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INDICE

PRACTICAL CONSIDERATION FOR DIGITALLY RECORDING EPIGRAPHIC STONE OBJECT: THE CASE STUDY OF THE NORA STELE (SARDINIA, ITALY)

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Riassunto: Le metodologie di rilievo 3D nell'ambito dei Beni Culturali vengono impiegate per la realizzazione di modelli 3D ad altissima risoluzione per fini di ricerca, restauro, conservazione e valorizzazione e le loro più frequenti applicazioni riguardano i manufatti di maggior rilievo conservati in ambito museale. I principali fattori che guidano la scelta di un particolare strumento sono: l'utilizzo del dato acquisito, la risoluzione e l'accuratezza. Per questi motivi per l'acquisizione della 'Stele di Nora' presso il Museo Archeologico Nazionale di Cagliari, sono stati utilizzati uno scanner a luce strutturata e il rilievo fotogrammetrico al fine di valutare tanto i vantaggi di questi metodi in campo epigrafico, quanto le possibilità di utilizzo dei modelli prodotti per la ricerca e la valorizzazione.
Parole chiave: Sistema a luce strutturata, modelli 3D, Stele di Nora, iscrizione, valorizzazione

Abstract: High resolution 3D survey systems have been adopted in recent years for use in Cultural Heritage with the aim of realising high resolution 3D models that are a valuable basis for reproduction, restoration and conservation purposes. The most frequent applications of 3D technology for artefacts remain the research around a museum's most exceptional object. The considerations that guided the choice of the scanning system are: data goals, spatial resolution, depth accuracy, and portability. For these reasons, 3D high resolution survey with structured light scanner and photogrammetry technique were applied for recording an epigraphic stone, 'the Nora Stele' at the National Archaeological Museum of Cagliari, to evaluate these methods and how the derived model could be used for research.
Keywords: Structured Light System, 3D model, Nora stele, epigraphic stone, enhancement

1. INTRODUCTION

In recent years, the Department of Cultural Heritage at the University of Padua has dedicated special attention to the application of digital technologies in the study and valorisation of cultural heritage. In terms of research, the development of new technologies, in particular linked to 3D surveying and modelling, has allowed the development of studies on the opportunity to combine traditional methods with computerised tools to analyse cultural heritage from the micro to the macro scale[1]. On the other hand, the ever-increasing need to disseminate and share research results both academically and to the general public has led to the use of dissemination tools, such as virtual reality applied both on sites and individual objects[2].

In particular, within the framework of the research carried out in Sardinia for a decade now, both the laser scanning and photogrammetric survey of architectural evidence and artefacts, and the modelling of reconstructed ancient environments, reproduced in virtual tours usable on

1 ROSSI *et alii* 2019; SUN *et alii* 2020; ADESSO *et alii* 2022.

2 BONETTO, ZARA 2018a; BERTO *et alii* 2021a; BERTO *et alii* 2021b.

site and off site with mobile VR devices, has found particular application in the archaeological site of Nora, where the University of Padua has been active for over thirty years. In the ancient city, a virtual tour with VR mobile devices was first put into action in 2016[3], and was later completely revisited, developed and now operating at the archaeological park (e-archeo project, 2022), paying specific attention to validation of the 3D reconstructive process[4].

A further thread of activities related to the digital enhancement of archaeological heritage in Sardinia is currently being carried out thanks to the collaboration between the University of Padua and the Direzione Regionale Musei Sardegna, with a first project for the visualisation of the island's main sites and their finds in VR and via touch screen at the National Archaeological Museum in Cagliari[5], as well as at the Antiquarium Turritano in Porto Torres, for which a virtual reconstruction of the building known as Terme Centrali/Palazzo di Re Barbaro is now available[6].

From a further development of these activities arises the present study, which aims to provide a detailed survey of one of the best-known Phoenician inscriptions in the Western Mediterranean – the 'Nora Stele' (fig. 1).

The European Evocation project, which was funded by the European Union's H2020 research and innovation programme under the grant agreement and by the Region of Sardinia (POR FESR 2014-2020), has conducted a digital survey of the Stele. The methodology used is the Multi-Light Image Collection capture where multiple photographs were taken from a fixed camera and different light positions, by uniformly moving a light source in a hemispherical (virtual) path in front of the stele an it allows the creation of an interactive image, highlighting the details of the inscription through the virtual modification of the point of light[7].

The Direzione Generale Musei – Museo Archeologico Nazionale di Cagliari aims to broaden its digital collection, and so reaffirmed the partnership with the University of Padua. Even under these conditions, the research activities conducted by Padua team aim: to create a high metric accuracy model for sub-millimetre metric analysis; to integrate structured light survey data with a very high resolution photogrammetric texture; to produce web output that allows the public sharing of research data; to obtain a model that can be used with multiple dissemination vehicles (for example 3D printing) for public[8].

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3 BONETTO, ZARA 2017; BONETTO, ZARA 2018b.

4 BONETTO *et alii* 2022; PIETRONI *et alii* 2023.

5 BONETTO, ZARA 2018a: 193-195.

6 BONETTO *et alii* 2023.

7 www.youtube.com/watch?v=nIWfwwJaL3c&t=4s

8 The research, the reproduction of the images and the publication are authorized by Ministero della Cultura. Direzione Generale Musei – Museo Archeologico Nazionale di Cagliari (aut. MIC/MIC_MAN-CA/06-05-2022/0001308-P; MIC/MIC_MAN-CA/18-10-2023/0002693-P). The research is supported by World Class Research Infrastructure – Sycuri (Synergic Strategies for Cultural heritage at risk), funded by University of Padua to CIBA - Centro interdipartimentale di ricerca studio e conservazione dei beni archeologici, architettonici e storico-artistici (Beni Culturali).

2. MATERIAL AND METHODS

2.1 The 'Nora Stele'

The 'Nora Stele' (also known as 'Nora Stone' or 'Nora Inscription') is one of the most remarkable Phoenician epigraphs in the Western Mediterranean[9], and, in broader terms, one of the oldest written documents in Western culture: most scholars date the Nora Stele by palaeographic method to the late 9 c. BC, although a dating to the middle 8th c. BC is not excluded.

The stele is engraved in a block of so-called 'Thyrrenian sandstone', a local calcarenite[10], slightly tapered upwards, and underside carved with a tenon (i.e., element for the insertion). It was discovered by the Dominican abbot Giacinto Hintz in 1773 in Pula, near the peninsula of Nora, located at the south-western edge of the Gulf of Cagliari. Nora is one of the most ancient settlements of Phoenician Sardinia, as mentioned by Pausanias[11] and Solinus[12], and as excavations carried out in recent decades have shown[13]; nevertheless, the original context in which the stele was placed is unknown, as it was found reused in a modern-day wall of a vineyard owned by Mercedarians[14].

