From Survey to Digital Reconstruction. Study of a Roman Fragment of an Ionic Volute

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Abstract

Today, the analysis of cultural heritage benefits from the use of digital technologies and tools. These offer the possibility of obtaining three-dimensional models with a high level of detail and geometric correspondence to real artefacts, which are suitable for use in cognitive processes and specific studies, promoting the development of critical and interpretative analyses directly in the digital environment. The research illustrated here analyses the potential of digital models in the study of archaeological heritage, assuming as a case study a stone fragment from the Roman era found during excavation activities at the archaeological site of Amiternum (AQ). The study moves from the structured light laser scanner survey of the artefact to its digital reconstruction. This is the result of the modelling process derived from the metrological analysis and the traces identified on the digital replica obtained from the scanning, as well as from the comparison with the theoretical rules for the construction of classical ionic volutes reported in architectural treatises. The results achieved underline the effectiveness of 3D digital surveying and the advantages of using digital models and reconstructions in the context of documentation for the knowledge and analysis of the archaeological heritage.

Keywords
digital documentation, structured light laser scanner, geometrical construction, 3D modelling, archaeological heritage.

Ionic volute fragment, from scanning to digital reconstruction. Graphic elaboration by the author.

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Introduction

In the last decades, the use of increasingly advanced digital technologies and tools has changed the approach to cultural heritage. New products, such as point clouds, meshes and three-dimensional models, resulting from the digitisation of architectural, archaeological and artistic artefacts have led to the definition of new methods of information acquisition, management and dissemination.

Indeed, the survey techniques used in the digitisation of cultural heritage permit the retrieval of a large amount of data that are stored and structured within digital content and containers that are always available and updatable.

This has brought great advantages to knowledge processes in which 3D modelling and visualisation have enabled scholars and researchers to structure complex information differently, perform critical and interpretative analyses, as well as to identify the optimal conservation and protection solutions directly in the digital environment [Marraffa, Fatta 2022; Liva 2022].

At the same time, digitisation and digital representation have improved the communication and fruition of heritage. With the definition of principles and guidelines on the use of rigorous methods to translate scientific data into a shared and comprehensible language [Nicolucci et al. 2006; Brusaporci, Trizio 2013], it becomes possible to communicate the tangible and intangible assets, and thus the information and outcomes resulting from the analysis processes, to the entire community, not only the scientific and technical ones, by using realistic and interactive 3D models or immersive virtual representations [Brusaporci et al. 2021; Clini et al. 2022].

The present paper fits into this framework and discusses the advantages of using the 3D digital survey in the documentation, analysis and virtual reconstruction of cultural heritage. In particular, the study was performed on a stone fragment from the Roman period, datable to the 1st century AD, preserved in the Archaeology Laboratory of the University of L'Aquila – Department of Human Sciences (fig. 1). The fragment was found in the archaeological site of Amiternum (AQ), in the locality of Campo Santa Maria. Excavation campaigns in the area, investigated since 2012 by the University of L'Aquila, which in 2020 bought the land, have contributed to identifying structures and artefacts belonging to different periods of activity, ranging from the 1st century BC to the end of the 14th century, and the ruins of the ancient cathedral of Amiternum [Forgione, Savini 2019]. The study aims to digitise and virtually reconstruct the archaeological find to facilitate its analysis and digital documentation not only from a dimensional and architectural point of view but also in a broader context, such as archaeology and anthropology.

Fig. 1. Stone fragment of Ionic volute datable to the 1st century AD (University of L'Aquila - Laboratory of Archaeology, DSU). Photograph by the author.

State of the art

The documentation of cultural heritage through high-performance 3D surveying tools has been facilitated by the codification of well-established procedures and increasingly high-performance, sometimes low-cost, hardware and software solutions. These tools, both image- and range-based, allow the recording and storage of a large number of data, i.e. point clouds and polygonal meshes, of complex artefacts with a high degree of precision and reliability and, therefore, can be the starting point in heritage knowledge, valorisation and communication processes.

