artec proprietary software.
The data elaboration workflow included the following steps: i) Scans checking and editing; ii) Alignment; iii) Global Registration; iv) Models generation (fusion); v) Models editing; vi) Texturing. During the revising step, the EVA scans were affected by misaligned frames, occurring because of the small size of the engravings and an insufficient number of geometrical features on the object. For that, some problematic scans were divided and edited or eliminated. In this way, the three EVA scan groups EVA were successful aligned and registered, with an acceptable error that did not affect the outputs used. The 3D model, consisting of 363.619 polygons, has a resolution of 0.5 mm. For the four Leo scans, after checking if we had any scan result not well aligned (the on-board real-time processing allows the quality of the scans to be checked already during the scanning) with a maximum error equal to 0.1, a sharp fusion was carried out, obtaining 2.286.106 polygons with a resolution of 0.25 mm. A final acquisition was conducted with a photogrammetric system [7] consisting of a DSLR Camera Nikon D800E, with a CMOS full-frame sensor (pixel size 4.87 micron) features an optical low pass filter with anti-aliasing properties removed. The camera was combined with an AF-S Micro NIKKOR 60mm f/2.8G ED, specific for sharp close-up and macro images. The artefact, placed on a rotating table, was framed in its entirety. A total of 72 images were acquired, divided into three sets at different angles to the object of 24 shots each (one every 15 degrees of rotation). The GSD (Ground Sampling Distance) – considering 60 mm of focal length, the pixel size and the distance of the optic from the object – is equal to 0,069 mm/px. A closed diaphragm, f/32 specifically, combined with diffuse lighting, allowed a sharp depth of field that was quite large in relation to the size of the artefact. The software used to manage the photogrammetric data is Agisoft Metashape, a stand-alone software product that allows, as well known, to process images into the high-value spatial information in the form of dense point clouds, textured polygonal models, georeferenced true orthomosaics. The data elaboration workflow included the following steps: i) Photos checking; ii) Alignment; iii) Build dense cloud; iv) Build mesh; v) Build texture; vi) Exporting. No problems occurred with the alignment phase, with an RMS reprojection error of 0.23 mm (1.55 pix). A 3D model of 2.710.738 faces was generated and textured, allowing the generation of an orthophoto of the dimensions of 6.232 x 6.584 px. The various 3D models obtained from the different sensors were aligned by identifying homologous points using the VIVID 910 as the master scan. Once aligned, other DEMs were generated with respect to the same best-fit plane generated at 5 mm from the surface of the inscriptions. Therefore, it was decided not to carry out a metric comparison between the models but to generate different maps to aid the reading of the inscriptions (figure 2). On the other hand, the photogrammetric model was used to generate a high-resolution orthophoto to allow the letters identified on the image to be written. On this one, various filters were tested to optimize the text recognition: HDR toning filter to apply the full range of HDR contrast and exposure settings to the image and a threshold filter to convert the coloured image into a high-contrast, black-and-white image.

4. Result and conclusion

As a first result, it appears clear that the applications with range-based systems have facilitated the reading and interpretation of the engraving, bringing to light new and significant elements for the reconstruction of the text (results that will be discussed and presented elsewhere). The attempts of reading previously produced limited achievements and not very encouraging results. It is possible to recognize traces of at least 12 lines of text written in Greek.

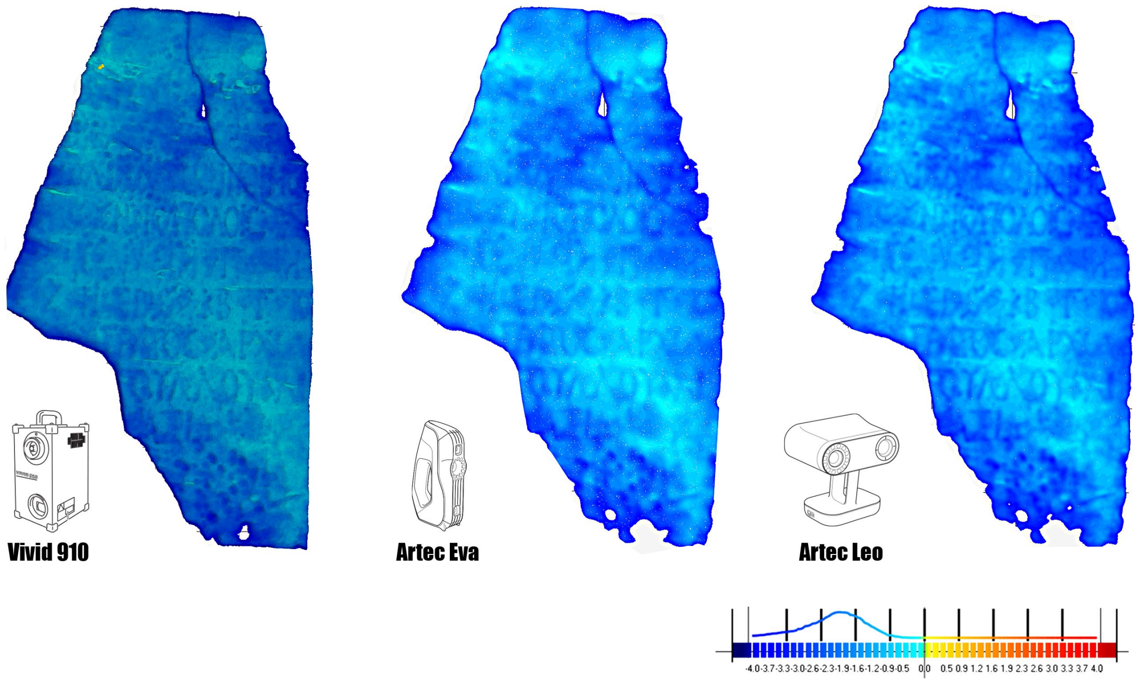

Figure 2. Different DEMs generated by range-based sensors, compared to the same best-fit plan.

