Archeologia e Calcolatori
35.2, 2024, 225-234
doi 10.19282/ac.35.2.2024.24

DATA EXTRACTION FROM 3D SCANNING: POST-PROCESSING FILTERING FOR ANALYTIC AND INFORMATIVE MODELS OF SMALL ARCHAEOLOGICAL FINDS

1. Introduction

This work, as part of the ITSERR Resilience European Project, has two aims: the semantic data extraction from 3D scanning of specific Near East archaeological artefacts; the qualitative evaluation of a specific 3D scanner, Artec Space Spider sensor (https://www.artec3d.com/), applied to small archaeological finds. This structured-light sensor, being portable and versatile, has been successfully tested in the archaeological domain as reported by other studies (Göldner *et al.* 2022; Marić *et al.* 2022; Diara 2023).

Over the years, the 3D digitization and analysis process related to cuneiform tablets had a great impact in the Near East research, allowing new detailed studies on writing methodology, semantics as well as prosopography (Cohen *et al.* 2004; Kotoula *et al.* 2017). In this work, the main dataset is related to cuneiform tablets as well as stone cylindric seals related to the third dynasty of Ur (2100-2000 BC). The here proposed archaeological dataset is related to important documents not only for the cuneiform text (administrative content), but also for other particular features and details extractable from objects surfaces: nearly visible details are related to sealing impression (behind the text) as well as biometric data (fingerprint evidence). For this reason, structured-light scanning coupled with post-processing analyses (filtering and shading manipulation) provides a deeper and detailed investigation on micrometric features, for improving research possibilities.

Filtering processes are referred to Multi-Scale Integral Invariant (MSII) filter improved with the ImageJ refinement related to math processes and image levels adjustments on MSII output (Mara *et al.* 2010). In this work, the incredible potential of this post-processing operation will be shown related to the figurative apparatus of sealing impressions as well as for highlighting details of scribe fingerprint on the humid clay.

The same 3D scanning workflow has been applied for a small cylindric seal and its plaster mould for investigating the depth of the figurative apparatus through a deviation analysis: at the same time, this archaeological stone artefact has been considered for its dimensions, 2.7 cm height and 1.3 cm diameter, especially for testing and evaluating the scanning behaviour of the Space Spider sensor with very small objects: this sensor was mainly designed for scanning objects bigger than 4 cm, up to medium dimension objects (depending on scans numbers and overlapping). Detailed 3D scanning and post-processing analyses unlock new frontiers in extracting and investigating important semantic data from archaeological finds, fundamental for expanding and updating research study on tangible and intangible Heritage assets, as well as visible and nearly visible features. Extracted data, in addition to 3D models and general semantic information of this dataset, need to be stored in an open access Common Data Environment (CDE) for helping data-exchange and dissemination (Fisseler *et al.* 2017).

2. Methodology

The methodology behind this research is based on 3D scanning through structured-light sensors. Over the years, this scanning methodology proved to be, along with photogrammetry, the best solution for 3D documenting archaeological finds. Different research demonstrated its reliability (Schild *et al.* 2022; Diara 2023). In fact, the grid pattern light typical of these sensors is able to hit and register complex surfaces: the trigonometric triangulation occurred between the light source, the camera and the surveyed object allow to record the incidence angle (α) as well as distances.

2.1 *Artec Space Spider*

For this research project, Artec Space Spider (SS) scanner was tested for 3D digitizing Near East clay artefacts, performing evaluation analysis on its sensors (light emitter and camera) as well as post-processing investigations on related outputs. It is a portable (handheld) optical scanner that uses blue light designed for acquiring features, sharp edges, and complex surfaces on small and medium-sized objects. Having 0.05 mm of 3D point accuracy (capturing phase) and 0.1 mm of final 3D model resolution, SS is incredible precise and reliable instrument for documenting complex and detailed archaeological artefacts. Other specifications of the structured-light sensor are reported in Tab. 1. The SS sensor works in parallel, through a USB connection, with the monitor feedback from Artec Studio software. In fact, this feedback revealed necessary in order to reduce the drift error caused by incorrect distances or angles of the operator as well as for referencing the scanning trajectory.

