LE STUDIUM Loire Valley Institute for Advanced Studies

LE STUDIUM Multidisciplinary Journal
ISSN 2669-7807
www.lestudium-ias.com

FELLOWSHIP FINAL REPORT

Democratizing Cultural Heritage Digitization: Affordable Photogrammetry for Books and Manuscripts

Alberto Campagnolo[1,2]

1 LE STUDIUM Institute for Advanced Studies, 45000 Orléans, France
2 Université Catholique de Louvain, 1348 Louvain-la-Neuve, Belgium

REPORT INFO

Fellow: **Alberto Campagnolo**
From Università degli Studi di Udine
Host laboratory in region Centre-Val de Loire: Centre d'études supérieures de la Renaissance
Host scientist: **Elena Pierazzo**
Period of residence in region Centre-Val de Loire: May 2022 – April 2023

Keywords :
Photogrammetry, Cultural Heritage, Written Artifacts, 3D Modeling, Digital Codicology

ABSTRACT

This paper explores the significance of photogrammetry as an accessible and innovative imaging technique for preserving and studying written cultural heritage. Focusing on the challenges of traditional digitization methods in capturing the materiality and craftsmanship of manuscripts and books, we present a cost-effective photogrammetry workflow using the 3DF Zephyr software. Demonstrating its potential, we discuss the generation of detailed 3D models and the integration with other software tools. The research findings were presented at the 19th International Seminar on the Care and Conservation of Manuscripts, and the paper is planned for publication in the conference proceedings. This work contributes to the broader discourse on Digital Codicology and encourages interdisciplinary collaboration in cultural heritage studies.

1 Introduction

The reproduction of documents in libraries and archives has a long history, with photographic surrogates emerging in the late 19th century to bring manuscripts and antiquarian books beyond their physical repositories. In the 1970s, memory institutions began experimenting with digital and computerised reproduction methods (McKitterick 2013, 71; Terras 2015, 63–64). However, the digitisation of books, which typically involves capturing page content through photography and imaging, fails to capture all the inherent qualities of physical books. These untransferable qualities give objects a significance that cannot be easily or effectively conveyed through traditional reproduction technologies (Campagnolo 2020, 32–33).

Recognising the importance of these untransferable features, scholars and practitioners from various disciplines focused on the book as an object (e.g., codicology, but also book conservation) are now directing their attention towards studying and understanding them with digital means. The very essence of the book in codex format—the quintessential book format in Western culture—lies in the technology of its physical structure, which is critical to its function.[1] This inherent technology is deeply ingrained in our society to the extent that books are often used unconsciously (Frost 1996, 92; Clarkson 1978, 34). Traditionally, books have not been considered susceptible to archaeological treatment (Adams and Barker 1993: 6), yet they hold immense significance as important and abundant human artefacts, capable of enriching our understanding of civilisation (Adorisio and Federici 1980, 483; Adams and Barker 1993, 7; Foot 1993, 124).

It is becoming increasingly evident that digital representations have the potential to revolutionise research in the same way they have transformed literature and other text-based fields of investigation. My research has addressed how a book's materiality, mechanics, functionalities, and other untransferable features can be digitised and researched virtually. In previous work, I have explored the theoretical possibility of meaningfully digitising book objects beyond their content, providing practical insights into achieving this remediation, with a particular focus on doing so with the least amount of technology possible, striving to democratise more complete digitisation efforts, and empowering scholars and conservators with applicable methodologies and tools. In this report, we will concentrate on affordable photogrammetric 3D modelling.

In this report, we will concentrate on affordable photogrammetric 3D modeling as a novel approach to digitally capture and study the untransferable features and materiality of books, aiming to empower scholars and conservators with practical methodologies and tools for comprehensive digitization.

