applied sciences

MDPI

Article

Moving beyond the Content: 3D Scanning and Post-Processing Analysis of the Cuneiform Tablets of the Turin Collection

Filippo Diara *, Francesco Giuseppe Barsacchi and Stefano de Martino

Historical Studies Department, University of Turin, Via Sant'Ottavio 20, 10124 Torino, Italy; francescogiuseppe.barsacchi@unito.it (F.G.B.); stefano.demartino@unito.it (S.d.M.)

* Correspondence: filippo.diara@unito.it

Abstract: This work and manuscript focus on how 3D scanning methodologies and post-processing analyses may help us to gain a deeper investigation of cuneiform tablets beyond the written content. The dataset proposed herein is a key part of the archaeological collection preserved in the Musei Reali of Turin in Italy; these archaeological artefacts enclose further important semantic information extractable through detailed 3D documentation and 3D model filtering. In fact, this scanning process is a fundamental tool for better reading of sealing impressions beneath the cuneiform text, as well as for understanding micrometric evidence of the fingerprints of scribes. Most of the seal impressions were made before the writing (like a watermark), and thus, they are not detectable to the naked eye due to cuneiform signs above them as well as the state of preservation. In this regard, 3D scanning and post-processing analysis could help in the analysis of these nearly invisible features impressed on tablets. For this reason, this work is also based on how 3D analyses may support the identification of the unperceived and almost invisible features concealed in clay tablets. Analysis of fingerprints and the depths of the signs can tell us about the worker's strategies and the people beyond the artefacts. Three-dimensional models generated inside the Artec 3D ecosystem via Space Spider scanner and Artec Studio software were further investigated by applying specific filters and shaders. Digital light manipulation can reveal, through the dynamic displacement of light and shadows, particular details that can be deeply analysed with specific post-processing operations: for example, the MSII (multi-scale integral invariant) filter is a powerful tool exploited for revealing hidden and unperceived features such as fingerprints and sealing impressions (stratigraphically below cuneiform signs). Finally, the collected data will be handled twofold: in an open-access repository and through a common data environment (CDE) to aid in the data exchange process for project collaborators and common users.

Keywords: 3D scanning; cuneiform tablets; digital imaging; fingerprints; MSII; sealings

check for updates

Citation: Diara, F.; Barsacchi, F.G.; de Martino, S. Moving beyond the Content: 3D Scanning and Post-Processing Analysis of the Cuneiform Tablets of the Turin Collection. *Appl. Sci.* **2024**, *14*, 4492. https://doi.org/10.3390/app14114492

Academic Editors: Marek Milosz and Jacek Kęsik

Received: 8 May 2024
Revised: 18 May 2024
Accepted: 23 May 2024
Published: 24 May 2024

1. Introduction

1.1. Cuneiform Tablets Documentation

Clay tablets are a writing medium that first appeared in Mesopotamia in the last centuries of the fourth millennium BCE. Although clay might seem to be an inconvenient material for writing, clay tablets remained in use for more than three thousand years and were adopted by state chanceries, administrative structures, and private people in a wide geographical area that includes Mesopotamia, Iran, Syria, the Levant, Turkey, Greece, and Egypt.

In Western Asia and in Egypt, cuneiform characters were impressed in clay by means of a stylus. The dimension, format, and layout of cuneiform tablets varied according to scribal conventions, time, place, and the purpose of the written text. Cuneiform tablets were produced in both rectangular and square formats; they range in size from as little as 3 cm × 3 cm to as large as 40 cm × 25 cm. All tablets have a convex form, and some of them are shaped like pillows. After forming a tablet from damp clay and smoothing the surface, scribes could write on one or both sides of the tablet as well as on the edges. When the writing process was completed, clay tablets were either dried in the sun or baked [1].

The scientific publication of cuneiform tablets has evolved over time, in step with the available technology. In the nineteenth century, cuneiform tablets were published in the form of hand-drawn copies. Epigraphists copied the tablets either at the sites where they were found or in the museums where they were preserved. Although these hand copies were made by experts, they incorporated a high degree of subjectivity depending on what the individual copyist saw on the tablet—especially when the surface of the tablet was damaged and the intricate cuneiform signs were only partially preserved, as was often the case. Scholars had to interpret the traces visible on the tablet, and sometimes they overinterpreted what they saw.

The development of photography offered the possibility of a more objective representation of the written surfaces of clay tablets. Although photography had been invented in the 1820s, it was not commonly used for commercial and artistic purposes until the second half of the nineteenth century. We are indebted to the photographer Roger Fenton (1819–1869) for the first photographs of cuneiform tablets. Fenton founded the Photographic Society, later called the Royal Photographic Society, in 1853. In the following year, he was appointed as the first official photographer of the British Museum in London and immediately started taking pictures of the tablets in the rich collection [2].

Until recently, hand copies and analogue (film-based) photographs remained the only available visual media for recording and studying cuneiform tablets. Today, with the aid of computers and digital photography, several scientific institutions have created data sets of cuneiform tablets. For example, the Cuneiform Digital Library Initiative (CDLI), founded by Robert Englund at University of California, Los Angeles (UCLA), aims to preserve digital images of cuneiform documents in public museums and private collections available on the internet. About 350,000 cuneiform tablets are currently accessible on the CDLI web site [3].

This rich collection of tablets in the form of digital images and data is a very useful tool for researchers. A major drawback of two-dimensional analogue photography is the difficulty of accurately recording cuneiform signs on the surface of curved tablets, which can be inscribed on all six sides. Digital photography and photogrammetry capture 3D images of tablets, eliminating human error on the part of copyists and allowing accurate paleographic studies.