Since 1830, the Nora Stele has been exposed in the National Archaeological Museum of Cagliari, but the first publication of the epigraph dates back to 1774, the year after its discovery, by Giambernardo De Rossi (fig. 2)[15].

From then on, the reading and translation of the problematic inscription was the subject of numerous studies: Alberto Ferrero della Marmora - soldier, naturalist and archaeologist that visited and studied Sardinia[16] - criticised De Rossi's drawing of the stele as extremely inaccurate, and since that time to the present, many drawings and squeezes of the inscription have been made by scholars, leading to different interpretations; a recent critical collection of such epigraphic analyses is due to Roberto Casti[17], but the ongoing scientific debate is far from over.

The epigraph has eight lines, with single letters of the Phoenician alphabet between them; overall, the stele has 44 alphabetic symbols (m 0,05-0,125). The absence of gaps or dividing is typical of Phoenician epigraphy, and the many possible word divisions originated the numerous readings of the text. The following is a possible transliteration[18]:

1. bt rš š
   r
2. ngr šh'

9 CIS, I, 144; AMADASI GUZZO 1967; ICO Sard. 1, 83-87.

10 PREVIATO 2016.

11 Paus. 10.17.5.

12 Sol. 4.1-2.

13 BONETTO 2021.

14 MAZZARIOL, ZARA 2024.

15 DE ROSSI 1774.

16 FERRERO DELLA MARMORA 1860.

17 CASTI 2019.

18 DE SIMONE 2019.

3. bšrdn š
4. lm h' šl
5. m sb' m
   m
6. lkt nbn
   r
7. šbn ngr
8. lmpy

The epigraph is probably complete, but some scholars have also questioned this statement[19]. It may bear the first mentions of Sardinia (šrdn, l. 3) and Nora (ngr, l. 2) names, while the word division of l. 1 leads to the two main interpretations of the whole text. The most widespread and more plausible theory refers to the construction of a sacred building in Nora in Sardinia (bt rš š/ngr šh' bšrdn, l. 1-3), probably for/to Pumay (lpmy, l. 8), while a second less likely hypothesis suggests a military expedition from/at Tarshish (b-tršš, l. 1), but in this case it remains complex to solve the rest of the text.
A final note should be made regarding the particular 'rubrication' of the stele: after the stele was brought to the Museum in Cagliari, the incisions have been coloured, owing to the use of red chalk; a subsequent restoration attempt in 20th c. caused the colouring of some letters to change from red to blue.

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2.2 Method

In recent years, high-resolution 3D survey systems have been adopted for use in Cultural Heritage. The aim is to create high-resolution 3D models with valuable morphological and morphometric characteristics that can be used for reproduction, restoration, and conservation purposes. In the past thirty years, there has been a technological revolution in computer vision for 3D acquisition and its application to real-world objects. This has been accompanied by major advances in mathematical treatment. These advances could be advantageously applied to extensive rock and epigraphic art documentation[20].
The 3D documentation of objects, monuments, and sites, as well as the 3D reconstruction of small artefacts can be undertaken with a wide range of digitization and surveying techniques. Pavlidis et alii point out that the amount of existing 3D digitization techniques is due to three main factors that affect the suitability and applicability of the existing systems[21]: complexity in size and shape; morphological level of detail and diversity of materials.
Although imaging technology has evolved significantly and is used in a variety of ways, 3D technology is still primarily used to study the most exceptional objects in a museum, to address

19 PUECH 2020.

20 PAPADAKI *et alii* 2015; SAMAAN *et alii* 2016; MONNA *et alii* 2018; FARESIN, SALEMI 2019; SALEMI *et alii*, 2021; LIMONGELLO *et alii* 2022.

21 PAVLIDIS *et alii* 2007.

specific research questions or conservation needs[22].
As Dahl et alii point out, the considerations that guided the choice of the system for creating the 3D models are[23]: data goals, spatial resolution, depth accuracy scanning time, consistency, and portability.
In particular:

- Data goals: in line with the broader research goals, the central objective of the scanning process is to capture as much information as possible about the physical object. This is achieved through two main components. The first component involves obtaining an accurate representation of the shape, including the details and irregularities of the surface. This geometric information allows for the reconstruction of the object, which can be manipulated and viewed from different positions. The second record contains information on the brightness and colour of the surface. This data is used to create a digital model of the object that accurately reflects its original appearance.
- Spatial resolution and depth accuracy: the scale of the finest detail that is recorded impacts the choice of methodologies. Increasing the resolution tends to increase both the cost and the time needed to scan an object. It is possible to have a variable model with multi-resolution levels of detail.
- Scanning time: the scan time for each object should be minimised, especially since access to collections is limited by museum availability and staff. It is important to maintain a balance between scan time and the quality of the scan.
- Consistency: the data acquisition process needs to be as consistent and as standardised as possible to enable comparisons between the same type of objects from different collections using same and different capture equipment.
- Portability: it is important to have equipment that can easily be moved between places and collections, and which can be set up quickly[24].

For all these reasons a structured light scanning system was applied for recording an epigraphic stone – the so-called "the Nora Stele". The goal is to list practical considerations about the digitalization of this type of objects and how the method could be used for study, reproduction, valorisation, and conservation purposes (fig. 3).
The Structured Light System technique is an active method that uses a projection device to actively project structured patterns. This scene is then captured by a typical digital image detector and processed to reconstruct the geometry from the deformations of the pattern in the digital image. This method is accompanied by texture acquisition and can lead to very impressive results in terms of accuracy and resolution[25]. The 3D model is a faithful and measurable digital representation of the object through the description of its morphological and morphometric characteristics[26]. The stele has a rather flat relief with few undercuts and its scanning process

22 AHSAN *et alii* 2022; BARRILE *et alii* 2022.

23 DAHL *et alii* 2008.

24 DAHL *et alii* 2018.

25 ZHANG 2018; SALVI *et alii* 2010.

26 BENTKOWSKA-KAFEL, MACDONALD 2018.

produced 141 range maps with a geometric level of accuracy of 40μm. The data collected by the scans are X, Y, Z coordinate triplets of each single point analysed. Data processing with Optical RevEng 2.4 SR 8 Pro software followed the standard steps of the 3D scanning pipeline[27]. The global alignment is the result of the 146507747 points alignment with a standard deviation of 0.0295 mm. Through the meshing phase the number of points produced a mesh of 4872611 triangles. No fill hole procedure was applied during the editing phase. This was made possible due to the high number of scans, despite the size of the stele and the high degree of overlapping, resulting in a high-resolution model (figg. 4-5).