2 The Significance of Codex Variation

A codex is a complex object comprising various structures and structural elements that form a complete book. While the number of basic structures and components used in codices is limited, the possibilities for their arrangement and variation seem virtually endless. This immense variety can be attributed to three key factors (Pickwoad 1995, 209–10). Firstly, book-making processes evolved and adapted over time, leading to changes in the formation of codices. As techniques developed, new ways of making and assembling the various parts of a book emerged, contributing to the diverse range of structures and configurations observed. Secondly, different geographic regions developed their solutions and styles in response to similar challenges. These regional variations often involved the use of different materials as well. Certain structures were limited to specific countries, while others were characteristic of individual nations or even confined to smaller geographical areas (Pickwoad 2014, 234). Lastly, book-making was a skilled trade taught and passed down through generations. Individual workshops or craftsmen may have developed unique techniques, often kept as trade secrets, then imparted from master to apprentice. As a result, these distinctive techniques were exclusive to the work produced by specific workshops, further contributing to the diversity of binding styles and structures. These factors collectively contribute to the incredible array of codex variations and demonstrate the rich history and craftsmanship behind the creation of each book object. Therefore, to comprehensively explore and understand the vast array of codex variations, it is imperative to develop robust methodologies that allow for the systematic study of their diverse structures, materiality, and craftsmanship.

3 Expanding Possibilities: Advanced Imaging Techniques and Digitization in Cultural Heritage

The advent of digitisation has introduced unprecedented possibilities for the preservation and study of cultural heritage materials. Digitisation enables the recording and extraction of information without disturbing or destroying the original sources and can transcend their limitations. However, conventional digitisation techniques primarily cater to the content of books and, in fact, hide signs and clues that can be read in the materiality of the substrate.

To overcome these limitations, specialised imaging techniques have emerged, allowing for the recovery, recording, and digitisation of characteristics that would otherwise be lost. Spectral imaging,[2] for instance, can digitally recover obscured details and provide insights into the deterioration of materials (Giacometti et al. 2017; France 2020). It offers a non-destructive tool for research into objects within cultural heritage institutions, enabling conservation studies and efficacy assessments of treatment processes (France, Emery, and Toth 2010; France 2016; Garside, Beltran de Guevara, and Duffy 2016; Korthagen et al. 2019, 23–26). On the other hand, high-resolution digital microscopy[3] unveils small-scale features and signs of degradation that are imperceptible to the naked eye (Garside, Beltran de Guevara, and Duffy 2016, 202–3). Photogrammetry[4] has also emerged as another valuable technique, allowing for detailed visualisations, accurate measurements, and virtual representations that can be explored and analysed from various perspectives (Luhmann et al. 2019). Reflectance Transformation

Imaging (RTI)[5] captures shape and structural information, revealing hidden attributes of objects. The combination of RTI with spectral imaging enhances feature detection capabilities, enabling conservators to uncover subtle details such as flaking pigments or hidden scoring on surfaces (Watteeuw et al. 2014; van der Perre et al. 2016; Watteeuw et al. 2016; Vandermeulen et al. 2018). Moreover, advanced imaging modules, such as the microdomes developed by the RICH (Reflectance Imaging for Cultural Heritage) project, cater specifically to the study of books. These modules allow for the imaging of book gutters, facilitating examining sewing threads and other information typically lost during traditional imaging methods (Watteeuw and Vandermeulen 2016).

In addition to imaging techniques, archaeometry methodologies have emerged as valuable tools for book and document analysis. Scientists now analyse the odour of paper as a diagnostic tool for conservation purposes (Strlič et al. 2009; Fenech et al. 2010; Kirschenbaum and Werner 2014, 422) and delve into the molecular makeup of parchment, including its DNA, to identify species, shed light on the manufacturing process, and gain insights into medium deterioration (Fiddyment et al. 2015; Beasts2Craft 2020; Fiddyment et al. 2019).

Furthermore, X-ray photography and Computed Tomography (CT) scans have been employed to examine intricate book structures and analyse unique decoration techniques (Pollard 1975; Duffy 2015; Pickwoad 2015, 50–54). These innovative approaches offer new research and investigation avenues beyond imaging alone.