The CDLI team, in collaboration with the Max Plank Institute, has begun scanning cuneiform tablets with a smart scanner produced by Breuckmann [3,4]. Museums around the world are tackling the digitalization of cuneiform tablets using different techniques and instruments [5–7]. For example, a team at the Vorderasiatisches Museum that is working together with researchers from the University of Münster has started scanning the large collection of cuneiform tablets from Babylon, which is preserved in Berlin. They use a reflectance transformation imaging (RTI) dome that is equipped with 64 LED lamps. The captured 3D images are of high quality, but the instrumentation is bulky and not transportable [8].

1.2. Cuneiform Tablets 3D Scanning and Analysis

This research project Italian Strengthening of ESFRI RI Resilience (ITSERR) [9,10], inscribed into the bigger European programme REligious Studies Infrastructure: tooLs, Innovation, Experts, conNections and Centres in Europe (RESILIENCE) in the framework of European Strategy Forum on Research Infrastructures (ESFRI), focuses on 3D documentation of Near East archaeological artefacts: cuneiform tablets, cylindric seals, bullae, and limestone reliefs. In particular, this work is related to the documentation of an analysis of clay tablets, especially for performing metrological analyses and extracting important metadata (related to tablet production and the humans behind the objects). Post-processing analyses (filters and shader application) will be performed on highly detailed 3D models for the purpose of boosting and investigating nearly-visible details on clay surfaces. Then, these data become fundamental for dedicated open-access repositories for data-sharing: the creation of common data environments (CDEs) for generating Digital Informative Twins will spread the knowledge sphere of these important archaeological artefacts. The schematic workflow is described into Figure 1.

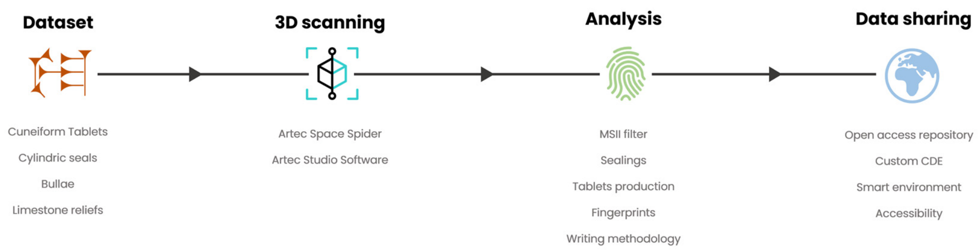

Figure 1. Schematic workflow of the project related to the 3D documentation and analysis of Near East archaeological artefacts.

Furthermore, this project is based on the evaluation of portable 3D scanners for documenting cuneiform tablets, seals, and sealings. Portable scanners can easily be transported to museums or excavation sites to record artefacts.

Our testing began with scanning the cuneiform tablets preserved in Turin at the Musei Reali (Figure 2), and we are grateful to Elisa Panero, Curator of the Archaeological Collection, for her continuous support. This collection of cuneiform tablets, the largest one in Italy, contains more than 650 documents.

Figure 2. Cuneiform tablet collection, Archaeological Gallery (Musei Reali of Turin—Italy).

All of the tablets have already been edited, transliterated, and translated [11,12]. Analogue photographs of the tablets, along with metadata, are presently available on the web site of the museum, but 3D images capture more detail, enabling a better comprehension of the content of the tablets as well as opening up opportunities for further research, as we will explain later.

The majority of the Turin cuneiform tablets come from the site of Umma in southern Mesopotamia and date back to the last century of the third millennium BCE. They are administrative texts that were issued by officials in the kingdom of the Third Dynasty of Ur.

We have started scanning a group of tablets distinguished by a peculiar feature: all were impressed with seals on one or both sides before they were inscribed [13]. This practice of pre-sealing documents, which was quite common at the time of the Third Dynasty of Ur, had a purpose different from that of sealing a tablet after the scribe had written on it.

A seal impression placed on a tablet that had already been written upon authenticated the content of the document and the identity of its issuer. The practice of sealing a tablet before inscribing it, on the other hand, is in some way comparable to the modern use of letterheads [14].

2. Materials and Methods

In order to perform smart and flexible 3D scans, we adopted the Space Spider scanner from Artec 3D (Luxembourg) [15] (Figure 3). This instrument, a portable handheld scanner, uses a structured-light scanning methodology to record patterns of light deformed by the scanned object. When a beam of structured light strikes the artefact, it is reflected back to the instrument at different angles and dimensions, enabling the scanner to determine the object's morphology [16–18] The Space Spider scanner was chosen not only for its portability, but also for its technical specifications: the 3D point accuracy is 0.05 mm, while the declared 3D resolution of the final output is 0.1 mm. Furthermore, the scanner has a camera sensor onboard (1.3 megapixels) for capturing RGB radiometric values. The scanner's ability to capture these data with accuracy, as well as its flexibility, make the Space Spider one of the best solutions for the 3D documentation of archaeological artefacts, including clay tablets [18].

Figure 3. Artec 3D Space Spider structured-light scanner.

2.1. The Cuneiform Sealed Tablet MAT 689

Tablet MAT 689 preserves an administrative document written in the Sumerian language. This tablet, despite its small format (51 mm × 46 mm), was pre-sealed on its entire surface, including the edges (Figure 4). Seal impressions are not always visible to the naked eye and can be seen more clearly in scanned images.

The seal used to make the impressions belonged to the scribe Lu-Haya, who was a member of one of the most distinguished families in the city of Umma. Lu-Haya used several different seals that are documented on multiple tablets from Umma, as reported by Myr 2005 (An updated version of Mayr's PhD dissertation, The Seal Impressions of the Garšana and the Umma Archives, will appear in the series CUSAS (vol. 7) in 2024. Publication is in progress).