The instrument used for the acquisition is Cronos Dual, a structured light system by Open Technologies (now Faro rebranded), with an accuracy of 10 ÷ 40 μm and a camera resolution of 2 x 1.3 MPixels.

The main objective of this study is to conduct a metric analysis of the epigraphic apparatus and stone support. The aim is to compare and potentially supplement the existing literature data with the new digital survey.

The structured light survey was complemented by a photogrammetric survey of the inscribed surface of the stele of Nora, since the preservation of the authentic surface colour is crucial for conservation and restoration planning as well as for tactile reproduction.

Photogrammetry technique belongs to the passive methods of reconstructing 3D digital models from a series of digital photographic images (or frames from a digital video) taken with digital photographic equipment and processed with specialist photogrammetry software. The outputs of this method are highly accurate digital 3D models with sub-millimetre feature accuracy overlaid with high-resolution photographic UV textures.

The acquisition phase, using NIKON Z50 and NIKKOR 35 mm F2.8, produced 25 images (sRGB, 8688 x 5792 pixels, 72 dpi). Data processing with Agisoft Metashape Professional 1.8.0 software followed the standard steps of the processing pipeline.

The SfM software works in 4 stages:

1. Feature detection, feature matching, and camera position estimation resulting in a sparse point cloud.
2. Dense point cloud reconstruction (resulting in a fully described model but only as points/vertices)
3. meshed surface reconstruction resulting in a mesh 3D model needed for the UV mapping.
4. Photographic surface texture reconstruction – UV mapping resulting in a photographic overlay describing the colours of the surfaces)

The dense cloud is the result of the 3446102 points alignment (fig. 6).

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3. CONCLUSION

3.1 Results and discussion

The application of Geomatic techniques in the survey of epigraphs and inscriptions allows a ri-

27 VRUBEL *et alii* 2009.

gorous and at the same time flexible way of documentation. Three-dimensional, non-invasive surveying can provide a digital representation of the inscription. This could be a valuable tool for research and knowledge acquisition in many aspects:

- The data can be analysed interactively, freely varying the lighting and shading characteristics of the carved surface;
- It is possible to perform automatic processing that extracts certain types of content;
- It is possible to merge the data with information of different origin, also in digital format, in order to increase the expressive content.

The 3D survey of the 'Nora Stele' and its output has allowed to list considerations on the use of the model whose informative outcomes in the overall reading of the artefact, specifically an inscribed stone object.

The structured light survey was functional for a metric analysis using digital models. Digitising delicate, inaccessible, or complex physical objects allows for accurate measurement of all aspects of a model, including length, angles, structure, and volume. Measurement scripts can also be created to examine variations in normal angles or calculate other morphometric parameters (tab. 1).

For the first time it was possible to take high-precision measurements of both the support and the individual letters; these data can be compared with measurements already published in the literature[28]. The object surveyed also presents characteristics that can be 'read' and measured at a submillimetre level such as: the size and shape of the engraved letters as well as all the scratches on the inscribed surface (tab. 2).

These data allow us to distinguish unintentional signs or those due to reuse from the letters engraved in the Phoenician period. Moreover, with specific regard to the sides of the block, a different type of workmanship is evident compared to the epigraphic mirror (fig. 7): this could be related to the different workmanship of the inscribed face, quite different from the finishing of the side faces, or to the reuse of the block documented by historical sources.

Even different is the surface of the upper face, in which elements of finishing activity were not as well preserved, but where at least signs of fracture and/or wear are partly identifiable (figg. 8-9).

The 3D survey has also allowed the development of studies on conservation and textural aspects.

The ability to capture objects by digital 3D survey seems like an improvement over traditional methods of visually recording an object or site.

Specifically, the photogrammetric survey with the production of photorealistic textures with regard to the appearance of colour allows considerations on the state of preservation of the 'rubrication' of the letters, which has been partially removed leaving well-differentiated traces of 'bluish' colour on the surface (fig. 10). Moreover, the analysis of the texture allows to map the traces of the light mortar related to the re-use of the stone, especially on the tenon.

28 CASTI 2019: 27-28.

NORA STELE MEASUREMENTS (M)	
Height	0,992
Height including tenon	1,146
Width in the middle (at line 5)	0,531
Width at the top	0,469
Average depth	0,263

Tab. 1 - Nora Stele main measurements taken on 3D model (processing E. Faresin)

NORA STELE LETTERS HIGHT (MM)						
Line 1		70	69	87	46	52
Line 2	83	92	70	82	92	107
Line 3	61	92	86	86	76	86
Line 4	77	88	85	77	87	62
Line 5		126	97	101	55	125
Line 6	92	110	92	85	106	78
Line 7	92	89	87	77	95	53
Line 8			86	125	77	57

Tab. 2 – Nora Stele letters, maximum heights taken on 3D model (processing E. Faresin)

Future development: public engagement and 3D collections for comparative studies

A first method for the communication to the general public of the model is the use of web apps designed for interactive navigation from mobile devices or PCs. An initial test was carried out using the dBC Digital Object Collections web app, developed by the department of Cultural Heritage of University of Padova[29]: the stele can be viewed at several zoom levels, measured, sectioned and accompanied by a descriptive sheet (fig. 11). Digital archives also enable the development of research on a global scale: the possibility to form a digital or even 3D printed collection of objects from different sources opens up new lines of possible research. Once objects are 3D digitised, they can be compared with similar objects from museums around the

29 Hybrid Sustainable Worlds; project founded by POR FESR 2014-2020, Regione Veneto.

world and being at a finer level of detail than previously[30].
Moreover, the use of 3D models, particularly 3D printed models, in public engagement is becoming increasingly common in museums. For younger people, the impact of handling an ancient artefact seems to make the overall heritage experience more memorable and educational. Replicas that can be handled also make great props for historical storytelling in educational or museum contexts.
The observation that handling realistic 3D printed objects (with context explained) can illicit emotional responses in some people is fascinating, especially when compared with on-screen data or even when viewing objects in cases. This phenomenon, which is worthy of further study, is due perhaps to touch being a direct sensory experience. In this case, a 3D print of the 'Nora Stele' has not yet been realised, but thanks to this acquisition, it will be possible in the future to produce one or more 1:1 scale replicas, which, for example, can be displayed in the next exhibition of the Museo Civico Patroni in Pula, giving to the visitors the artefact in its context of discovery.

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30 DAHL *et alii* 2018.