Integrating advanced imaging techniques and archaeometric methodologies, such as spectral imaging, high-resolution digital microscopy, Reflectance Transformation Imaging (RTI), and photogrammetry, with digitisation expands the possibilities for preserving and understanding cultural heritage. These techniques allow for capturing hidden attributes, fine surface details, and three-dimensional representations, providing valuable insights into materiality, condition, and historical context. However, the cost and accessibility of advanced hardware and software can pose challenges. To address these barriers, we will introduce, in the subsequent sections, a cost-effective methodology for photogrammetry. By presenting accessible approaches, we aim to encourage wider adoption and empower researchers and conservators to leverage these powerful imaging techniques for studying, conserving, and preserving cultural heritage, even with limited resources.

4 Accessible Photogrammetry

Of all the techniques mentioned above, photogrammetry is particularly versatile and easy enough to be implemented to capture physical information about shape and surface topography, which is generally lost in traditional digitisation projects. Professional systems provide high-definition digital replicas, but a quick and low-tech approach yields results that allow for the distant reading of these objects and permit their study outside of a library's reading room.

Photogrammetry, an imaging technique with origins in the 19th century, has, until recently, relied on high-end cameras and expensive proprietary software for precise results. These tools used proprietary algorithms to extract shape information and reconstruct three-dimensional (3D) geometry from photographs. However, the cost and complexity associated with photogrammetry limited its accessibility to well-funded institutions and expert practitioners.

Fortunately, significant advancements have revolutionised photogrammetry, making it more accessible to a wider range of users. Today, affordable consumer-grade cameras, including DSLR or mirrorless cameras and even smartphones, are capable of capturing high-quality images suitable for photogrammetric reconstruction (Saif and Alshibani 2022; Heng Siong, Ariff, and Razali 2023; Monterisi, Capolupo, and Tarantino 2023). This affordability has opened doors for enthusiasts, researchers, and conservators to engage with photogrammetry and its applications.

Moreover, new software solutions have democratised the field even further. These software packages leverage multi-view

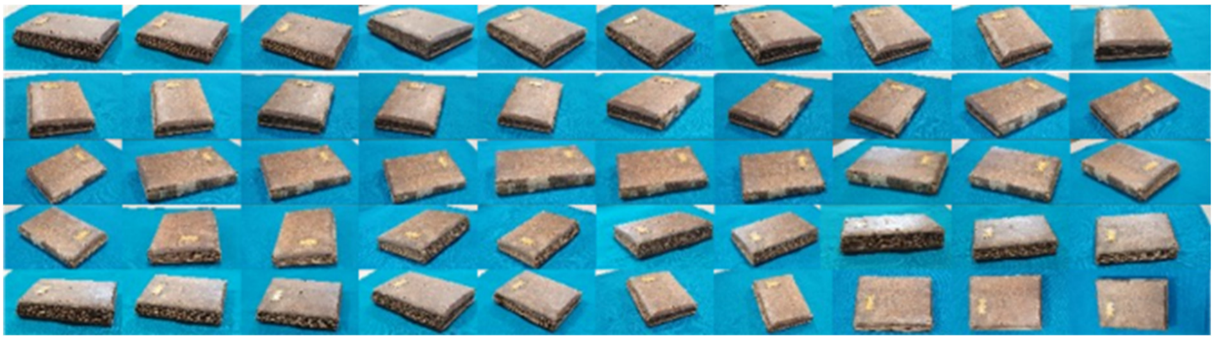

Figure 1 The sequence of images taken for Le Labo - Cambrai Ms 342.

geometry, feature matching, and robust reconstruction techniques to enable users to generate accurate and detailed 3D models. While open-source options exist, not all provide simple interfaces that cater to users with limited technical expertise, such as conservators and traditional book scholars. However, for medium-sized projects like book digitisation, commercial software solutions are available with user-friendly interfaces and comprehensive documentation. These solutions accommodate users with varying levels of expertise, fostering broader adoption and usage. It is essential to understand how to implement the imaging technique effectively to achieve satisfactory results for study and research with minimum effort.