Figure 4. Cuneiform sealed tablet MAT 689. Images from the CDLI database. In the figure, verse and obverse were rotated in order to visualize the seal impression correctly.

This tablet was scanned with the Space Spider twice, and a total of 2752 frames were captured. The reconstruction process, via Artec Studio software (version 18.0), returned a 3D model containing approximately 3.6M polygons: fusion processing was set to a 0.08 mm maximum resolution and a 0.16 mm maximum error threshold (Figure 5). Next, the RGB texture layer was computed. By using Artec Studio, the 3D object could be visualized and initially analysed by manually manipulating digital lights. In fact, horizontal and azimuthal light beams can be toggled and manipulated depending on the details to be highlighted. In this way, the individual who analyses the 3D tablet is able to concentrate grazing lights and shadows to enhance micrometric details. Thus, the early analysis of sealings can be performed by changing light directions. The text and figurative scenes on the underlying seal impressions can be better visualized as well.

Figure 5. Three-dimensional model of the cuneiform sealed tablet MAT 689. (**A**) Textured model; (**B**) scan colour model.

2.2. The Cuneiform Tablet MAT655

Another administrative Sumerian tablet from Umma, MAT 655, is of particular interest because the 3D scanning operation revealed the fingerprints of the scribe who fashioned the tablet from clay (Figure 6).

Figure 6. Cuneiform tablet MAT 655. Images from the CDLI database.

This tablet was documented by six 3D scans, collecting 3066 frames in total. The final 3D model, with a resolution of 0.1 mm, contained approximately 3.6M polygons. The fusion process was set to a 0.08 mm maximum resolution and a 0.16 mm maximum error threshold. The 3D reconstruction process yielded a high level of detail according to the tablet's dimensions (height, 33 mm; width, 32 mm; depth, 16 mm) and the polygon density ratio. The distinguishing feature of this tablet, the nearly invisible fingerprint, required more transversal scans to capture all the details.

The manually virtual light manipulation using Artec Studio software assisted in the initial detection of surface features; the grooves of the fingerprint were enhanced by switching lights and shadows (Figure 7). Using the measurement tool, the surface area of the fingerprint was computed to be approximately 110 mm^2.

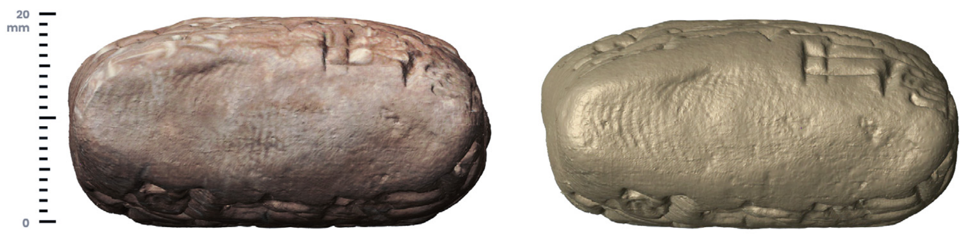

Figure 7. Tablet MAT 655: textured 3D model on the left; scan colour with manipulated light on the right.

2.3. The Envelope Tablet—MAT 740

The Turin collection also preserves some tablets from Mesopotamian sites other than Umma, as well as from other periods. We tested the capabilities of the Spider scanner on an Old Babylonian tablet of unknown provenance that documents a legal act. This tablet, catalogued as MAT 740, is of particular interest because its clay envelope is also preserved (Figure 8).

The clay envelope, which is broken into three pieces, was documented in 3D by 3 separate scans, one for each piece. The reassembled clay envelope measures 87 mm (height) × 55 mm (width), while the inner tablet measures 64 mm (height) × 43 mm (width). A fourth scan session was dedicated to the entire reassembled envelope as an oriented and aligned unique piece to which single scans could be matched. In total, 10,300 frames were collected, and we obtained 3 highly detailed and oriented scans: 2 related to the clay envelope and 1 related to the inner tablet. The entire 3D model of the administrative document contains approximately 23M triangles. Fusion processing was set to a 0.08 mm maximum resolution and a 0.16 mm maximum error threshold (Figure 9).

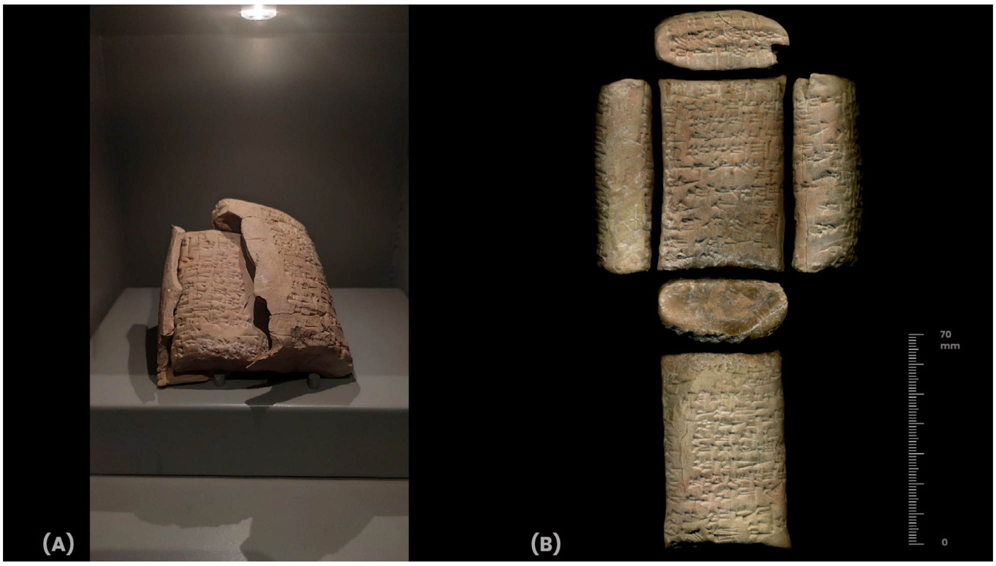

Figure 8. The envelope tablet MAT 740: (**A**) picture from the archaeological exhibition; (**B**) images of the internal tablet from the CDLI database.