The excessive erosion of the surface makes the grooves of the letters often only barely perceptible to the naked eye. Based on the elements that it was possible to acquire so far, we can say that this is a text of a funerary nature. The area of discovery (in front of Porta Marina Sud) was occupied by a Roman-age necropolis, with burials that date back to between the first and the third century AD, where a conspicuous group of funerary inscriptions was found, even though all of them were written in Latin. The name of the funerary dedication subject was probably contained in the first lines of text, which unfortunately are not well readable. In the central part of the text, we found the references to the age, expressed in years, months, and days, according to the typical form of Latin epigraphs. This aspect suggests that we are faced with a situation typical of a Romanized city that, on the other side, was still using the Greek language. In particular, concerning the 12 lines of the writing of which traces remain, in the central part (lines 4-7) it is possible to recognize, with relative certainty, some expressions or key-words that are fundamental to identify the type of inscription and guide the text reconstruction (figure 3): i) line 04 EN ΠΟΤΙΟΛΟΙC (ἐν Ποτιόλοις): state in place (in Puteoli), related to something that the personage to whom the inscription refers had done in Puteoli (Pozzuoli); ii) line 05 [E]ZHCEN (ἔζησεν) = “lived”, suggesting that this is a funerary inscription; iii) line 06 Z HMEPAC (Z ἡμέρας) = 6 days: the previous part should contain the years and months indicating the duration of the life of the person to whom the inscription refers; iv) line 07 APXΩN (ἀρχῶν) = term relating to a magistrate's office probably held by the individual. The reference to a Greek-type role possibly held by the deceased is another distinctive aspect of Velia in the Roman age. Indeed, as for other Greek-origin cities of southern Italy, Romans were very often likely to hold, for matters of social prestige, Greek-type offices. The text analyzed, therefore, turns out to be of twofold importance, as it not only enriches the dossier of Greek inscriptions dating back to the Roman age found in Velia but also, above all, currently constitutes the only Greek funerary inscription coming, most probably, from the necropolis of Porta Marina Sud. It also contributes to a better definition of the social and cultural context of the city in Roman times, especially as regards the use of the Greek language. Aware of the preliminary aspect of this work, which would undoubtedly require the analysis of a more significant number of digital survey scenarios and graphic restitution, the results achieved stimulate interest in other experiments to support the interpretation of the text contained in the epigraph.

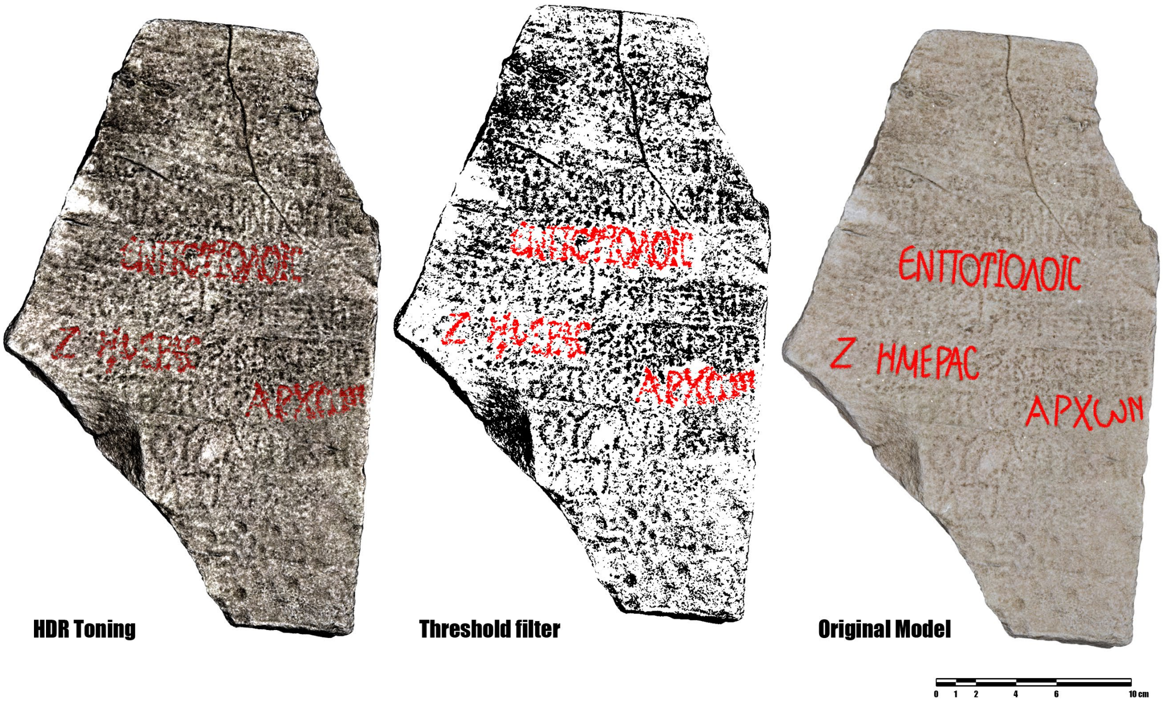

Figure 3. Lettering clearly distinguishable by DEM and RGB analysis overlayed on the orthoimage.

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