4.1 Practical Points for Photogrammetry

Photogrammetry involves capturing and analysing a series of photographs taken from different positions to obtain accurate 3D measurements. The success of the entire procedure relies heavily on acquiring high-quality data. Therefore, ensuring that the image capture network provides sufficient and reliable information is crucial. An advantage of photogrammetry is its data versatility, as the photographs can be utilised across various photogrammetry software systems, even if we focus on outlining the use of specific software. This flexibility allows for experimentation and comparison between different software tools, enabling users to achieve the desired results effectively. Fundamentally, photogrammetry revolves around the ability to measure objects and spaces in three dimensions using two-dimensional inputs, namely photographs. Using mathematical algorithms and advanced techniques, photogrammetry can extract precise measurements and generate detailed 3D models. To obtain accurate measurements, minimising uncertainty is essential. This can be achieved by introducing redundancy in the data. Ideally, every part of the subject being imaged should be covered by multiple viewpoints or camera positions (Figures Figure 1 and Figure 2). Additionally, the captured images should overlap by at least two-thirds to ensure comprehensive coverage and capture all necessary details. By adhering to these practical points in photogrammetry, such as acquiring good enough data, reusing data across software systems, and employing redundancy through overlapping images, users can achieve more accurate and reliable results.

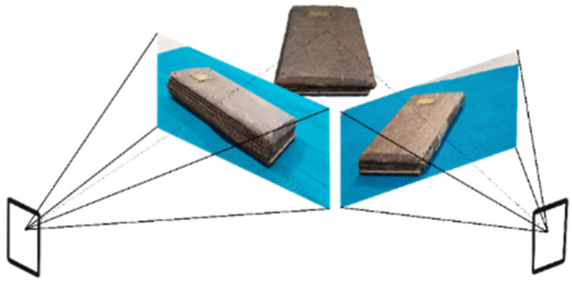

Figure 2. A 3D model generated by combining the information taken from overlapping images of the object (Le Labo - Cambrai Ms 342).

Ideally, one would need a professional or semiprofessional camera, uniform and diffuse lighting that creates as few shadows as possible, as well as targets and scale bars that ensure accurate and photogrammetric measurements (Figure 3). Targets are specific objects or markers placed within the scene being captured. They serve as reference points for the photogrammetry software to accurately calculate distances, orientations, and scales within the 3D reconstruction. On the other hand, scale bars are physical objects of known dimensions placed in the scene. They provide a calibrated reference for the software to accurately measure and scale the reconstructed 3D models (Zhang et al. 2010).[6] These targets and scale bars are crucial in achieving precise and reliable measurements. By including targets in the captured images, the software can triangulate the positions of these points in 3D space, allowing for accurate distance and scale calculations. Scale bars provide a known physical reference within the scene, enabling the software to calibrate the reconstructed models and ensure accurate object sizes and proportions measurements. However, it is important to note that while these ideal conditions are preferred, they may not always be feasible or allowed in normal reading room situations or when using free photogrammetry software. Nevertheless, it is still possible to achieve research-worthy results by using more accessible equipment, such as a compact camera or smartphone with a good camera, and by leveraging the capabilities of free software alternatives.

Figure 3. Example of a scene with diffused lighting setting and reference scale and targets (Le Labo – Cambrai Ms 323).

4.2 An Affordable Software Solution for Photogrammetric 3D Model Generation

In recent years, the field of 3D modelling has witnessed remarkable advancements, revolutionising how researchers, professionals, and enthusiasts create accurate and immersive digital representations of real-world objects. While numerous software solutions exist for photogrammetric 3D model generation, evaluating their capabilities and limitations is essential to choose the most suitable option for specific applications. One notable software solution that stands out is the 3DF Zephyr (free edition) developed by 3DFLOW (https://www.3dflow.net/3df-zephyr-free/).
This software provides a comprehensive suite of tools and features that enable users to process, align, and generate high-quality 3D models from image datasets.