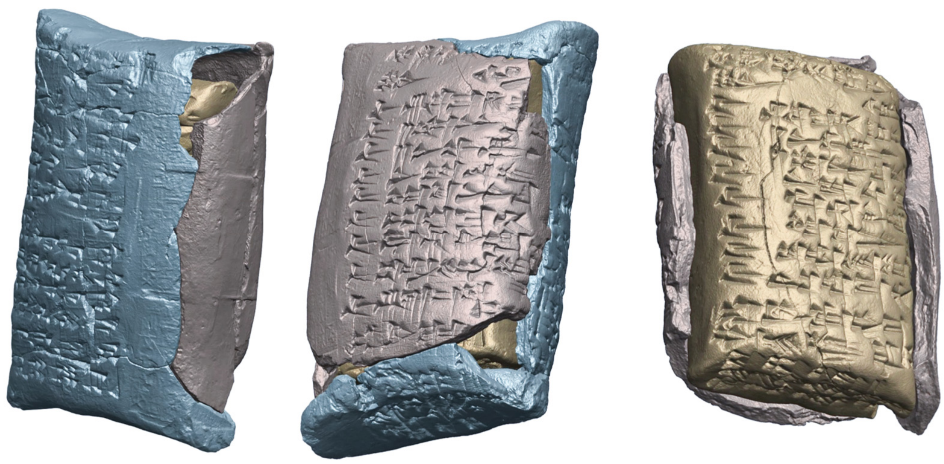

Figure 9. The envelope tablet MAT 740: 3D model of the entire envelope (external tablet) and a particular model of the internal one.

2.4. Post-Processing Filtering

Three-dimensionally documented clay tablets were deeply analysed using post-processing operations based on image computation. In fact, the multi-scale integral invariant filter (MSII) was adopted to extract micro-surface details on polygonal meshes. This filter, implemented inside the open-source software GigaMesh (version 240221) [19–21], enhances the micrometric details and features of 3D models, distinguishing different surface depths and layers.

The obtained 3D models were detailed, including the texture layer, and further analyses were performed during filtering operations using GigaMesh. Although the texture conformed to reality, as is detailed later, filtering and shading operations were carried out without the texture layer because these post-processing computations consider only metric and morphologic features and not RGB colours, which may introduce confusion and prevent an accurate analysis.

The cuneiform tablets presented herein were analysed using an MSII filter with changing parameters depending on surface depths: for example, feature vector element (FVE) parameters and colour ramp visualization were managed in different ways for the purpose of boosting the details of each tablet.

3. Results

Concerning the cuneiform tablet MAT 689, the MSII filter was adopted in two ways: first with 13 feature vector elements (FVEs) and an inverted colour ramp, and then with 5 feature vector elements and a normal colour ramp (Figure 10).

Figure 10. Three-dimensional model of tablet MAT 689: (**a**) scan colour; (**b**) MSII FVEs 13 inverted; (**c**) MSII FVEs 5 normal.

Through this process, the seal impressions in the background could be visualized in different ways by enhancing details on the surface layers. This analysis, via MSII filter, was fundamental for enhancing and revealing unperceived features that lay below the inscribed cuneiform signs. Other filtering processes, such as ambient occlusion and radiance scaling, did not permit such a detailed analysis of the sealings.

Although the sealings on the obverse and reverse were previously visualized and documented by Giovanni Bergamini [12], our post-processing analysis revealed an additional complete seal impression on the edge of the tablet. Bergamini was probably unable to see and analyse this important detail revealed by the MSII filter, and his drawing of the figurative apparatus of the sealing lacks the details on the edge. The analysis proposed herein constitutes an updated and integrative version of the Bergamini drawing (Figure 10).

Post-processing work allows for a clearer reading of the scene engraved on the Lu-Haya seal that was impressed on the tablet MAT 689. A god sits on a two-niched throne, and the god's raised left arm and an astral symbol, undetectable by the naked eye, are now visible. In addition, the post-processed images clearly show that the figure on the left, who is being introduced to the god, is raising both of his arms (Figure 11).

The clay tablet MAT 655 underwent the same post-processing analysis. Filtering the 3D model recovered all micrometric details from surfaces. In fact, the MSII filter was fundamental for boosting the fingerprint grooves and providing a clear vision of all the evidence (Figure 12). This post-processing analysis was designed to set up the MSII 3 feature vector and 13 FVEs. During this analysis, the fingerprint grooves were measured: the average distance between grooves was 0.7 mm, while the depth of a single groove was 0.09 mm.

Figure 11. Three-dimensional model of the tablet MAT 689 and sealing analysis: comparison of the original Bergamini drawing and the version obtained via MSII analysis.

Figure 12. Tablet MAT 655: fingerprint evidence on 3D model acquired via MSII filter (feature vector 3; feature vector elements 13).

The image of the scribe's fingerprint provides a wider perspective on the life of the tablet and establishes a connection with the humans who made these objects. Scanning the entire corpus of the Turin tablets for fingerprints will aid us in distinguishing between the individual scribes who wrote the tablets, even when their names are not recorded in the texts.

