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Digital Documentation and Reconstruction of Fragile Organic Artefacts: A State-of-the-Art Review

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Abstract

The study and preservation of fragile organic artefacts represent an ongoing challenge in cultural heritage conservation, particularly when traditional physical reconstruction is unfeasible due to degradation or fragmentation. This paper provides a state-of-the-art review of digital documentation and reconstruction practices for organic materials such as leather, textiles, and wood, with an emphasis on their material characteristics, conservation risks, and computational potential. Central to this discussion is a case study of a 12th-century leather bag recovered from an underwater excavation in the port of Rhodes Island. The study combines close-range photogrammetry, laser scanning, and recent AI-driven methods, including Neural Radiance Fields (NeRF) and Gaussian Splatting, to propose a replicable and transparent workflow for the non-invasive documentation and digital reassembly of fragile artefacts. The paper also explores the role of interdisciplinary collaboration, semantic annotation, and interactive visualization in enhancing interpretative accuracy and public accessibility. The findings underscore the need for methodological transparency, data traceability, and ethical considerations in the digital management of vulnerable cultural heritage.

1. Introduction

The study and preservation of fragile organic artefacts constitute a significant and complex challenge within the fields of conservation science, archaeology, and cultural heritage studies. These artefacts—frequently recovered from archaeological contexts or preserved within historical collections—are often encountered in a fragmented, degraded, or incomplete state. Their systematic reconstruction is essential for both the comprehensive interpretation of their historical and cultural significance and their long-term safeguarding. Conventional reconstruction methodologies, typically based on manual processes, are inherently labour-intensive, time-consuming, and frequently subject to interpretive bias (Leitão, 2004).

In recent years, advancements in digital imaging, computational modelling, and computer vision techniques have introduced novel frameworks for addressing the limitations of traditional methods. Digital documentation workflows, encompassing three-dimensional (3D) scanning, computed tomography (CT), and high-resolution photographic imaging, always enable the non-invasive acquisition of detailed morphological and structural data. These datasets provide the foundation for digital reconstruction in the field of Conservation, employing approaches such as 3D modelling, image registration, and machine learning algorithms to facilitate the digital reassembly, simulation, and restoration of damaged or incomplete objects (Ekengren, 2021; Kantaros, 2025; Halldórsdóttir, 2024; Yao, 2024; Tamburini, 2021; Sakellariou, 2024).

Particular attention is required when dealing with organic materials—including leather, textiles, paper, and wood—which are especially susceptible to deterioration caused by environmental conditions, microbial colonization, and taphonomic processes. The so-called "organic turn" in archaeological theory, coupled with a growing awareness of the "curatorial crisis" in museum storage and conservation capacities, has brought renewed urgency to the development of robust and replicable digital documentation strategies tailored to such vulnerable materials (Randerz, 2023; Gigilashvili, 2023; Geweely, 2023; Bracci, 2013; Vyskočilová, 2019; Johnston, 2022)..

This study offers a comprehensive state-of-the-art review of current practices, technologies, and research trajectories in the digital documentation and reconstruction of fragile organic artefacts. Specifically, the paper is structured around four key thematic axes:

(a) the inherent material characteristics of organic archaeological artefacts and the associated conservation challenges;
(b) the principal 3D documentation technologies employed, with emphasis on close-range photogrammetry and laser scanning;
(c) contemporary digital reconstruction methodologies applied to fragmentary organic objects; and
(d) emerging approaches of 3D reconstruction from image datasets, including artificial intelligence (AI)-based methods and Neural Radiance Fields (NeRF). These domains are further contextualized through a representative case study and critically discussed in relation to future research directions and methodological considerations.

2. Characteristics and Challenges of Organic Archaeological Artefacts

Archaeological leather artefacts, derived from processed animal hides, represent a uniquely fragile and scientifically significant class of organic heritage. Their survival is highly dependent on burial conditions, as leather is exceptionally susceptible to physical and biochemical degradation processes. The primary structural component of leather —collagen— undergoes progressive deterioration through oxidation, hydrolysis, microbial attack, and de-tanning, leading to fragmentation, loss of tensile strength, shrinkage, and surface deformation. In particular, microbial colonization under waterlogged or oxygen-deprived conditions accelerates the breakdown of lipids and tannin-collagen bonds, destabilizing the material at a molecular level (Halldórsdóttir, 2024; Yao, 2024; Tamburini, 2021).