Despite its extreme portability and compactness, the SS scanner presents some operational issues, especially related to the acquisition area: in fact, in complex and small spaces the scanning process and movement could be risky especially due to wired connections and the visual feedback on the laptop screen. Capturing archaeological artefacts in limited spaces (horizontal and vertical) may take longer than expected as well as additional safety precautions. The physical environment may affect the SS scanning operation. Global and punctual illumination can change the overall precision and quality of 3D outputs. At the same time, temperature is a critical parameter to be consider

3D point accuracy	0.05 mm
3D resolution	0.1 mm
Angular Field of View	30°×21°
Linear Field of View (min)	90×70 mm
Working distance	0.2-03 m
Linear Field of View (max)	180 140 mm
Texture resolution	1.3mp
Acquisition speed	1 mln points / s
Reconstruction rate	7.5 fps (up to)

Tab. 1 – Space Spider structured-light sensor specifications.

before the scanning operations: the suggested target is 37° degree in order to reach the maximum operative behaviour of SS.

3. Documentation and analysis

3.1 *Cuneiform tablet - MAT 477*

The Sumerian administrative document, referred to the MAT 477 tablet, was surveyed and 3D digitised to analyse the sealing methodology beneath the cuneiform text. This archaeological artefact (45×42×17mm) comes from Tell Jokha, Umma, in Iraq and it is related to the third dynasty of Ur (2100-2000 BC). It shows a massive pre-sealing process (Akalla scribe), in the verse and obverse, stratigraphically below the text. The visible figurative apparatus is related to a seated figure (on a decorated throne) with a cup in a hand and a small headwear. Above the cup, a rising sun is visible. The scanning procedure (two scans) returned 2,032 acquired frames having a deviation error of 0.1 mm (RMSe).

The 3D reconstruction process returned a highly detailed and populated polygonal mesh (triangles): approximately 7 million polygons having 0.1mm of resolution. Digital light manipulation, inside the Artec Studio software, initially helped the identification of multiple sealing processes, then the application of ambient occlusion and radiance scaling filters have contributed to a more detailed comprehension of the figurative apparatus. However, through the Multi-Scale Integral Invariant filter (MSII), via GigaMesh software (Mara 2010; Homburg *et al.* 2022) details of the sealing impression were enhanced, becoming more readable (Fig. 1). MSII analysis was performed without the texture layer, also because the latter often does not allow to observe depth and micrometric details.

This analysis, managing 'feature vector elements' and colour ramp, revealed the sealing methodology: the cylindric seal was partially rolled and/or just impressed to provide visibility to the written legend and the seated figure

Fig. 1 – Cuneiform tablet MAT 477: a) photo; b) 3D model and custom lights; c) MSII analysis.

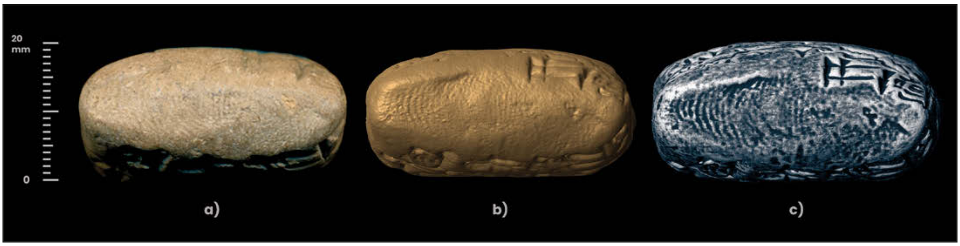

Fig. 2 – Cuneiform tablet MAT 655: a) photo; b) 3D model and custom lights; c) MSII analysis.

on the throne (the governor). For each tablet face the sealing is repeated and overlaid five times and, via filtering analysis, the micro-stratigraphic analysis among sealing impressions can be performed (Fig. 1).