Several studies in the literature illustrate the comparison of the image - and range-based survey techniques, or through the integration of several datasets, demonstrating the reliability of the different procedures and the accuracy of the data acquired in diverse contexts [Patrucco et al. 2019; Adamopoulos et al. 2021; Melendreras Ruiz et al. 2021; Russo, Senatore 2022].

Structured light scanner surveys carried out on small and medium-sized artefacts, such as sculptures and archaeological finds, return three-dimensional models that can support the knowledge and documentation processes underlying the conservation and restoration of these assets [Manfredini et al. 2016; Marra et al. 2021; Trizio et al. 2022].

The high level of resolution and accuracy of these models has led to research on the advantages of these also in the field of communication and enhancement of cultural heritage. In this sense, physical prototypes, through 3D printing, and digital ones, which are available within museum collections or on web platforms, have been developed to foster new forms of knowledge and approach to cultural heritage [Barbosa Caldeira, Fonseca Motta 2016; Canciani et al. 2017; Urcia et al. 2018; Mezzino et al. 2022; Parrinello et al. 2022].

At the same time, it should be emphasised that digital models obtained through different modelling techniques (CAD, Nurbs, parametric and generative) are also very useful in the analysis and documentation of cultural heritage. In particular, with reference to the studies on the classical orders, generative models of the five architectural orders [Bianconi et al. 2018] and digital models of the Ionic capital have been realised on the basis of the different constructions described in several architectural treatises, from Vitruvius to Palladio [Migliari, Angelini 1998; Paris 2006].

These studies are related to specific sector studies, which have addressed the issue of the design and proportioning of the orders [Migliari 1991]; the analysis of the anomalies, with respect to the rule, of some parts of the Ionic capital that can be found from the modelling of this architectural element [Migliari, Angelini 1998]; and, finally, the identification of the volutes tracing of the Ionic capital using an inverse procedure compared to those of theoretical constructions and which exploits the analysis of the signs found on the stone elements [Inglese 2017].

From digital survey to virtual reconstruction

The Roman fragment analysed depicts an Ionic-influenced volute with a vegetal decoration on the back. Although the piece is interrupted by several breaks and lacunae that cause a loss of continuity, the eye of the volute and some marks are recognisable, such as the horizontal and vertical axes, two circles concentric to the eye, a pair of axes inclined at an angle of 47° to the previous ones and, finally, eight small holes, with a diameter of less than 1 mm, inside the eye.

The artefact was surveyed using structured light lasers with blue light technology to make some considerations from the geometric and constructional point of view of the volute, as well as to carry out a virtual reconstruction of the fragment that could support both the analysis and documentation phase and the communication phase of the archaeological heritage. Three different scans were performed with the Artec Eva 3D Scanner (fig. 2) and the Artec Spider 3D Scanner (tab. 1) to obtain a three-dimensional digital model with a high degree of geometric correspondence to the real object.

Fig. 2. Digital acquisition of the artefact by 3D structured light scanner. Photograph by the author.

n. scansione	Error	Frame	n. polygons [M]
Eva_Scan 01	0,7	747	1,4
Eva_Scan 02	0,8	663	1,1
Eva_Scan 03	0,5	769	1,5
Spider_Scan 01	0,2	567	16,4
Spider_Scan 02	0,5	420	7,28
Spider_Scan 03	0,2	284	6,67

Table 1. Summary of data acquired by the structured light laser.

The data processing of the two different scans, i.e., the editing, alignment and registration of the three datasets, was carried out within the Artec Studio 17 Professional application (tab. 2), which, following the texturing process, returned two 3D models with color data and different levels of detail (fig. 3).

Since the model obtained by the Artec Spider 3D Scanner has a higher level of morphological and qualitative detail (4.6 M triangular meshes) than the one obtained by the Artec Eva 3D Scanner (152 K triangular meshes), it was used to perform different analyses on the artefact.