As with the tablets analysed previously, the features of the envelope (MAT 740) were first investigated using the light manipulation tool to identify seal impressions and fingerprints, which were enhanced during the MSII analyses. The MSII filter for extracting surface contour features of impressions based on different depth levels was used.

The MSII process, using various analyses of feature vector elements, was fundamental for detecting fingerprint evidence on the edge of the inner tablet—a distinctive feature related to the scribe who made the envelope (Figure 13). The interior of the envelope shows traces in negative form of the signs written on the outside of the envelope, as well as chaotic fingerprint impressions (Figure 14).

Figure 13. The envelope tablet MAT 740 and the extracted fingerprint (yellow circle): internal tablet. (**a**) MSII filter FVEs 3 normal; (**b**) MSII filter FVEs 3 inverted; (**c**) MSII filter FVEs 13 inverted.

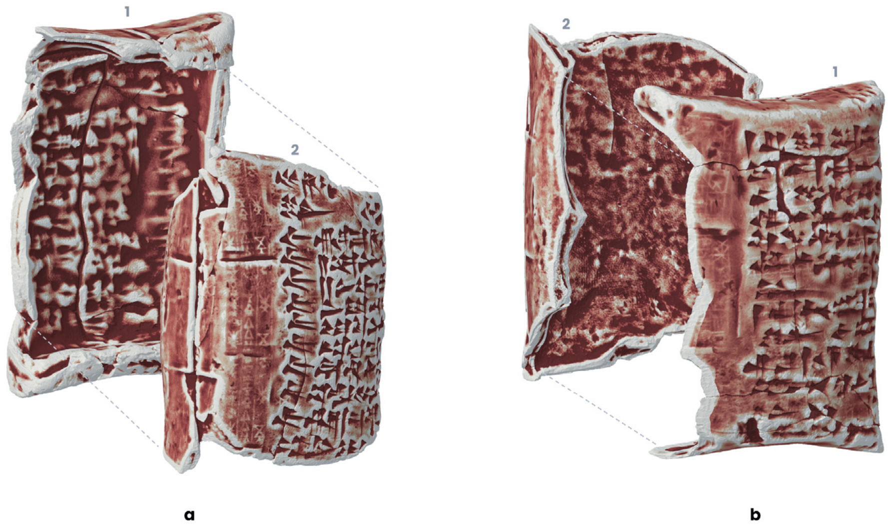

Figure 14. The envelope tablet MAT 740: (**a**) external tablet (side 1) and details of the sealing as well as negative impressions of cuneiform signs; (**b**) external tablet (side 2) and details of the sealing along with chaotic fingerprint impressions.

Metric Evaluation of Space Spider Sensor

Another goal of the WP9 project is related to the metric evaluation of structured-light sensors for the 3D documentation of Near East artefacts. The Space Spider sensor, with a 3D point accuracy of 0.05 mm, is able to reach the deepest angles of cuneiform writing and to perceive the micrometric thickness of seal impressions. In this way, micro details on clay surfaces are properly recorded. For this reason, this structured-light sensor has proven to be one of the best 3D scanners for documenting small- and medium-sized archaeological finds [22–24].

The acquired scans were cleaned by removing frames with deviation errors higher than 0.1 mm (root mean square error—RMSe). Despite the fact that declared and suggested 3D output resolution is 0.1 mm, during the scans, the fusion step can be pushed further to obtain more polygonal density and surface details. However, pushing the declared 0.1 mm resolution too much can sometimes be useless, and the process may create 3D surfaces with artefacts and anomalies.

We tested the fusion process at 0.08 mm with a max threshold error of 0.16 mm, and the three archaeological examples presented herein experienced no anomalies and the surfaces were correctly represented. We also captured more details (Figure 15).

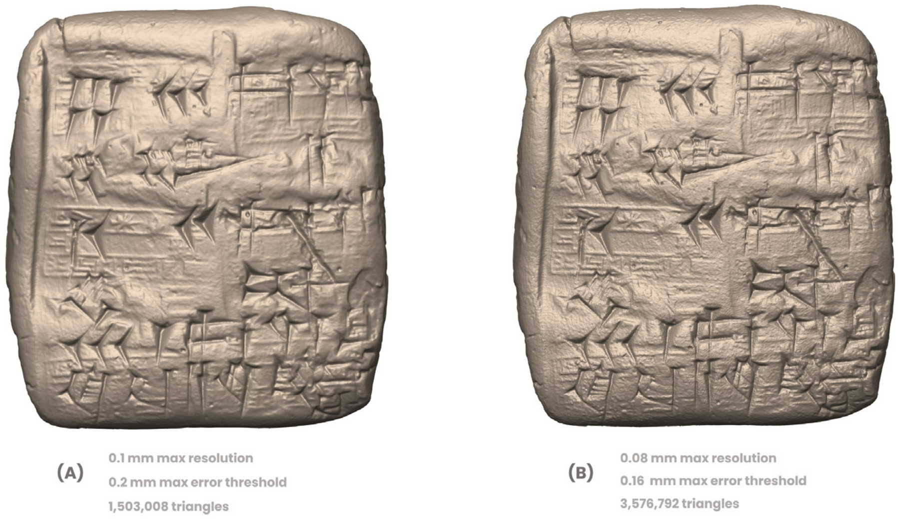

Figure 15. Cuneiform tablet MAT 689. Comparison of 3D models: (**A**) scans fusion set at 0.1 mm max resolution and 0.2 mm max error threshold; (**B**) scans fusion set at 0.08 mm max resolution and 0.16 mm max error threshold.