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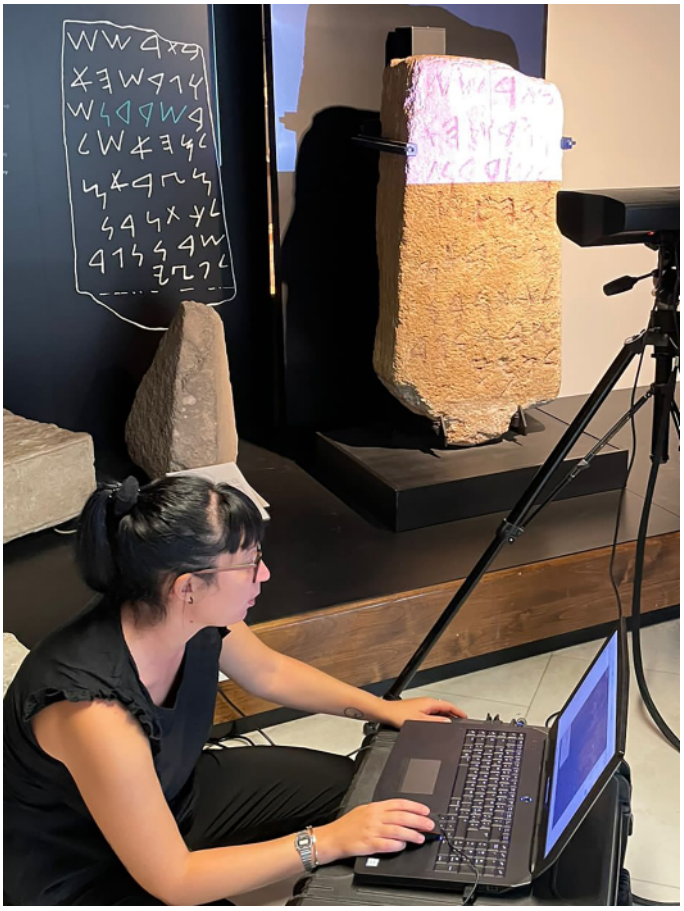

Fig. 1 - Cagliari - National Archaeological Museum. The 3D Survey of the Nora Stele, 2022 September (photo A. Zara)

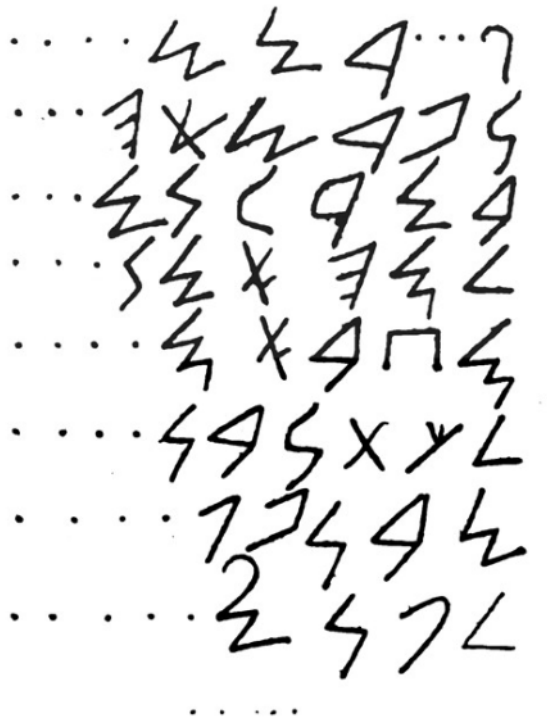

Fig. 2 - Drawing of the Nora Stele in its editio princeps (DE ROSSI 1774, 350)

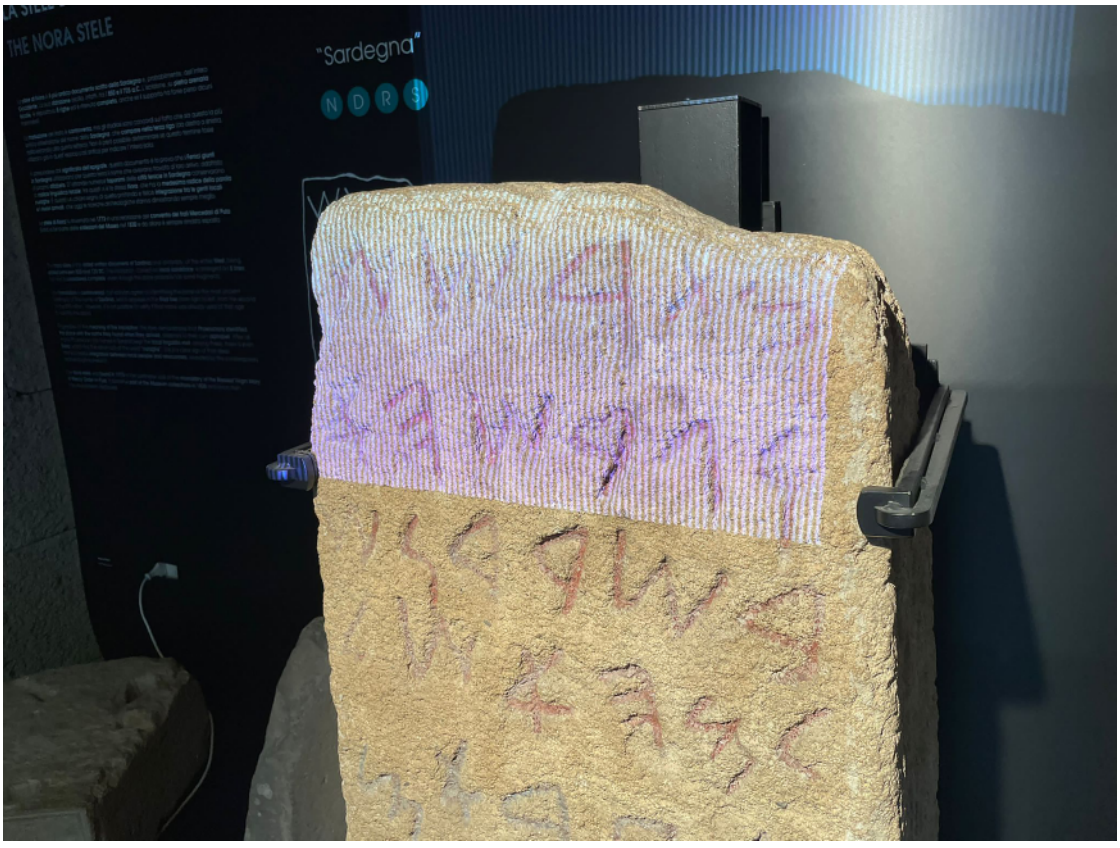

Fig. 3 - The acquisition phase of the Nora Stele with the projection of light patterns (photo A. Zara)