First, a metrological analysis was carried out to verify the use of the measurement units of the period and the presence of any proportional ratios of the fragment's elements. It was possible to measure from the 3D model the dimensions of the volute's eye, whose diameter is 2.45 cm, which is equivalent to 1 Roman inch, corresponding to 1/12 of a Roman foot (29.48 cm) [Salvatori 2006]. From the centre of the volute's eye corresponding with one of the central holes incised on the artefact, the two inner circumferences were traced (fig. 4), respectively with a diameter of 1.63 cm and 0.82 cm. By comparing these

	Global registration [s]	Outlier removal [s]	Sharp fusion [s]	Texture [s]
3D Artec Eva Scanner	12,7	33,8	106,6	34
3D Artec Spider Scanner	21,8	479,3	211,9	34

Table 2. Summary of processing time.

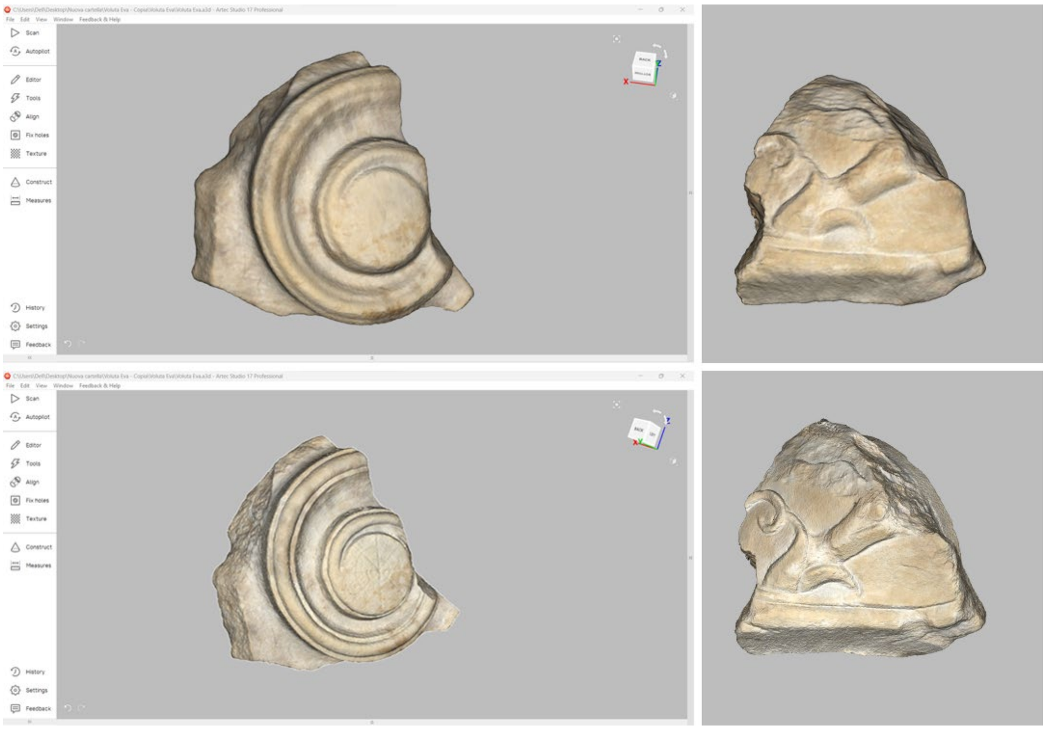

Fig. 3. Models obtained by scanning with structured light laser: top, Artec Eva 3D Scanner model (152 K triangular meshes); bottom, Artec Spider 3D Scanner model (4.6 M triangular meshes). Graphic elaboration by the author.