As a result, these materials are frequently discovered in a damaged or incomplete state, rendering their analysis and reconstruction a formidable task. The identification and matching of fragments can be particularly challenging when dealing with large numbers of severely degraded pieces. Moreover, materials such as textiles and leather are flexible and prone to deformation, which further complicates digital reconstruction processes in comparison to rigid materials. The recent "organic turn" in archaeology has underscored the growing scholarly interest in these materials, coinciding with the broader "curatorial crisis"

that museums face in managing, storing, and preserving sensitive artefacts (Gigilashvili, 2023).
Despite their historical significance, such heritage objects have often been regarded as less important than inorganic finds, leading to their underrepresentation in both conservation efforts and research agendas (Johnston, 2022). Even after conservation, these materials may continue to exhibit secondary signs of deterioration. These challenges highlight the urgent need for specialized methods of documentation, analysis, and preservation, tailored to the unique vulnerabilities and scientific value of these irreplaceable cultural testimonies (Randerz, 2023).

2.1 Focus on leather: material properties, degradation

Leather, derived from animal skin through tanning, is primarily composed of collagen, a fibrous protein that gives it structural integrity (Brodsky, 2005; Haines, 2006, Kennedy, 2003; English Heritage, 2012). The decay of leather artifacts in burial environments is influenced by factors such as the type of leather, animal species, manufacturing processes, and burial conditions (Haines, 2006; Cameron, 2006). Leather tends to survive better in anaerobic, waterlogged environments, where tannins can react with ferrous ions, causing discoloration and potential loss of flexibility due to leaching of oils and tannins (Gregory, 2015).
Preservation of leather can be enhanced by materials like copper and oak wood due to their antibacterial and high tannin content, respectively, but contamination with iron salts may lead to oxidative damage and further deterioration. The chemical composition of leather varies based on the chemicals used in treatment and naturally occurring elements in the tanning process (Singley, 1988; Cronyn, 2003; Karsten, 2011; Bekić)
The color of leather can change over time, maintaining shape even after prolonged burial, though leaching can affect flexibility. Increased water penetration can lead to hydrolysis and collagen degradation, resulting in delamination, where layers separate due to insufficient tanning or degradation of collagen bonds. Consequently, many leather artifacts from marine excavations are often found in fragments, making preservation challenging (Ganiaris, 1982; Spriggs, 2003).
The selection of appropriate conservation strategies for archaeological leather must be informed by both the preservation state and the specific degradation mechanisms involved. Digital documentation through three-dimensional scanning offers valuable means for monitoring the condition of leather artefacts and evaluating the impact of conservation interventions. A thorough understanding of the material's properties and the degradation mechanism is essential for ensuring both the effective conservation and digital reconstruction of fragile leather artefacts of archaeological significance.