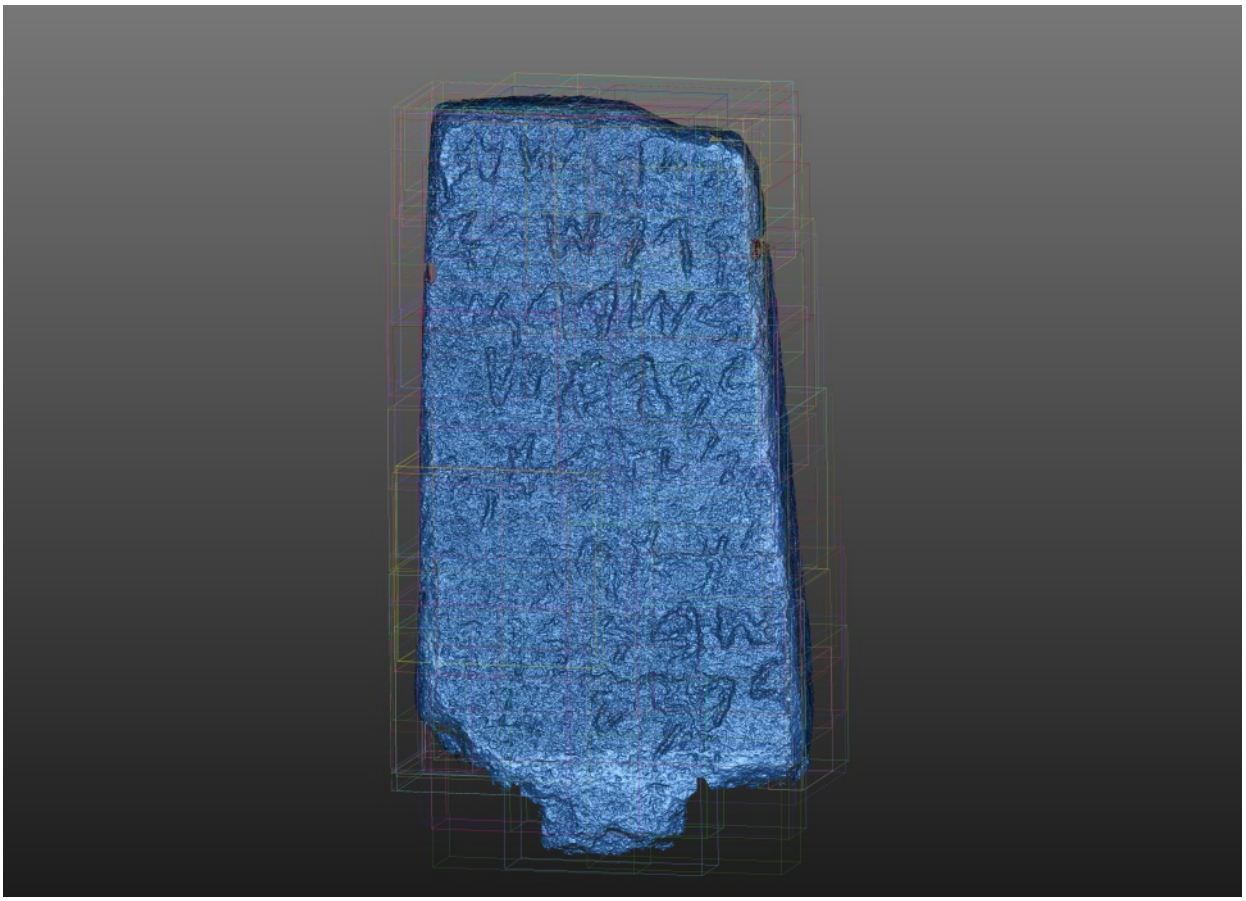

Fig. 4 - The 3D high density point cloud obtained with the structured light system and composed by 141 range and 146507747 points (processing E. Faresin)

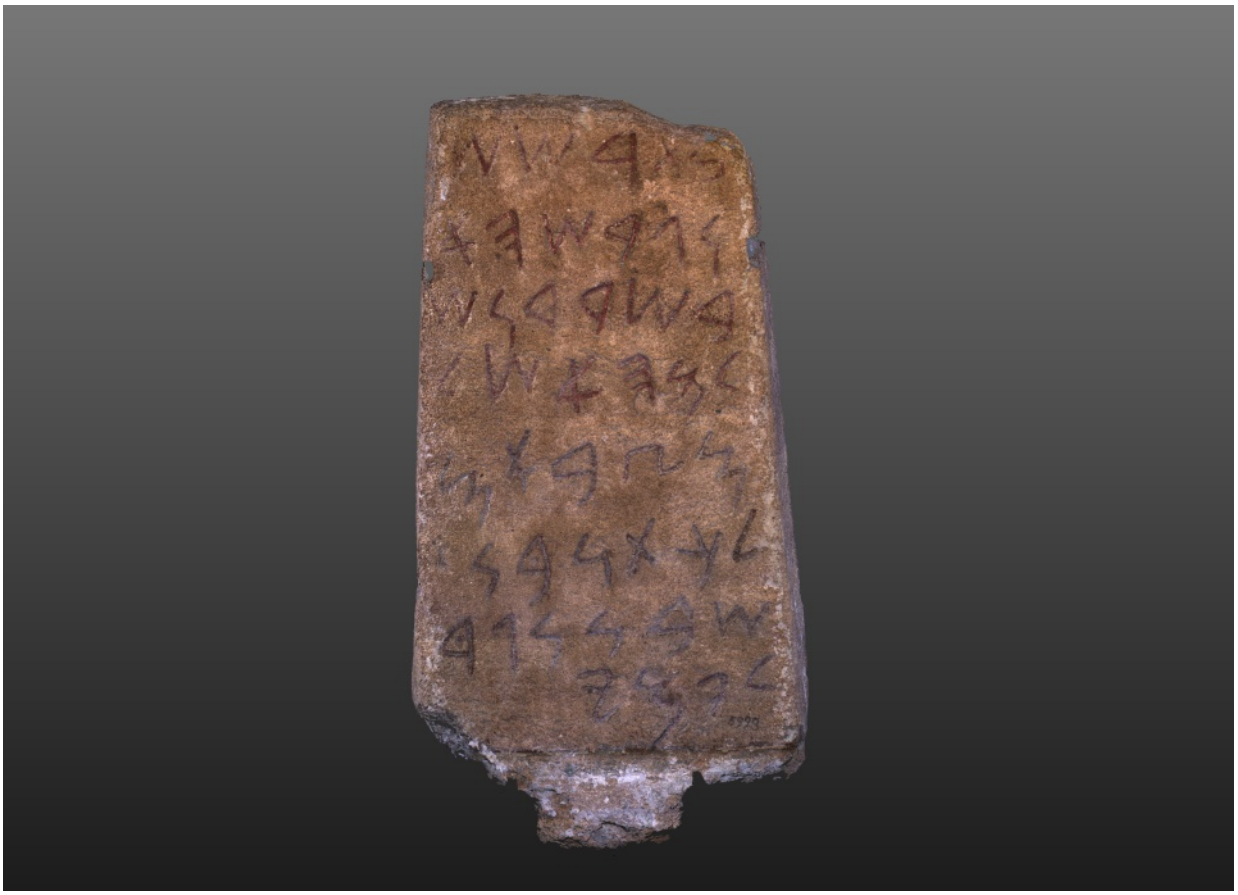

Fig. 5 - The 3D high density point cloud with RGB data (processing E. Faresin)