4. Open-Access Repository and CDE

All relevant information gathered during the scanning and post-processing phases will be collected in a database/open-access repository designed for this purpose.

Most of the data for the database represent two main typologies of objects: cuneiform tablets (and inscribed objects) and sealings. Given the contents of the tablet collection housed in the Musei Reali of Turin, we began compiling the dataset using information on the Sumerian cuneiform tablets from the Ur III period that were recovered from Umma and Drehem [11,12,25]. The dataset meets two essential criteria, which are reflected in very specific sets of queries: basic information and sealing practices.

4.1. Basic Information

The primary focus of the database is to provide a clear and easily accessible overview of all relevant information concerning the physical features of the tablets and sealings that were subjected to 3D scanning. Items are categorized as tablets, seals, or inscribed objects and listed according to their museums or collection numbers. When recording the materials kept in the Musei Reali of Turin, we included both the museum catalogue number and the number assigned to the item in the Cuneiform Digital Library Initiative (CDLI). This facilitates quick comparisons between the information contained in our database and the CDLI repository.

The database field record for each artefact's essential data is related to its place of origin, its size (height, width, and thickness), and its approximate date (if known). Regarding the place of origin, details concerning the country of origin and the main excavation sites are recorded.

Drop-down menus make it easy to retrieve information concerning the material and the state of preservation of each object. We decided to differentiate between three different levels of preservation: complete, fragmentary (some parts of the item are missing), and damaged (the item is complete, but a significant portion of the surface is abraded or damaged). The materials of the tablets and inscribed objects are categorized as clay (in the case of cuneiform tablets) or stone (in the case of seals and other inscribed objects). Further information concerning the materials of artefacts and other features noted during the processing of the scanned images, such as the presence of fingerprints on the surfaces of clay tablets, can be recorded in the remarks field.

4.2. Sealing Practices

The second purpose of the database is to facilitate comparative analyses of particular elements relating to the document or the sealing method. Fields relating to the language of the text and its textual typology respond to this need. The field for recording the content of the text includes a direct link to the transliterations available via the CDLI.

As noted above, 3D scanning and post-processing work reveal details on the surfaces of objects that cannot be detected by the naked eye. Thus, specific fields are dedicated to sealing methods. Two fields are designated for recording the presence of sealings on an artefact and the person who performed the sealing (or rather, the owner of the seal). This allows for very fruitful cross-references with the database of seals and seal impressions hosted by the CDLI and the Database of Neo-Sumerian Texts (BDTNS), which is restricted to the Ur III period [4].

In a free text field, further elements are recorded concerning the number of seal impressions and the orientation and level of the impressions with respect to the inscribed text (i.e., whether the document was pre-sealed or post-sealed), as well as other characteristics that may be identified during a thorough inspection of the sealed surface of the tablet. This field is the place for recording information gained through 3D modelling and post-processing work. For instance, while working on the corpus of Ur III cuneiform documents preserved in the Musei Reali of Turin, we observed that the text of some tablets clearly indicates that the tablet was sealed, even though the tablet itself shows no traces of actual sealings, perhaps because it was enclosed in a clay envelope. The ability to capture invisible surface details in high-definition 3D models could clarify such matters. Finally, a field for recording bibliographical references relevant to the artefacts in the database is provided.

The 3D and semantic data collected from important administrative documents must be securely archived as well as published in order to preserve and disseminate knowledge. Online smart repositories and common data environments (CDEs) could be the proper solution, although they may need to be tailored to specific datasets.

Regarding the project described herein, the tablet dataset deals with different types of information and file formats, ranging from 3D models to 2D images and related metadata. Open-access repositories and CDEs should permit a homogenous view of these data to facilitate complete access and investigation by project collaborators and common users. For this reason, we designed a draft version of an online CDE (Figure 16) for the purpose of analysing cuneiform tablets and their features via a web browser (without any specific hardware limitations).

Figure 16. Draft version of the common data environment for 3D data and metadata on cuneiform tablets.

In the future, this draft version will be implemented by the Italian National Council of Research, thus becoming stable and secure.

From a technical point of view, this environment is essentially composed of a 3D scene coupled with the semantic database apparatus. In this way, 3D models are linked to metadata: descriptions, materials, extracted features, metric information, and the content of the tablet can be easily analysed. Finally, a full-immersion 3D viewer was developed for the purpose of navigating the digital representation of the tablet and performing simplified post-processing analyses.

In the updated version of the repository, relational and semantic queries based on specific ontologies and standards can be performed to investigate historical and extracted metadata and relate them to 3D models.

Designing a smart and open-access environment will facilitate the exchange of semantic data and ease project management and revisions.

5. Discussion

This work focused on the possibility of updating, integrating, and initiating analytic studies on Near East archaeological artefacts. As seen before, clay tablets from Umma enclosed sensitive and extremely important information to be documented and preserved. One of the novelties of this project is related to the possibility of updating seal impression studies, especially to extract the figurative apparatuses as well as to integrate previous studies. Accurate scanning, highly detailed 3D outputs, and MSII analysis could contribute to updating and expanding the investigation and interpretation of sealing procedures.

At the same time, the post-processing analysis of sealings could initiate new semantic connections regarding scribes.

As we have seen, the seal impression of MAT 689 was originally documented by Giovanni Bergamini [12,13], but a deeper and innovative analysis via highly detailed 3D scanning has permitted significant integration of the proposed figurative apparatus.

The extraction of seal impression reveals the methodology behind the marking step: as reported on the tablet MAT 689, sealings were made by both rolling the cylindric seal and impressing a specific area of the textual and figurative apparatus.