2.2 Preservation and visual documentation issues

Cultural heritage conservation remains one of the most pressing challenges in contemporary society. Growing awareness of the potential loss or restricted access to tangible heritage has prompted more curators and conservation professionals to adopt 3D technology as a means of documentation, analysis, preservation, and communication (Bracci, 2013).
A wide range of research projects has emerged exploring new modes of interaction with digital objects, examining the capacity of such tools to support education and research across various disciplines, while also identifying their limitations.
One of the technical challenges associated with 3D acquisition methods, such as optical laser and structure-light scanning, involves the accurate capture of some intricate fine details and materials. Although contemporary hand-held 3D scanners offer high accuracy, certain surface textures—particularly highly reflective or very dark ones—can interfere with data acquisition. Reflective surfaces cause unpredictable light scattering, resulting in incomplete scans or noisy point clouds. To mitigate these issues, projects already explore the use of additional techniques, such as polarizing filters, to reduce reflectivity without compromising the integrity of the object.
Three-dimensional digital documentation and the production of accurate physical replicas via 3D printing can significantly contribute to heritage preservation by enabling the creation of tangible educational resources and providing alternative display options that reduce the handling of authentic objects. The integration of 3D digitisation and printing enhances accessibility, resilience, and pedagogical utility, offering a sustainable model for preserving and studying cultural assets.
Given the fragility of organic materials, such as textiles, and their frequent recovery in fragmentary condition, the development of computational techniques for digital reconstruction is critical to minimizing the need for physical manipulation. Digital restoration may serve different roles depending on context and application, including simulation-assisted planning of conservation interventions.
Digital restoration and reconstruction are increasingly widespread practices in the domain of virtual heritage (Makris, 2021). Virtual reconstruction aims to produce a digital model in support of physical conservation and restoration, while digital restoration can also involve the revival of visual elements—such as photographs or films—or the recreation of an object's original form within a digital environment. However, maintaining the credibility of the original content and avoiding misleading realism is essential. It is equally important to apply the same conservation ethics, theoretical frameworks, and professional responsibilities in the digital domain as one would in the physical conservation of artefacts.. Every digital reconstruction should follow a transparent methodology that communicates the degree of authenticity, making clear distinctions between factual evidence and interpretative speculation.
Documentation is a fundamental component in assessing the methodologies and outcomes of visual reconstructions in relation to the specific contexts and intended purposes. Proper documentation should include not only the sources and metadata used but also the interpretive process that led to the visual representation. This ensures both scientific transparency and epistemic accountability in the use of visual reconstructions within conservation and heritage practices (Pietroni, 2021).

3. 3D Documentation Technologies for Fragile Artefacts

The digital documentation of cultural heritage faces a range of challenges that impact the accuracy and reliability of outcomes. The management of heterogeneous data in various formats, combined with the collaborative nature of documentation platforms, creates significant difficulties in ensuring the traceability and validity of information. Technical limitations also emerge in the 3D digitisation of fine details and reflective surfaces, which can compromise data quality.
Additionally, the fragility of artefacts and the frequent presence of incomplete datasets further complicate documentation and reconstruction workflows. In digital restoration, maintaining authenticity and avoiding the creation of a false sense of realism is of paramount importance. Lastly, material degradation, such as microbial decomposition, continues to pose a persistent threat to the preservation of archaeological artefacts.

3.1 Close-range photogrammetry

Close-range photogrammetry begins with the systematic capture of overlapping photographs around the target object.

Traditionally, this is done with DSLRs or UAVs, but modern workflows increasingly leverage smartphone-based apps—such as Polycam, Scaniverse, Scandy Pro, Pix4D, SiteScape and Luma AI—that automate multi-shot acquisition, generate live previews of coverage, and even perform on-device SfM processing. These tools typically export either fully reconstructed 3D meshes (in formats like OBJ or glTF) or, alternatively, the raw image sets plus embedded metadata (camera poses, focal lengths) for downstream processing.
First, all photographs are imported into an SfM/MVS software (e.g. Agisoft Metashape, RealityCapture, Meshroom), which automatically detects and matches key points to estimate camera positions. A dense 3D mesh is then reconstructed via Multi-View Stereo and optimized, before textures from the original images are projected onto the geometry. The resulting photorealistic model is immediately ready for analysis, measurement, conservation planning, or dissemination (Konstantakis, 2024; Abergel, 2023; Konstantakis, 2023).

3.2 Active range scanning

Active range scanning encompasses non-invasive methods such as laser scanning—which projects a laser beam and measures either the time-of-flight or phase shift of the return signal—and structured-light scanning, in which known light patterns are cast onto the surface and their distortions are captured by cameras; both approaches yield dense, sub-millimetre point clouds for highly accurate geometric documentation.
This type of scanning finds broad application in surveying historic buildings, archaeological sites, and museum works of art and artefacts, supporting structural monitoring, conservation recording, and the creation of long-term digital twins. To entangle its metric fidelity with photogrammetry's rich textured surface detail, many projects now fuse laser/structure-light scans and image-based models via point-cloud alignment, mesh reconstruction, and high-resolution texture mapping (Konstantakis, 2024; Konstantakis, 2023).