When considering affordable software solutions for 3D model generation, comparing them with other options is crucial. Smartphone apps and cloud-based solutions have gained popularity due to their convenience and accessibility. They offer the ability to generate 3D models on the go, directly from a smartphone (Micheletti, Chandler, and Lane 2015). However, these solutions often have limitations that restrict their utility in certain applications. One common limitation is the lack of offline processing capabilities, making working in environments with limited or no internet connectivity inconvenient.

Additionally, smartphone apps may have limited processing power, restricting their ability to handle large image datasets or challenging scenarios involving complex objects with intricate geometry or textures, such as books and bookbindings. In contrast, the 3DF Zephyr software offers a viable alternative for users seeking more robust processing capabilities. While the free edition does not provide all the advanced features of the paid version, it allows users to process up to 50 images per project, providing sufficient redundancy to capture intricate details of book objects. Furthermore, the inclusion of 3DF Masquerade[7] as a companion tool enhances the accuracy of foreground object representation through semi-automated background removal,

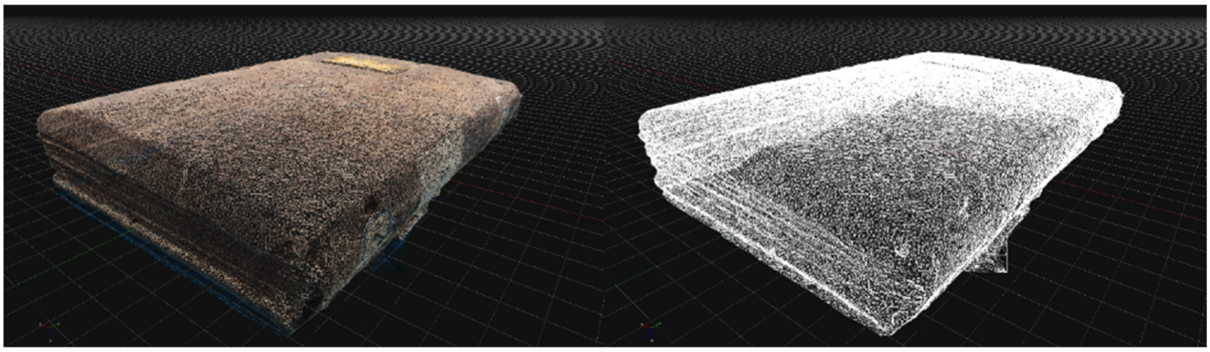

Figure 4. Wireframe rendering (Le Labo - Cambrai Ms 342).

mitigating some of the challenges associated with capturing complex objects.

4.2.1 Workflow for 3D Model Generation

The process of generating a 3D model using 3DF Zephyr follows a well-defined and user-friendly workflow that guides users through each crucial step, from importing the image dataset to obtaining the final textured model. To begin, users select the New Project option and import a series of photographs captured from various angles around the object of interest.[8]

This process is designed to be intuitive, allowing for simple drag-and-drop functionality or image selection from a designated folder. The software supports multiple file formats, including widely used formats such as JPEG and PNG, ensuring compatibility with a wide range of cameras and devices.

Figure 5. The four phases of the 3D model reconstruction: sparse point cloud, dense point cloud, mesh with stereo point cloud colouring, and textured mesh (Le Labo - Cambrai Ms 342.)

Once the images are imported, 3DF Zephyr initiates the camera calibration process, which determines the intrinsic and extrinsic parameters of the camera used to capture the photographs. This calibration step is crucial for the accurate reconstruction of the 3D geometry. By default, the software applies suitable calibration settings for general book projects, providing a solid foundation for subsequent processing steps. Advanced users can fine-tune the calibration parameters based on specific project requirements, allowing for greater control and customisation.

After the camera calibration, the software generates a sparse point cloud that accurately represents the object's structure in 3D space. This step utilises the advanced 3DF Samantha algorithm, which extracts key points from the imported images, aligns them, and constructs the initial sparse point cloud. Leveraging sophisticated techniques such as feature detection and matching, the algorithm establishes correspondences between the images, resulting in a robust and accurate reconstruction of the object's geometry. In the free version of the software, users can upload a maximum of 50 images per project, although a minimum of 40 images is recommended for a satisfactory reconstruction. It is advisable to recapture any images that need to be discarded due to issues such as being out of focus or containing excessive noise. Upon processing sufficient usable images, the software presents a sparse point cloud representation in 3D space (Figure 5, top left).