Another innovative aspect of this work is related to the possibility of extracting metrically accurate biometric data from clay tablets: After the 3D reconstruction, the MSII filter contributes to extracting and enhancing nearly visible sensitive information from the surface. Fingerprint impressions of scribes can be investigated with micrometric precision, 3D resolution, and an ad hoc post-processing operation. These data may be fundamental for analysing the people behind the objects: In this regard, the age estimation analysis [26–28] and multiple fingerprint matches via fingerprint typology and metric analysis are necessary parameters for identifying the scribes who wrote these documents. However, documenting sub-millimetric details on archaeological finds is always challenging. In the last fifteen years, the 3D documentation method has been designed. Portable structured-light scanners have accelerated the digitization process of risky heritage assets as well as archaeological artefacts permanently preserved in museums.

This research project is also intended to highlight the possibilities of 3D scanning through portable solutions: the Artec Space Spider is revealed as a flexible and smart instrument for quick scanning sessions performed on site (museums). For large projects, a rapid scanning session is currently a much-needed operation. Depending on details and dimensions, the structured-light scanning and early reconstruction of cuneiform tablets requires about 10–15 min. By using other methodologies and instruments, the acquisition and processing time could significantly change: For example, photogrammetric survey is quite swift, but requires time-consuming processing (about 20–30 min, including image masking, image orientation, tie-points extraction, dense cloud, mesh creation, cleaning operations, and texture mapping).

In this regard, the Space Spider sensor, with a 3D point accuracy of 0.05 mm, is an extremely valuable instrument for capturing micrometric details on the surfaces of tablets.

Of course, other commercial scanners like Artec Micro [15], with a 0.01 mm 3D point accuracy and a 0.029 mm 3D resolution, could perform better; however, this solution is not completely portable or flexible.

6. Conclusions

Detailed 3D documentation and precise analysis unlock new possibilities for the investigation of cuneiform tablets beyond the textual content.

A structured-light scanning methodology implemented using a Space Spider scanner facilitated the accessibility and documentation of a tablet collection. Although there are other detailed documentation possibilities (e.g., photogrammetry and RTI Dome), 3D scanning provides quick and highly detailed 3D documentation that is useful for offering different outputs as well as conducting multiple analyses.

As we have seen, the analysis of the tablet MAT 689 highlighted the importance of post-processing imaging for updating existing studies on seal impressions. The three-dimensional modelling of archaeological artefacts should not be an end in itself, but a means for extracting specific data and performing further analyses.

The MSII filtering process shows enormous potential for detecting micro-evidence pertaining to tablet production. Notably, fingerprint analysis can generate broader studies on the people behind the archaeological artefacts by establishing new smart connections between tablets coming from the same site. The entire Turin collection is currently the subject of such research, and in the future, these methods can also be implemented in museums worldwide to generate comparative analyses of particular elements related to fingerprint impressions or sealing methods.

This initial analysis on different clay tablet typologies unlocks new possibilities for future works (some of these are already in progress). Based on these possibilities, a future ongoing work is related to the fingerprint analysis of a cuneiform tablet coming form Puzrish-Dagan (Drehem, Iraq). As mentioned previously, the high 3D point accuracy of actual structured-light sensors, in addition to micrometric analysis via MSII or virtual RTI, provides a wider outlook on fingerprint impressions on clay tablets. Accurate metric investigations can result in more precise studies on age estimation, gender analysis, scribe workshops, and object production.

At the same time, another future ongoing project will concentrate on the analysis of the state of damage and preservation of the limestone relief of the Assyrian King Sargon II, a masterpiece preserved at the Musei Reali of Turin. Through Space Spider scanning, MSII analysis, and virtual RTI, the damaged and erased decoration (common practice in the 19th century) of the Assyrian King will be deeply investigated in order for us to understand the original figurative apparatus of robes.

Finally, the creation of a smart open-access repository and CDE will open up new research possibilities by dismantling data accessibility barriers, allowing full access to and exchange of metadata, 3D models, and extracted semantic data.

Author Contributions: Conceptualization, F.D., F.G.B. and S.d.M.; methodology, F.D.; software, F.D.; validation, F.D., F.D., F.G.B. and S.d.M.; investigation, F.D., F.G.B. and S.d.M.; resources, S.d.M.; data curation, F.D., F.G.B. and S.d.M.; writing—original draft preparation, F.D., F.G.B. and S.d.M.; writing—review and editing, F.D., F.G.B. and S.d.M.; visualization, F.D., F.G.B. and S.d.M.; supervision, F.D., F.G.B. and S.d.M.; project administration, S.d.M.; funding acquisition, S.d.M. All authors have read and agreed to the published version of the manuscript.