3.3 Comparative Tables

Techniqu e	Application	Description	Examples
Computer Vision (SfM, MVS, DL)	Fragmented textiles, manuscripts, ceramics	3D reconstruction, alignment, pattern recognition	Reconstructi on of damaged vessels, manuscripts
CT Scanning	Fossils, wood, textiles, wax	Non-invasive imaging for internal/ external morphology; structural segmentation	Fossil bone restoration, possible textile applications
Deep Learning Inpainting (GANs)	Textiles, costumes	Reconstruction of missing parts using semantic-aware AI models	Silk garments, historical costumes

Table 1: Digital Reconstruction Techniques for Organic Artefacts

Challenge	Description
Fragment Matching Difficulty	High fragment count, degradation, and variability complicate automated matching
Handling Fragile Materials	Risk of further damage during digitization or physical processing
Interpretive Subjectivity	Each step can introduce bias; transparency in decision-making is critical
Technical Constraints (e.g. Imaging)	Phantom imaging limited to flat surfaces; inpainting may fail on irregular patterns
Authenticity vs. Speculation	Reconstructed models must differentiate between original and hypothesized components

Table 2: Common Challenges in Digital Reconstruction of Organic Artefacts

4. Emerging AI-Based Approaches

Nowadays, AI methods are needed to automate and accelerate complex reconstruction tasks, improve accuracy by minimizing human bias and error, and enable scalable analysis of diverse artefact collections with limited annotated data. The reviewed sources highlight a range of emerging AI-based approaches in the fields of digital heritage documentation, analysis, and the digital reconstruction of archaeological artefacts (Gîrbacia, 2024).
In the domain of digital 3D reconstruction of fragmented objects, computer vision techniques—often incorporating artificial intelligence—offer transformative capabilities. Notably, the following are reported:

- The use of machine learning algorithms to automate and enhance reconstruction workflows (Pietroni, 2021; Han, 2019).
- The application of deep learning for the detection and segmentation of individual fragments from images or scans, leveraging Convolutional Neural Networks (CNNs) and Region-based CNNs (R-CNNs) for fragment recognition and classification, thereby facilitating digital reassembly (Pietroni, 2021; Lu, 2025).
- The development of Generative Adversarial Networks (GANs) and advanced CNNs to improve reconstruction precision and efficiency (Han, 2019).
- The prospect of further integrating advanced deep learning and AI models into object reconstruction pipelines, including the design of specialized neural networks for tasks such as texture recovery, material recognition, and automated alignment (Lu, 2025).
- The use of transfer learning and domain adaptation techniques to leverage pre-trained models for related tasks,

reducing the need for extensive labeled datasets and increasing model adaptability across different object types and acquisition conditions (Lu, 2025).

In the field of digital reconstruction of archaeological textiles, machine learning and deep learning applications are still in early stages but demonstrate substantial potential (Han, 2019; Lu, 2025).. Existing computational solutions for puzzle-like problems—typically based on geometric and chromatic criteria—are evolving through the integration of deep learning. Although fully automated solutions for heavily deteriorated textiles are unlikely in the near future, AI can support semi-automated processes by offering intelligent suggestions to specialists. Future research may explore automated weaving pattern analysis using classical image processing combined with supervised CNNs (Pietroni, 2021; Konstantakis, 2024).

Moreover, in the context of digital documentation and annotation of cultural heritage, experimental applications of supervised machine learning for segmentation are reported, along with efforts toward the automated generation of annotation layers based on semantic segmentation of point clouds.

In summary, the reviewed literature underscores the growing importance of AI-driven approaches in addressing complex challenges in the digital management, analysis, and reconstruction of cultural heritage. Machine learning and deep learning, in particular, are emerging as key enabling technologies, offering scalable and adaptive solutions for a variety of heritage-related applications.