Once the sparse point cloud is generated, users should proceed to the dense point cloud reconstruction, which enhances the level of detail in the model. This step involves

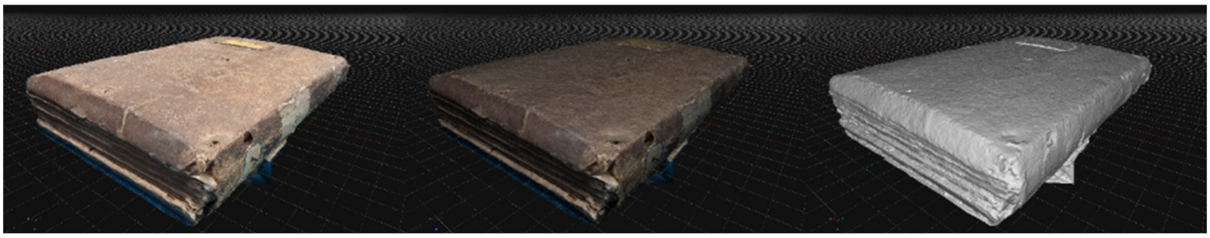

Figure 6. Surface details highlighted by toggling lighting and colour rendering (Le Labo - Cambrai Ms 342).

estimating the depth information for each point in the point cloud, resulting in a more refined representation of the object. The 3DF Stasia algorithm is then employed to densely sample the sparse point cloud and generate a high-quality, dense point cloud. The resulting dense point cloud exhibits a higher level of geometric detail, significantly enhancing the visual fidelity of the 3D model (Figure 5, top right).

After the dense point cloud reconstruction, the software progresses to the final stages of the workflow: meshing and texture mapping. Meshing involves connecting the points in the dense point cloud to create a mesh representation of the object's surface geometry. This process ensures that the mesh is watertight and exhibits consistent topology (Figure 5, bottom left). Subsequently, the texture mapping stage involves projecting the original images onto the mesh surface, adding realistic colour and texture to the 3D model. This step enhances the model's visual appeal, resulting in a more immersive experience for viewers (Figure 5, bottom right).

4.2.2 Exploration and Analysis of the 3D Model and Integration with Additional Software Tools

Upon the completion of the 3D model generation process, users gain the ability to explore and analyse the model thoroughly. 3DF Zephyr offers a user-friendly interface that facilitates seamless manipulation and interaction with the model. Users can effortlessly rotate, zoom, and pan the model, enabling detailed observations from different angles and providing valuable insights into its shape and structure. Furthermore, the software provides a range of visualisation options, allowing users to toggle between wireframe, solid, and textured views. These options offer a comprehensive examination of specific aspects of the model, such as surface topography, by utilising features like wireframe rendering (Figure 4). Additionally, users can control the computed lighting and point cloud colouring, enabling them to reveal finer surface details by activating or deactivating these visual elements (Figure 6). This comprehensive set of visualisation tools empowers users to delve deep into the intricacies of the model and uncover its hidden nuances.

One notable advantage of 3DF Zephyr is its capability to provide metric measurements within the generated 3D model. However, it is important to note that the reconstruction obtained from the structure-from-motion process inherently lacks a known scale factor. To achieve metric scaling and enable accurate measurements, it becomes necessary to introduce at least one distance constraint or control point constraint. While precise measurements typically require scale bars and targets, which are exclusive to the full version of the software, the free edition offers a workaround for obtaining approximate metric measurements. By incorporating known metric distance constraints, users can scale the reconstructed model and perform measurements with reasonable accuracy. This functionality is particularly valuable in applications involving dimensional analysis or comparative measurements. To illustrate this process, consider a scenario where the user possesses at least one measurement in millimetres for the 3D reconstruction. For instance, let us assume the known height of the book is 200 mm. To apply metric scaling, users can utilise the quick measurement tool. By selecting the first and last points of the desired distance (corresponding to virtual points representing where measurements would have been taken in the real world), the measured distance is determined, such as 28.8749. With knowledge of the "real" distance in metric space