3.2 *Cuneiform tablet - MAT 655*

The MSII process was also fundamental for extracting biometric data from a surface related to the MAT 655 tablet. In fact, the early analysis of the 3D model (0.1 mm resolution and 2.4 million polygons), coming from Ur III from Umma (Iraq), allowed us to detect a fingerprint impression on it. The scanning procedure (three scans) returned 1,911 acquired frames having a deviation error of 0.1 mm (RMSe). For this reason, a post-processing analysis on this feature has been planned to enhance and boost the detailed visibility of the impression, allowing precise measurements and future matching possibilities (Fig. 2). This micrometric evidence was analysed via MSII filter as well as through a deviation analysis. The former, as mentioned before, was carried out for extracting

3.3 *The cylindric seal and its mould – 70021*

The other analysed archaeological artefacts are a cylindrical stone seal, catalogued as 70021, and its plaster mould. They have been selected for their particular figurative apparatus (as described below, in the mould description) as well as for testing the SS behaviour with a very small object (the seal dimensions are 2.7×1.3cm). The scanning procedure (six scans) returned 2,185 acquired frames having a deviation error of 0.1 mm (RMSe). Despite the seal being damaged (lack of material on the sides of the main figure), the plaster mould shows the complete sealing apparatus composed of the written legend on four rows and two standing figures. The 3D scanning phase started by vertically placing the cylindric artefact, then, for a second scanning session it was placed leaning on the main surface (horizontally). In both situations, the SS scanner was held at 30° and 45° degrees from the incidence surfaces. Acquired data was enough to reconstruct the stone object in its entirety (0.1mm resolution and 580 thousand polygons).

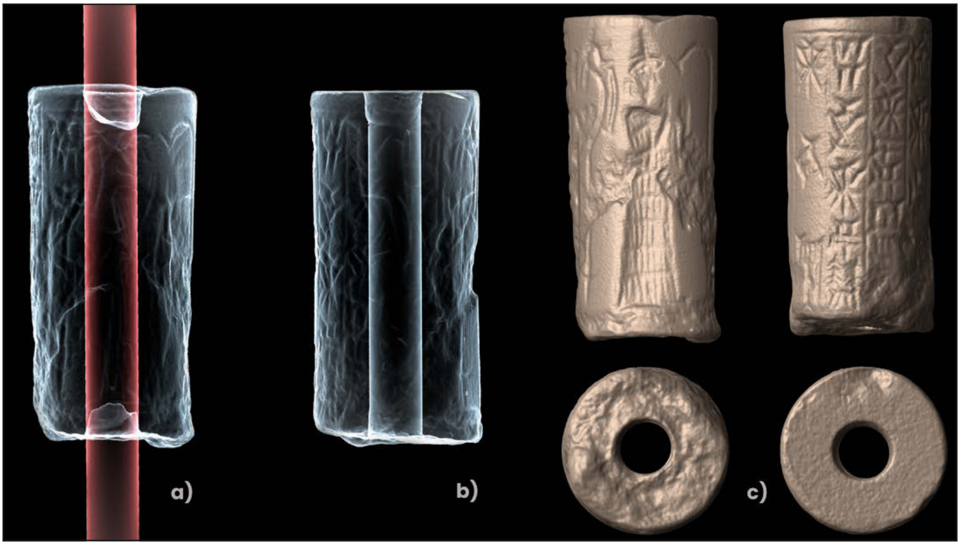

Fig. 3 – a) 3D model of the cylindric seal before Boolean operations; b-c) after Boolean operations.

However, after the final detailed surface fusion, the 3D model of the seal was at the centre of a parametric manipulation via boolean subtraction, in order to obtain the hole passing through both sides. This operation was designed because the scanner failed to reach this part: acquired data related to the hole were not enough for closing inner surfaces (Fig. 3). However, the obtained final model of the seal, despite its dimension, is detailed in the entire cylindric surface: the figurative apparatus as well as the textual legend are faithfully reproduced, allowing the reading of every cuneiform sign (avg. 4×4 mm space for each sign).