5. Case Study Contextualization: A Byzantine Leather Bag from Rhodes

The object under study is a Byzantine leather bag, recovered during an underwater archaeological excavation conducted by the Ephorate of Underwater Antiquities (EUA) at the commercial harbor of Rhodes. The artefact is in a highly fragile and fragmentary condition, with only partial remains of its original structure preserved. Measuring approximately 36 cm in height, 27 cm in width, and 23 cm in depth, the object appears to have been an oval-shaped, pliable container -possibly a leather utricle-used for storing or transporting soft goods or semi-solid organic materials (Figures 1 and 2).

This object was discovered carefully stowed astern between two hull frames, with the hairy side of the skin turned inward—an arrangement that may seem counterintuitive by modern standards but aligns with documented historical practices. Ethnographic parallels from Ottoman-period food preservation techniques, still observed in parts of the northern Aegean and Turkey into the 20th century, suggest that such containers were standard tools for maintaining and transporting perishable goods like cheese (Koutsouflakis, 2021).

Given the organic composition of the material (leather) and its degraded state, conventional physical reconstruction is not feasible. Therefore, based on previous parts and the particular morphological and taphonomic challenges of leather, a multi-method digital documentation and reconstruction strategy is proposed. This includes close-range photogrammetry, structured-light depth scanning, and state-of-the-art AI-based techniques such as Neural Radiance Fields (NeRF) and Gaussian Splatting.

The overarching goal of this process, which is ongoing, is to assess the potential of these technologies in supporting the preservation, interpretation, and digital reassembly of fragile organic artefacts, while proposing a replicable workflow for similar future cases.

Figure 1. Leather bag (Goat pelt) containing cheese from the 12th century shipwreck excavated in the port of Rhodes (Koutsouflakis, 2021)

Figure 2. Leather bag in the university lab

To enhance the accuracy and robustness of this effort, several methodological components are considered:

- Pre-digitization assessment: A systematic evaluation of the artefact's preservation state, recording tears, deformations, and surface losses, is crucial. Controlled lighting and potential mitigation of reflection artifacts—e.g., through polarizing filters—can improve texture fidelity during photogrammetric capture. The integration of laser scanning provides high-resolution geometric data, particularly useful when combined with photogrammetry's color and texture fidelity.
- Artificial Intelligence in reconstruction: AI-driven methods offer promising avenues for the classification and digital reassembly of fragmented leather artefacts. Leveraging features like surface texture, fold patterns, thickness variation, and discoloration gradients, deep learning approaches—such as convolutional neural networks (CNNs) and region-based R-CNNs —can support semi-automated segmentation and the digital reconstruction of missing or degraded areas. A comparable example is the digital conservation of a non-rigid figurine, where deformation over time and structural instability necessitated a material-sensitive and ethically informed approach to digital restoration. The integration of 3D documentation, animation-based workflows, and ICT expertise in that case highlights the broader importance of

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aligning digital conservation methods with the physical properties and singularities of flexible heritage objects (Makris, 2021).

- Expert integration: Collaboration with archaeologists, conservators and computer scientists is essential throughout. Their knowledge of typologies, manufacturing techniques, and historical context will inform both the plausibility and interpretation of the digital reconstruction. Decisions and assumptions should be fully documented, with visual distinction between original and reconstructed parts in the resulting 3D model.
- Cross-validation of methods: The artefact will be documented using various techniques. By comparing results -in terms of surface fidelity, completeness, and interpretability- this study seeks to evaluate the strengths and limitations of each approach. Error metrics and consistency checks between photogrammetry and laser scanning, will guide methodological refinement.
- Interpretation: The final 3D model will be used for digital visualization across platforms (e.g., web, VR, AR), and potentially 3D-printed in reduced scale for educational and tactile engagement. An interactive digital narrative may enhance public understanding of the bag's function, origin, and reconstruction process.