measurements with those of the Roman foot, it appears that the diameter of the first circumference corresponds to 1/18 of this, thus slightly smaller than the *digitus*, which is equal to 1/16 of the Roman foot (1.84 cm), while the second diameter amounts to 1/36 of the Roman foot, i.e., 1/3 of an inch. The latter ratio also represents the increment of constant proportionality between the radii of the three circumferences.
In a second phase, several circumferences passing through the seven holes engraved inside the eye were traced to reconstruct the spiral that defines the volute (fig. 5a). The latter presents a regular development (fig. 5b) and consists of circular arcs that have a continuity of order 1, namely curves that not only share the position of the extreme points but also have the directions of the tangents in these coincident [Mancini 2019].
A digital reconstruction of the missing parts of the volute was created starting from the geometric reconstruction of the spiral and the 3D model obtained from the laser scanning. At this phase, Rhinoceros software was used, recurring to manual modelling to control the creation of the surfaces in analogy with the hypothesis and in accordance with the survey.
The digital reconstruction of the artefact obtained (fig. 6) made it possible to make considerations, in line with previous studies on volutes and their tracing [Migliari, Angelini 1998; Paris 2006; Inglese 2017], on the correspondence of the volute to the rules theorised by Vitruvius and in Renaissance treatises.
There are several differences concerning the constructions theorised in the treatises (fig. 7). First of all, the centres used for the construction of the spiral are not arranged at the vertices of the square inscribed in the minor or intermediate circumference, except for points 1, 2 and 3, which deviate from it by 0.3 mm. The spiral wraps around itself for two and a half turns, disregarding the canon of Vitruvian and other Renaissance treatise writers as it closes on the eye in the lower quadrant rather than the upper.
Finally, further anomalies compared to the heights of the volute reconstructed with the partitions envisaged in the historical treaties [Migliari 1991; Inglese 2017] are found when considering the heights obtained from the reconstruction. Specifically, the lower part of the volute is 1.6 parts against the 3 expected, while the upper part is composed of 2.2 parts against the 4. Even if the volute were to be reconstructed to reach at least one of the two heights defined in the Vitruvian rule, in the reconstruction of the connection

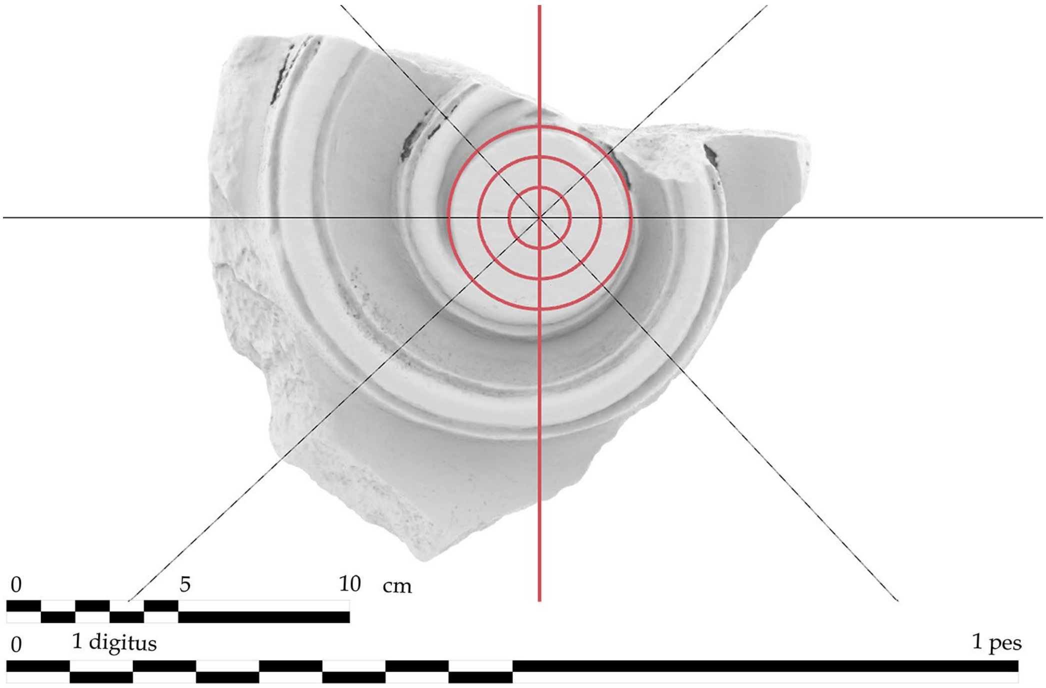

Fig. 4. Metrological analysis of the volute. Graphic elaboration by the author.