Musei Reali's curators have also produced a plaster mould of the entire seal impression: by rolling the seal, the figurative and written apparatus of the sealing measures 2.6×3.6 cm, with an approximate area of 9.36 cm^2: two figures are facing each other as in a meeting scene with sticks and banners. The scanning procedure (two scans) returned 1,267 acquired frames having a deviation error of 0.1 mm (Root mean square error - RMSe). It has been investigated through post-processing metric analyses for understanding the depths values of the decorative scene. For this reason, a deviation analysis was computed: a best fit plane was created for the background for calculating distances between it and figures and text. This computation reported a figures depth between 0.6 mm and 1.1 mm instead of writing depth that is between 0.25 mm and 0.9 mm, furthermore, the standard deviation is 0.6 mm and the RMSe is 0.25 mm (Fig. 4).

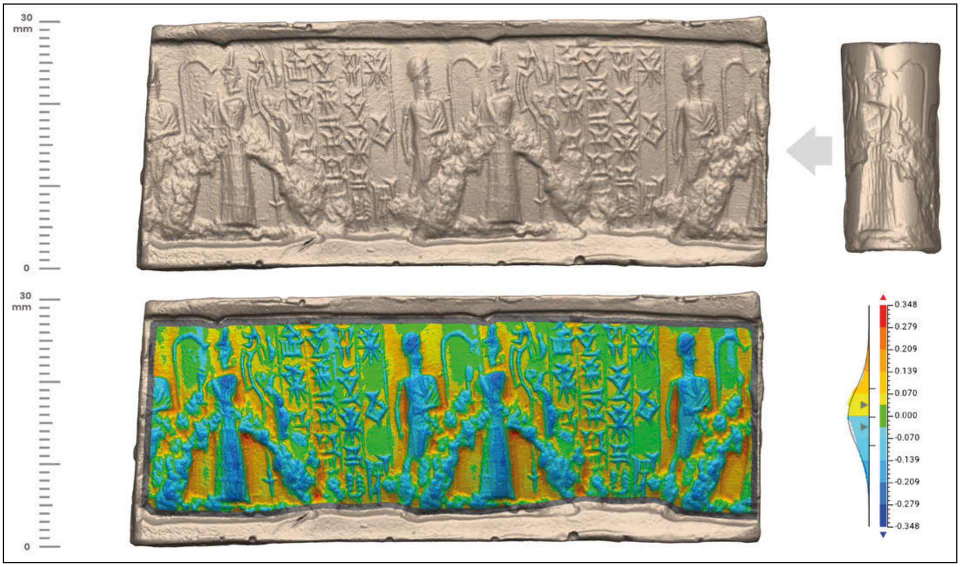

Fig. 4 – 3D model of the plaster mould and its deviation analysis.

4. Common data environment

This 3D and semantic dataset have been temporarily stored inside an ad-hoc online Common Data Environment (CDE) for unlocking smart data access and exchange. Project collaborators as well as common users can easily investigate the dataset via browser. In fact, it is a web environment, browser-based, developed by using JavaScript language and XEOKIT: the former is a well-known developing language while the latter is an open source programming toolkit for 3D scenes on WebGL. This smart environment is composed of three pages. In fact, in addition to the initial home page with the list of stored cuneiform tablets, it includes a split view on the 3D model of the selected artefact coupled with semantic metadata: besides historical and physical information, metadata also enclose particular features and semantic details coming from 3D analyses, such as fingerprints and sealings evidence (Fig. 5). In this way, the cuneiform tablet can be analyzed, in the same web page, as concerns semantic information as well as its volumetric entirety in the 3D scene.