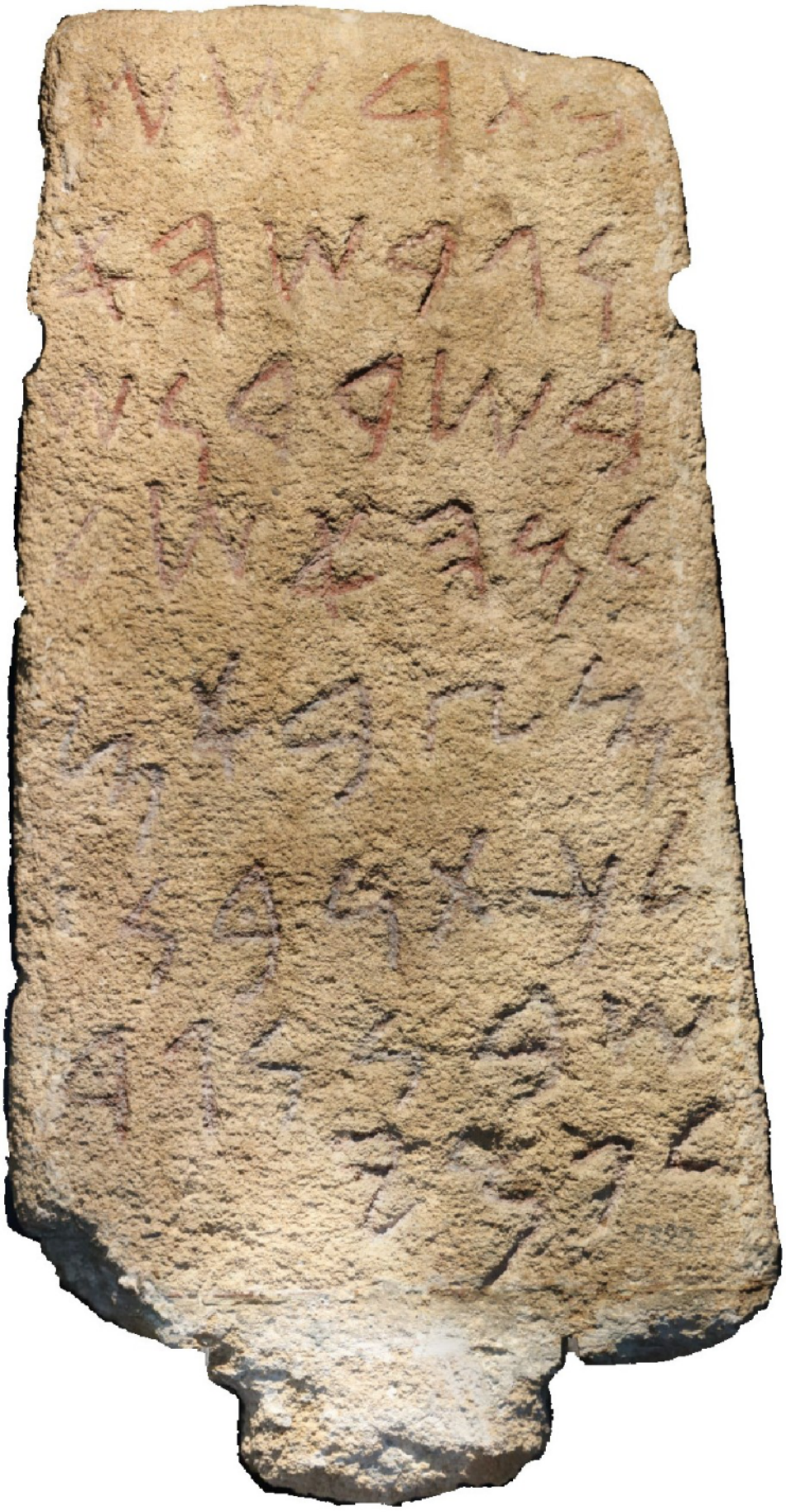

Fig. 6 - The 3D model with high-resolution photographic texture (processing E. Faresin)