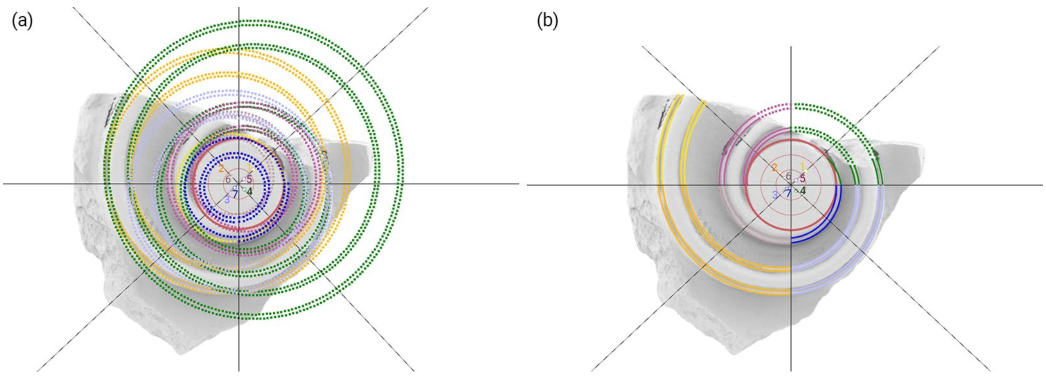

Fig. 5. (a) Construction of the circumferences passing through the holes engraved on the artefact. (b) Reconstruction of the spiral of the volute. Graphic elaboration by the author.

between the volute and the back part (side baluster) of the scanned fragment would be found some anomalies. Therefore, it is considered that the maximum height of the volute examined could not exceed 4.8 parts.

Conclusions

The research presented, aimed at the study and digital reconstruction of a Roman-period volute found during excavation activities at the site of Amiternum, offered an opportunity to evaluate the effectiveness of active tools, such as the 3D laser scanner, in the field of documentation for the knowledge and analysis of the archaeological heritage.
The metrological analysis of the traces on the artefact permitted the digital reconstruction of the stone fragment and the comparison of the model obtained with the theoretical constructions of the Ionic capitals and their volutes addressed by the treatises. The several anomalies in relation to the rules highlight, on the one hand, the use of specific proportions in the realisation of the architectural elements and, on the other hand, a contrast with the Vitruvian principles during the construction period of the artefact.
However, the many breaks and gaps also lead to questions about the original location of the fragment within a specific architectural element, be it a capital or a cornice. In this regard, the analysis of the artefact can be enhanced by digital scanning, which allows for detailed

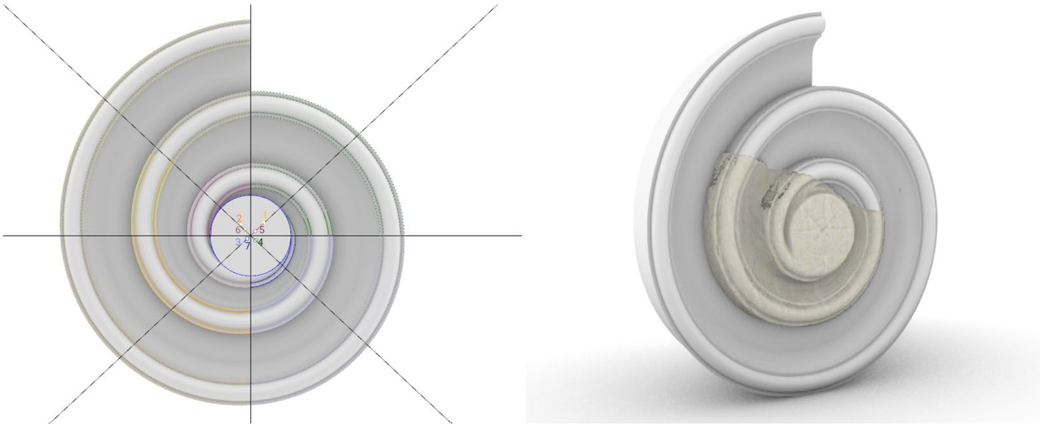

Fig. 6. Digital reconstruction of the fragment: frontal view, left; perspective view, right. Graphic elaboration by the author.