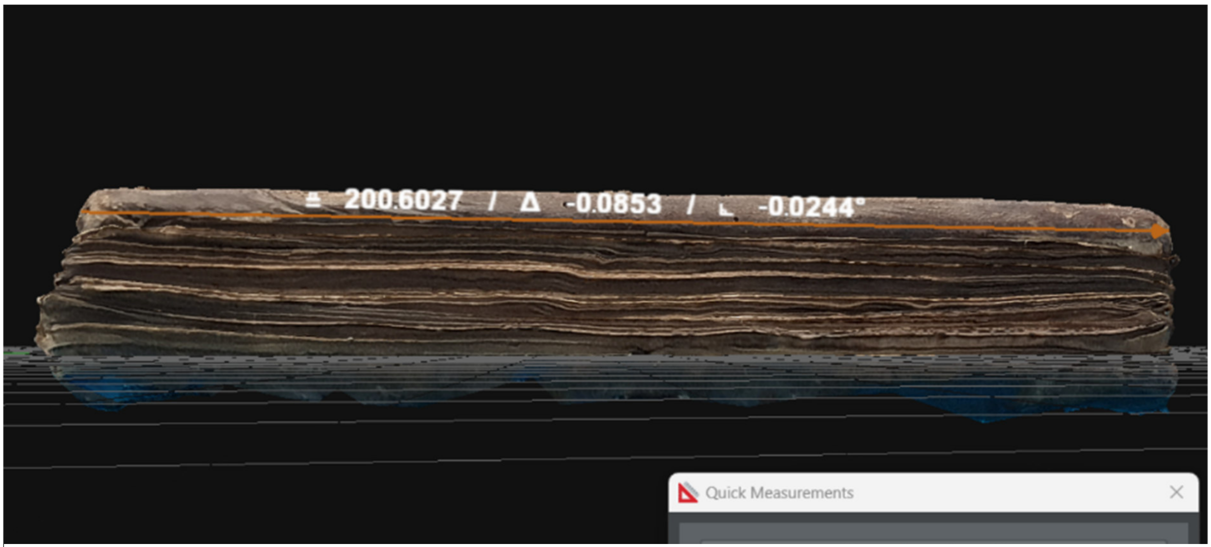

Figure 7. Distance measured in metric units after adjusting the scale of the model (Le Labo - Cambrai Ms 342).

(millimetres), it can be inferred that the reconstructed object needs to be scaled by a factor of 200 / 28.8749 = 6.9264. To achieve this scaling, users can employ the Scale/Rotate/Translate object tool and manually input a scale factor of 7.0000 (rounded up). Subsequently, the world would be scaled metrically, enabling metric measurements using the quick measurement tool. As a result, the plotted distance measurement will now approximate 200 mm for the same segment as before (Figure 7).

Finally, it is important to acknowledge the limitation of the 3D model generated using the process above. Since the model is based on a set of images taken with the book placed on one of its sides, it inherently lacks information regarding the hidden side of the object. The process should then be repeated for both sides of the book. As a consequence of the modelling procedure, when the model is turned upside down, it will appear empty, with the upper side mirrored 'inside' the open 'box-book'. While this limitation may hinder the production of full virtual reproductions of the book, it offers distinct advantages within the context of capturing detailed information about the shape and surface topography of the object. By observing the surface details in reverse, certain features can be highlighted and made more discernible to the eyes, providing valuable insights during analysis (Figure 8). Although achieving a comprehensive 3D model would require a more professional setup, the current approach captures detailed information for in-depth study, allowing users to explore the object's characteristics without physically handling it or being present at the library.