In conclusion, this case study aims not only to digitally reconstruct a unique Byzantine organic artefact, but also to critically reflect on the technical, interpretive, and ethical challenges of working with such materials. By integrating non-invasive capture methods, AI-enhanced reconstruction, and expert-driven validation, the study aspires to contribute a replicable, transparent, and interdisciplinary model for future digital heritage initiatives.

6. Implementation of the digital model

6.1 Image Acquisition

To create a high-fidelity 3D model of the leather bag, an extensive photogrammetric imaging process was conducted in a controlled laboratory setting. Two distinct image acquisition workflows were employed. Approximately 300 high-resolution photographs were captured using a DSLR camera mounted on a tripod under consistent lighting conditions, ensuring precise geometric accuracy and texture detail. In parallel, around 900 additional images were acquired in the field using a mobile device via the Polycam Pro application. While these mobile-based captures offer lower resolution, they enable rapid, dense coverage from multiple angles through on-device processing and depth sensing. Each dataset served a different purpose within the reconstruction pipeline and was later evaluated for potential integration or comparative analysis. The use of diffused controlled lighting and fixed camera positions ensured uniform illumination and minimized harsh shadows or specular reflections that could interfere with the photogrammetric algorithms.

A major challenge during the imaging process was the extreme fragility of the object. The leather artefact was partially supported with Reemay® (non-woven polyester spunbond), a conservation-grade material commonly used to stabilize deteriorating organic materials. These textile supports — delicately stitched in place to prevent further structural collapse — could not be removed without risking additional damage. As a result, the bag was photographed with the support materials in situ, a constraint that affected both imaging geometry and lighting, especially in areas where the gauze produced micro-shadows or subtle surface distortions. These supports will remain in place until the completion of the ongoing conservation process.

To avoid movement, the object itself remained stationary throughout the shoot, while the camera positions were systematically varied to capture multiple elevations and achieve full 360° coverage. Figure 3 illustrates the photographic setup, showing the leather bag positioned for imaging amidst the lighting array and a tripod-mounted camera.

Figure 3. 3d modelling photographic setup

6.2 Photogrammetric Processing

The collected images were processed using a Structure-from-Motion (SfM) photogrammetry workflow to reconstruct the 3D geometry and texture of the bag. In the initial pipeline, Metashape software was employed for its efficiency in handling large image datasets and producing ultra-detailed models. All photographs were input into the software, which automatically aligned the images and generated a dense point cloud representing the bag's surface. The result is a textured 3D mesh by triangulating the point cloud, resulting in a high-resolution digital replica of the artefact (Figure 4).

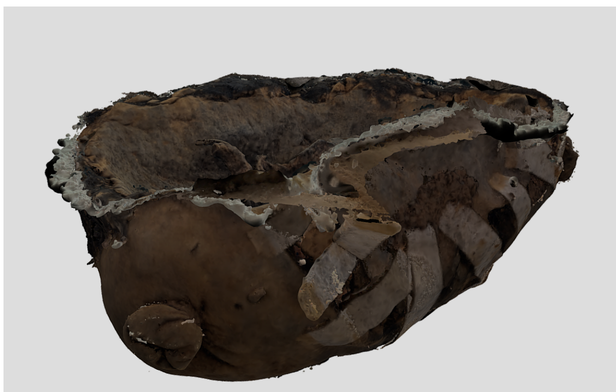

Figure 4. 3D model of the leather bag in Agisoft Metashape

The acquired photographs were imported into Agisoft Metashape to initiate the post-processing phase. Post-processing steps were kept minimal: aside from the automated texturing, the main interventions involved trimming residual background geometry (e.g. lab bench and support stand artifacts). The entire reconstruction workflow was documented for transparency, including camera calibrations and software settings, to ensure the process is replicable and traceable for future studies.