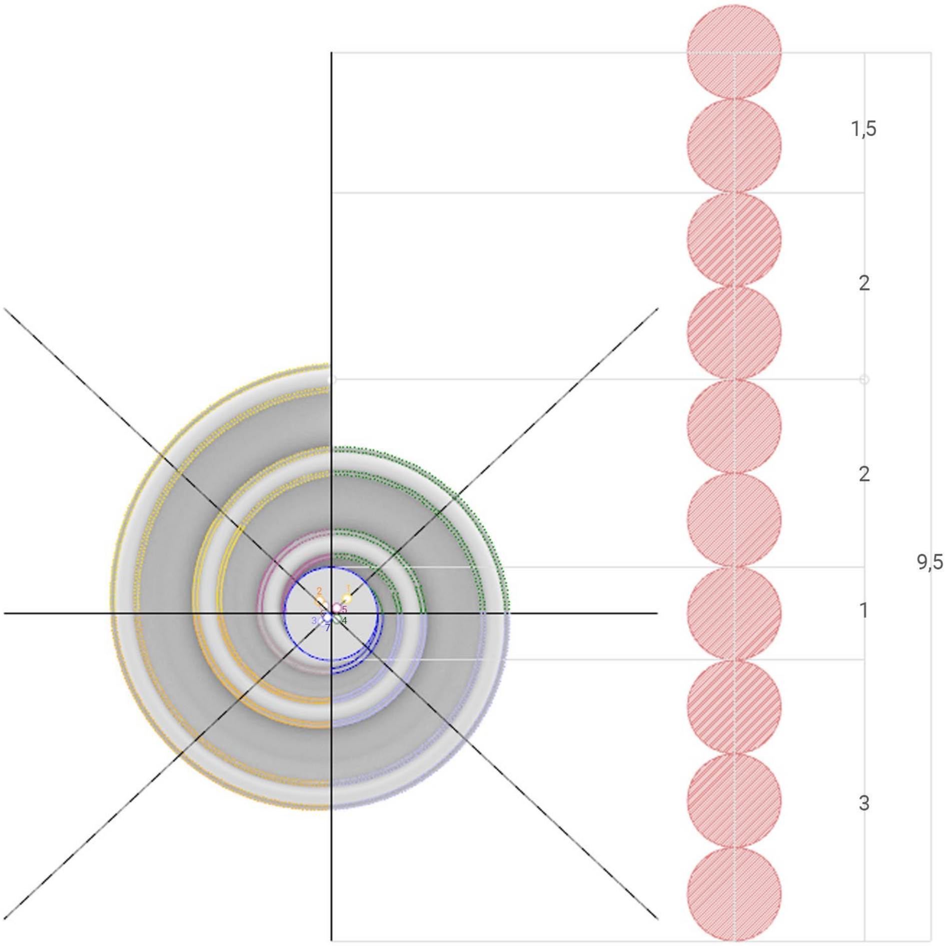

Fig. 7. Reconstruction of the volute according to the grid used to establish proportions elaborated by Paris (2008). Graphic elaboration by the author.

analyses, such as zoomed views, specific sections and comparisons with other elements, in a digital environment. At the same time, the three-dimensional model obtained from the survey and the reconstructed one can be used both to make physical replicas, obtained through 3D printing processes, to be used in the context of the valorisation and fruition of the heritage also for the tactile perception by visually impaired people, but also as contents of databases and digital platforms that favour the sharing of information and the dissemination of knowledge.

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