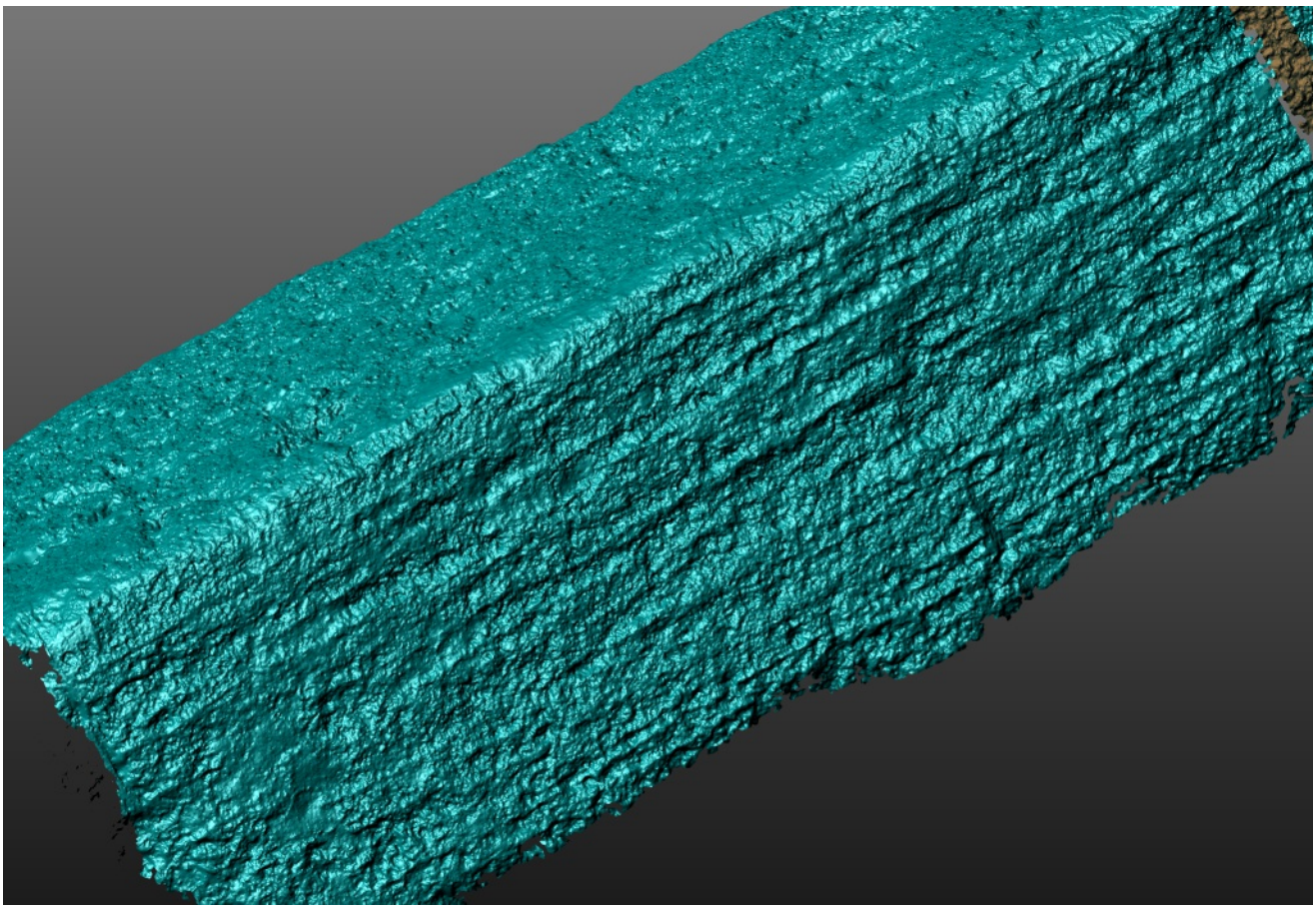

Fig. 7 - The 3D model emphasises the different type of workmanship by virtually moving the light (processing E. Faresin-A. Zara)

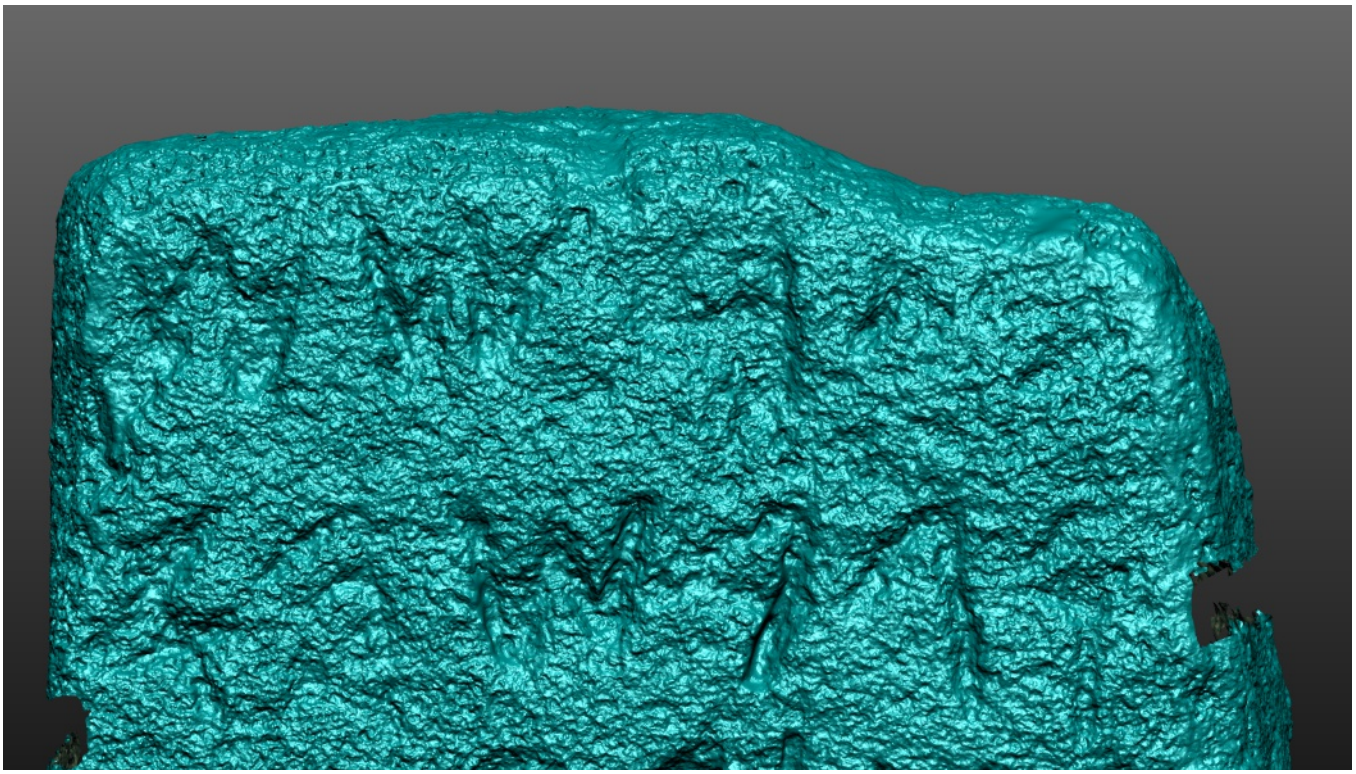

Fig. 8 - Fracture detail on the top of the stele, front view (processing E. Faresin-A. Zara)