Furthermore, this environment has been implemented by a fully immersive 3D inspector for investigating the 3D model more in detail. Inside it, the toolbox panel allows to pick and measure distances and angles in real-time directly on the model, then, it allows to manage the 3D view of the model

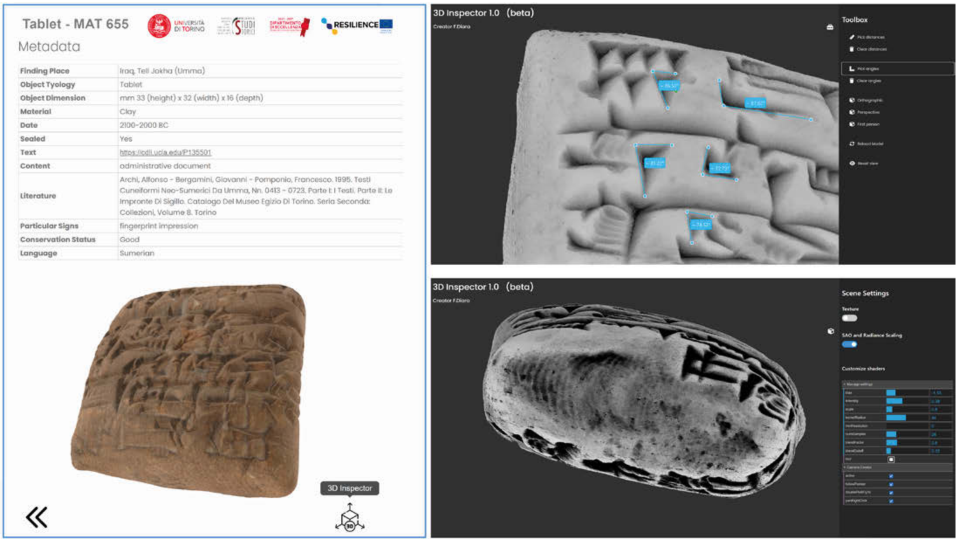

Fig. 5 – Draft version of the CDE designed for this project: on the left, the split view related to metadata and 3D model; on the right, the 3D Inspector functionalities.

(orthographic, perspective, first person). In addition to these features, the Scene Settings includes the texture toggle (switch on and off) for activating or deactivating the radiometric texture, useful for performing filtering and shading analyses. In this regard, the Scene Settings also include the smart handling of Scalable Ambient Occlusion (SAO) and radiance scaling filter for enhancing and micrometric details of surfaces on different layers (Fig. 5). Through this option, simplified post-processing analyses on the 3D model can be easily performed via browser (without hardware limitations). Functionalities and options can be added and removed from the source code depending on different access levels for different users. This open and smart environment, in addition to break down accessibility barriers, allows and helps analyses, revisions and data exchange related to specific archaeological artefacts. Besides, the here proposed dataset (3D models) and CDE source code have been published and stored in the repository Zenodo to guarantee full open access (Diara 2024a, 2024b).

5. Conclusions

The here presented 3D scanning allowed to quickly reproduce high-detailed digital archaeological artefacts for extracting additional and nearly visible data to be collected in a proper CDE. In this regard, informative and analytic models, through post-processing analyses, have been produced to help the overall interpretation on the production methodology of Near East archaeological artefacts: cuneiform tablets and seals. Space Spider sensors revealed accuracy, reaching 0.05 mm on the acquisition point on tablets and cylindric seal: as expected, the inner surfaces of the passing hole of the seal were not acquired correctly and then a Boolean operation was needed.

Through the post-processing analysis of the tablet MAT 477, the sealing process was investigated and better understood: despite the typical rolled procedure, the here presented tablet experienced a repeated partial impression of the seal. The scribe workshop (under specific directives) expressed the willingness to insert only the written legend and the governor figure. Moreover, the MSII filtering process detected impression micro stratigraphy: overlapping of figurative apparatus is noticeable. At the same time the fingerprint analysis, via measurements and cross-matching operations, unlocks new possibilities for studying people behind the archaeological object, allowing expanding analyses of past societies.

Filippo Diara
Dipartimento di Studi Storici
Università degli Studi di Torino
filippo.diara@unito.it

Acknowledgements

This work was supported by the PNRR (National Recovery and Resilience Plan) project Italian Strengthening of ESFRI RI Resilience (ITSERR) founded by the European Union, NextGenerationEU (CUP: B53C22001770006). The author would like to acknowledge the others ITSERR WP9 TAURUS members, in particular Stefano de Martino (WP9 reference and Full Professor in Anatolian Studies) and Francesco Giuseppe Barsacchi (Junior Assistant Professor in Anatolian Studies), for the review on the analyses of the presented dataset.