Funding: 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).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: The authors would like to acknowledge Elisa Panero (curator of the Archaeological Collection) and Cristina Meli (Restorer) of the Musei Reali of Turin for their constant support.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Balke, T.E.; Tsouparopoulou, C. *Materiality of Writing in Early Mesopotamia*; De Gruyter: Berlin, Germany; Boston, MA, USA, 2016. [CrossRef]
2. Welch, J. Aristocratizing the Community: Roger Fenton and British Photography in the 1850's. Ph.D. Thesis, Princeton University, Princeton, NJ, USA, 2004.
3. CDLI Website. Available online: https://cdli.mpiwg-berlin.mpg.de/about (accessed on 8 May 2024).
4. Tsouparopoulou, C. Progress Report: An Online Database for the Documentation of Seals, Sealings, and Seal Impressions in the Ancient Near East. *Stud. Orient. Electron.* **2014**, *2*, 37–68.
5. Hameeuw, H.; Geert, W. New Visualization Techniques for Cuneiform Texts and Sealings. *Akkadica* **2011**, *132*, 163–178.
6. Kotoula, E.; Akoglu, K.G.; Frahm, E.; Simon, S. QR Coded 3D Prints of Cuneiform Tablets. *Int. J. Art Cult. Des. Technol. (IJACDT)* **2017**, *6*, 1–11. [CrossRef]
7. Antinozzi, S.; Fiorillo, F.; Surdi, M. Cuneiform Tablets Micro-Surveying in an Optimized Photogrammetric Configuration. *Heritage* **2022**, *5*, 3133–3164. [CrossRef]
8. Kleber, K. Die Edition und Erforschung von Neubabylonischen Keilschrifttafeln Aus Babylon. *Alter Orient Aktuell* **2022**, *19*, 4–9.
9. ESFRI RI Resilience Project. Available online: www.resilience-ri.eu (accessed on 8 May 2024).
10. ITSERR—Resilience Associated Project. Available online: www.itserr.it (accessed on 8 May 2024).
11. Archi, A.; Pomponio, F. *Testi Cuneiformi Neo-Sumerici da Drehem, Catalogo del Museo Egizio di Torino. Serie Seconda: Collezioni*; Ministero per i Beni Culturali e Ambientali. Soprintendenza al Museo delle Antichità Egizie: Torino, Italy, 1995; Volume 7.
12. Archi, A.; Bergamini, G.; Pomponio, F. *Testi Cuneiformi Neo-Sumerici da Umma, Parte I: I Testi. Parte II: Le Impronte di Sigillo. Catalogo del Museo Egizio di Torino. Seria Seconda: Collezioni*; Ministero per i Beni Culturali e Ambientali. Soprintendenza al Museo delle Antichità Egizie: Torino, Italy, 1995; Volume 8.
13. Bergamini, G. Gli scribi di Umma. Prassi di validazione del documento e certificazione d'autorità in età neo-sumerica. In *L'ufficio e il Documento. I Luoghi, i Modi, Gli Strumenti Dell'amministrazione in Egitto e Nel Vicino Oriente Antico*; Mora, C., Piacentini, P., Eds.; Quaderni di Acme: Milano, Italy, 2006; pp. 209–220.
14. Laurito, R.; Mezzasalma, A.; Verderame, L. Texts and Labels: A Case Study from Neo-Sumerian Umma. In *Proceedings of the 51st Rencontre Assyriologique Internationale, Chicago, IL, USA, 18–22 July 2005*; Biggs, R.D., Myers, J., Roth, M., Eds.; The Oriental Institute of the University of Chicago Studies in Ancient Oriental Civilizations 62: Chicago, IL, USA, 2005; pp. 99–110.
15. Artec3D Website. Available online: https://www.artec3d.com (accessed on 8 May 2024).
16. Georgopoulos, A.; Ioannidis, C.; Valanis, A. Assessing the performance of a structured light scanner. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.* **2010**, *38*, 5.
17. Mugnai, F.; Tucci, G.; Da Re, A. Digital image correlation in assessing structured-light 3D scanner's gantry stability: Performing David's (Michelangelo) high-accuracy 3D survey. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2021**, *46*, 463–469. [CrossRef]
18. Diara, F. Structured-Light Scanning and Metrological Analysis for Archaeology: Quality Assessment of Artec 3D Solutions for Cuneiform Tablets. *Heritage* **2023**, *6*, 6016–6034. [CrossRef]
19. Gigamesh Software. Available online: https://gigamesh.eu/ (accessed on 8 May 2024).
20. Mara, S.H.; Krömker, S.; Breuckmann, J.-B. 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, France, 21–24 September 2010. [CrossRef]
21. Homburg, T.; Zwick, R.; Mara, H.; Bruhn, K.-C. Annotated 3D-Models of Cuneiform Tablets. *J. Open Archaeol. Data* **2022**, *10*, 1–8. [CrossRef]
22. Fisseler, D.; Müller, G.G.W.; Weichert, F. Web-Based Scientific Exploration and Analysis of 3D Scanned Cuneiform Datasets for Collaborative Research. *Informatics* **2017**, *4*, 44. [CrossRef]
23. Göldner, D.; Karakostis, F.A.; Falcucci, A. 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* **2022**, *17*, e0267163. [CrossRef] [PubMed]
24. Innerhofer, F.; Reuter, T.; Coburger, C. More Than Just Documenting the Past: 15 Years of 3D Scanning at the Archaeological Heritage Office of Saxony. In *The 3 Dimensions of Digitalised Archaeology*; Hostettler, M., Buhlke, A., Drummer, C., Emmenegger, L., Reich, J., Stäheli, C., Eds.; Springer: Cham, Switzerland, 2024. [CrossRef]
25. Mayr, R.H. Seal Impressions on Tablets from Umma. Ph.D. Thesis, University of Leiden, Leiden, The Netherlands, 1997. Available online: https://www.academia.edu/45128929/Seal_Impressions_on_Tablets_from_Umma (accessed on 8 May 2024).
26. Arslan, A. Studying Fingerprints in Archaeology: Potentials and Limitations of Paleodermatoglyphics as an Archaeometric Method. *Turk. J. Archaeol. Sci.* **2023**, 1–16.

27. Kamp, K.A.; Timmerman, N.; Lind, G.; Graybill, J.; Natowsky, I. Discovering Childhood: Using Fingerprints to Find Children in the Archaeological Record. *Am. Antiq.* **1999**, *64*, 309–315. [CrossRef]
28. Králík, M.; Novotný, V. Epidermal Ridge Breadth: An Indicator of Age and Sex in Paleodermatoglyphics. *Var. Evol.* **2003**, *11*, 5–30.