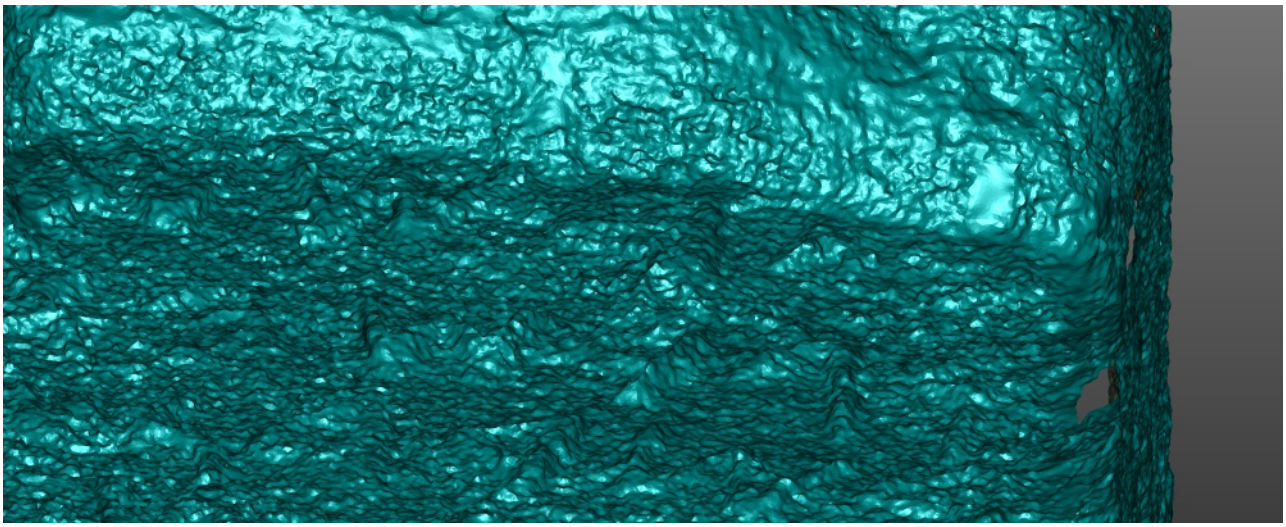

Fig. 9 - Fracture detail on the top edge of the stele, front view (processing E. Faresin-A. Zara)

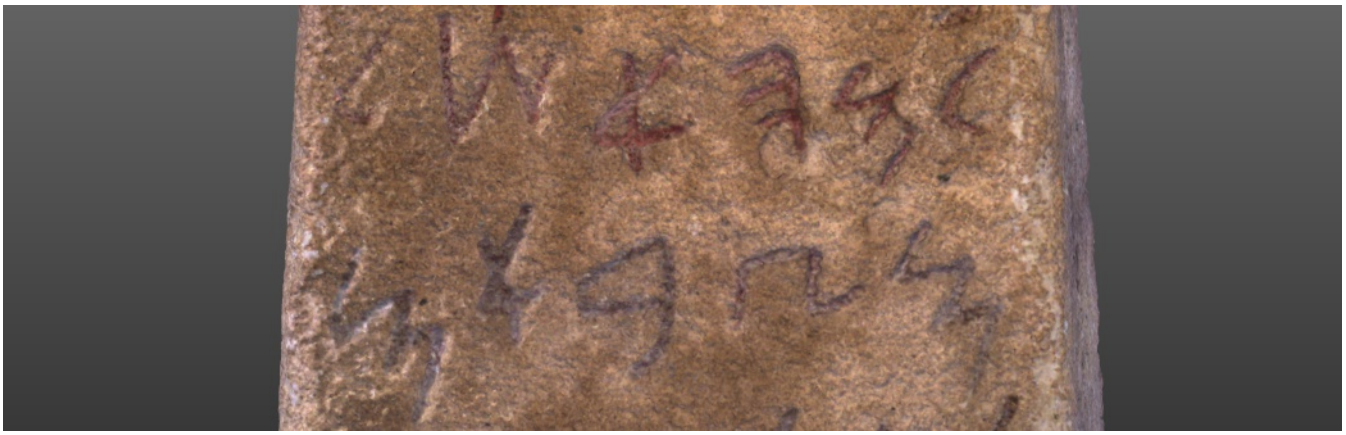

Fig. 10 - Lines 4-5 of Nora Stele: the line 4 (on the top) shows the 'rubrication', while the bluish line 5 (on the bottom) shows the attempt to erase the red colour (processing E. Faresin-A.Zara)

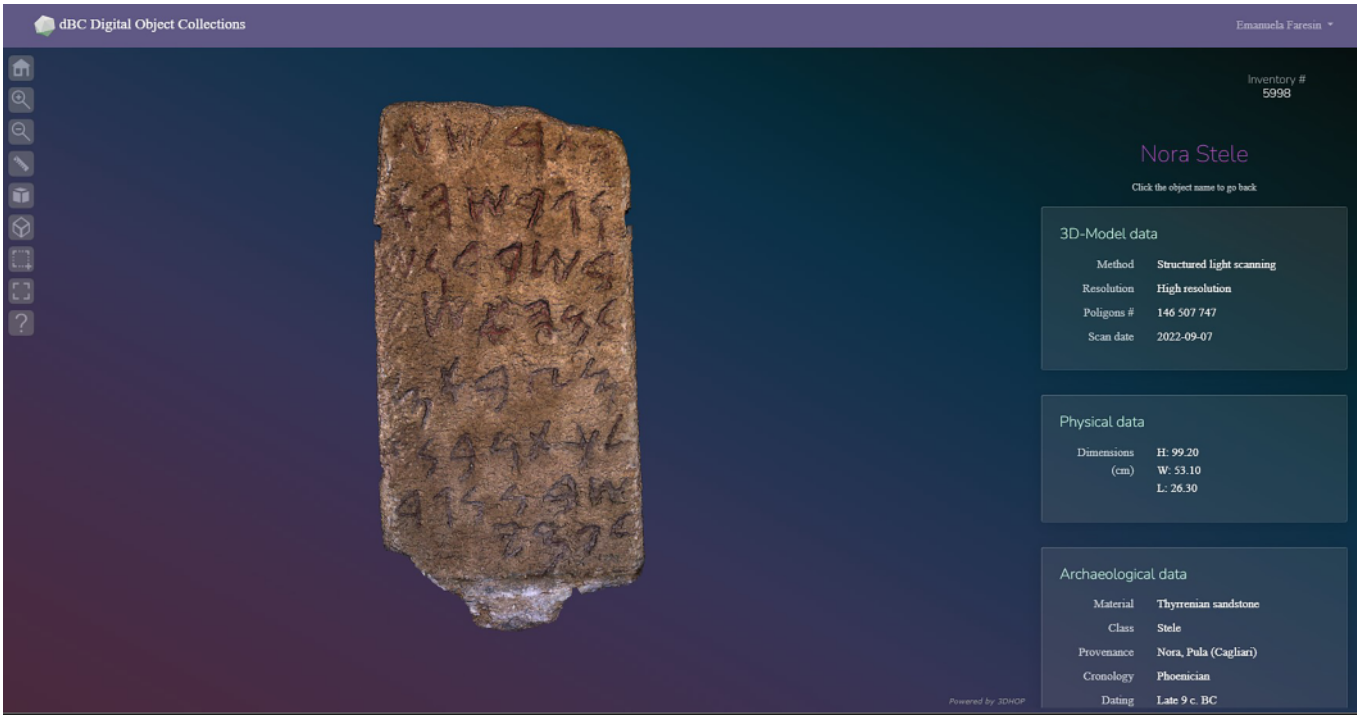

Fig. 11 - Interface of the dBC Digital Object Collections webapp: 3D Model, historical and technical data of Nora Stele (processing M. Tognon-E. Faresin-A.Zara)