REFERENCES

Cohen J.D., Duncan D.D., Snyder D., Cooper J., Kumar S., Hahn D.V., Chen Y., Purnomo B., Graettinger J. 2004, *iClay: Digitizing cuneiform*, in *Proceedings of the IEEE Conference on Visual Analytics Science and Technology (VAST)* (https://doi.org/10.2312/VAST/VAST04/135-143).

Diara F. 2023, *Structured-light scanning and metrological analysis for archaeology: Quality assessment of Artec 3D solutions for cuneiform Tablets*, «Heritage», 6, 9, 6016-6034 (https://doi.org/10.3390/heritage6090317).

Diara F. 2024a, ITSERR - dataset_1, Zenodo (https://doi.org/10.5281/zenodo.10908664).

Diara F. 2024b, ITSERR - CDE, Zenodo (https://doi.org/10.5281/zenodo.10837436).

Fisseler D., Müller G.G.W., Weichert F. 2017, *Web-based scientific exploration and analysis of 3D scanned cuneiform datasets for collaborative research*, «Informatics», 4, 44 (https://doi.org/10.3390/informatics4040044).

Göldner D., Karakostis F.A., Falcucci A. 2022, *Practical and technical aspects for the 3D scanning of lithic artefacts using micro-computed tomography techniques and laser light scanners for subsequent geometric morphometric analysis. Introducing the StyroStone protocol*, «PLOS ONE», 17, e0267163 (https://doi.org/10.1371/journal.pone.0267163).

Homburg T., Zwick R., Mara H., Bruhn K.-C. 2022, *Annotated 3D-models of cuneiform tablets*, «Journal of Open Archaeological Data», 10, 1-8 (https://doi.org/10.5334/joad.92).

Kotoula E., Akoglu K.G., Frahm E., Simon S. 2017, *QR coded 3D prints of cuneiform tablets*, «International Journal of Art, Culture, Design and Technologies», 6, 1-11 (https://doi.org/10.4018/ijacdt.2017070101).

Mara S.H., Krömker S., Breuckmann J.-B. 2010, *GigaMesh & Gilgamesh: 3D multiscale integral invariant cuneiform character extraction*, in *Proceedings of the VAST: International Symposium on Virtual Reality, Archaeology and Intelligent Cultural Heritage, The Eurographics Association (Paris 2010)* (https://doi.org/10.2312/VAST/VAST10/131-138).

Marić I., Šiljeg A., Domazetović F. 2022, *Precision assessment of Artec Space Spider 3D handheld scanner for quantifying tufa formation dynamics on small Limestone Plates (PLs)*, in *Proceedings of the 8th International Conference on Geographical Information Systems Theory, Applications and Management GISTAM* 2022, Wien, SciTePress, 67-74 (https://doi.org/10.5220/0010886900003185).

Schild L., Sasse F., Kaiser J.-P., Lanza G. 2022, *Assessing the optical configuration of a structured light scanner in metrological use*, «Measurement Science and Technology», 33, 085018 (https://doi.org/10.1088/1361-6501/ac6e2f).

ABSTRACT

Actual 3D scanners based on the structured-light principle are opening to possibilities for creating detailed models (polygon populations) with micrometric resolutions. Consequently,

highly detailed models allow specific investigations. This work focuses on 3D scanning and post-processing analysis/filtering of Ancient Near East finds, especially seals and cuneiform clay tablets, fragile artefacts that can hold a lot of semantic information beyond transliteration: e.g. seal impressions (figurative and textual sealings), fingerprint evidence, retracing and erased text. Behind the ease of use of portable structured-light scanners, hides the enormous potential for feature extraction and processing. Metric analysis (e.g. deviation analysis) coupled with the application of MSII (Multi-Scale Integral Invariant) filter enhance data extraction, changing the overall perception on details of the archaeological artefact.