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6.3 Preliminary Results and Quality Assessment

The initial 3D model of the leather bag is highly detailed, capturing the object's shape and surface texture with remarkable fidelity. A total of 682,997 tie points were generated under high-accuracy settings, along with 1,279 high-quality depth maps. The dense point cloud comprised 19,443,747 points, while the final mesh—also produced in high quality—consisted of 3,264,405 faces and 1,643,893 vertices. In terms of spatial resolution, the point spacing in the densified cloud reaches the sub-millimeter level, which is critical for documenting small-scale details (e.g. stitching holes or grain patterns). The model is also geometrically complete for all surfaces that were accessible to photography – the exterior of the bag and its fragmentary edges have been fully recorded. Some occlusions do remain: for instance, portions of the interior that could not be viewed without handling the artefact are absent in the model, and areas in direct contact with the supporting base were only partially captured. Despite these minor gaps, the overall coverage is comprehensive, and the model conveys the bag's current form in its entirety. The photo textured surface provides a realistic color representation, aiding visual interpretability. Importantly, a qualitative review by the team's archaeologists and conservators indicates that the digital model accurately reflects the artefact's physical condition (locations of tears, lacunae, and surface wear), underlining the documentary value of the reconstruction.

7. Discussion

Several well-known technical challenges were anticipated during the photogrammetric phase, owing to the artefact's exceptional fragility and complex surface properties. The leather bag's irregular, semi-collapsed geometry, combined with its dark, matte coloration and occasional surface gloss, presented non-trivial difficulties for image acquisition. In particular, deep shadows and localized specular reflections—especially around folds and textured regions—complicated uniform lighting and interfered with image alignment. The use of diffused LED lighting helped mitigate these issues but required extensive fine-tuning to avoid overexposure or glare.

Due to the artifact's unstable condition, it could not be repositioned or supported independently. Instead, it was documented in situ with both internal and external conservation support in place. These included stabilizing materials such as non-woven polyester textiles (Hollytex®), which, while essential for structural preservation, introduced visual occlusions that affected both keypoint detection and surface geometry during reconstruction.

Additional complications arose from the difficulty of safely accessing all sides of the object. The artefact could not be laid on its side without risking deformation or collapse, limiting certain viewing angles. Furthermore, the unique and rare nature of the find demanded exceptional care: no directly comparable artefact exists in the archaeological record, thus necessitating highly cautious handling and a carefully staged removal from its protective storage environment to minimize physical stress.

Collectively, these challenges highlight the importance of balancing technical optimization with conservation constraints, particularly when dealing with sensitive, one-of-a-kind organic materials.

Looking ahead, building on the high-resolution photogrammetric model produced in this study, the next step focuses on the digital reconstruction of the leather bag's original form. Rather than acquiring new geometric data, the existing 3D mesh will serve as the foundation for computational reassembly. AI-assisted methods, such as fragment matching and digital inpainting, will be employed to interpolate missing regions—particularly around torn or collapsed areas—while preserving a clear distinction between documented geometry and reconstructed hypotheses.

This approach strengthens the analytical value of the model and enables a transparent, reproducible workflow that supports further interdisciplinary exploration, including 3D visualization, comparative typological studies, and potential fabrication of research-grade replicas.

8. Conclusions

Overall, this initial implementation demonstrates a successful proof of concept for the digital documentation approach. The fact that a tangible 3D model of the fragile leather bag has been produced at this stage reinforces the practical viability of the proposed workflow.

The experience gained – from optimizing lighting and camera network design to dealing with data-intensive processing – provides valuable insight for the ongoing project. To strengthen the practical aspect of the reconstruction, we emphasize that the digital reconstruction is not merely theoretical but has been actively realized: the Byzantine leather bag has, in effect, been "digitally documented" in its current state, yielding a detailed 3D surrogate that can be examined, measured, and used for further analyses. Moving forward, this preliminary model will serve as the foundation for more advanced steps (such as AI-driven reassembly of missing parts or simulations of the bag's original shape when filled). It also offers a reference against which improvements from additional data (e.g. *laser scans* or NeRF-based models) can be compared.

The successful creation of the leather bag's 3D model at this stage validates the effectiveness of the documentation strategy overcome major material and stability issues, and enhances the interdisciplinary understanding of the artefact, marking a significant step toward the project's overall goal of a replicable and transparent digital reconstruction workflow of such rare and demanding artefacts of cultural heritage.

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