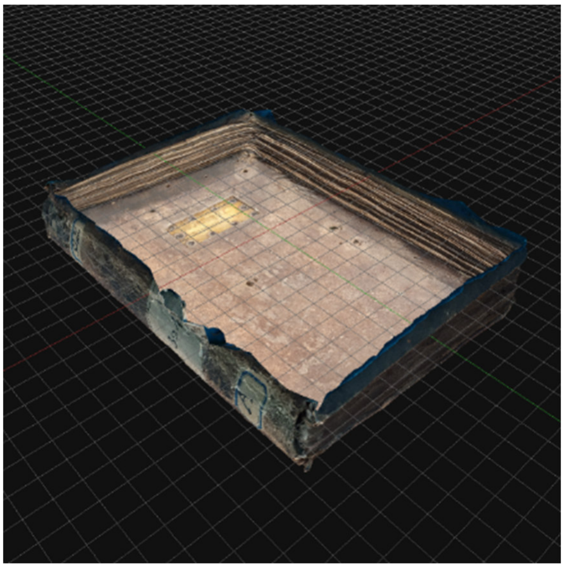

Figure 8. "Empty box" effect of the model when turned upside-down (Le Labo - Cambrai Ms 342).

To enhance the functionality and expand the capabilities of 3DF Zephyr, the software offers the option to export the generated 3D model in various standard formats, including OBJ or PLY. By providing compatibility with a wide range of 3D modelling and visualisation software, these formats allow users to further analyse, edit, or render the model according to their specific requirements. For users seeking to create a complete 3D model based on the photogrammetric modelling of both sides of an object, an additional software tool called

CloudCompare (https://www.danielgm.net/cc/) can be utilised. CloudCompare offers advanced post-processing capabilities and the ability to merge multiple 3D models, adding flexibility and versatility to the modelling workflow. To generate the complete 3D model, the process involves exporting the models from 3DF Zephyr and saving them as *.obj files. These models can then be loaded into CloudCompare, where the next steps are performed. To ensure a seamless merging of the models, it is recommended to use the Segment tool in CloudCompare to remove any poorly meshed parts from the underside of both models. Once the cleaning process is complete, users can select and align both models using the Align tool in CloudCompare. This alignment process involves identifying at least four overlapping points in both models. By aligning and combining the models based on these common points, a complete 3D model is generated within CloudCompare. This full 3D model can then be exported as a compatible 3D object file, which can be opened and further utilised with any standard 3D software.

Figure 9. Full 3D model after re-joining the two half models in CloudCompare (Le Labo - Cambrai Ms 342).

5 Conclusions

The digitisation of cultural heritage materials, particularly books and manuscripts, has ushered in unprecedented possibilities for their preservation and study. In this paper, we have explored the significance of codex variation and the inherent challenges in capturing the materiality and craftsmanship of these complex objects through traditional digitisation techniques. To address these limitations, we focused on photogrammetry, an imaging technique with immense versatility and accessibility, and its potential to revolutionise the study of cultural artefacts.

While the potential of advanced imaging techniques (e.g., spectral imaging, high-resolution digital microscopy, RTI, and photogrammetry) is undeniable, concerns over cost and accessibility remain. Here, we addressed these barriers by exploring the practicality of affordable photogrammetry. The democratisation of photogrammetry through affordable consumer-grade cameras and user-friendly software, such as the 3DF Zephyr (free edition), can empower researchers, conservators, and traditional book scholars to engage with this technique and capture detailed 3D models of cultural artefacts.

We propose a workflow for 3D model generation using 3DF Zephyr that can guide users through the crucial steps of camera calibration, sparse and dense point cloud reconstruction, meshing, and texture mapping and methodologies to make virtual measurements and work with the 3D model.

The accessibility and effectiveness of this technique can empower researchers, conservators, and scholars to unlock and virtualise further details of the materiality and craftsmanship of books and manuscripts that were once concealed or untransferred into the digital. Emerging technologies and advancements in imaging techniques will continue to push the study and preservation of cultural heritage. Through this research, we hope to inspire and encourage wider adoption of photogrammetry, fostering a community of empowered individuals dedicated to the conservation and study of our shared cultural legacy.

In conclusion, the democratization of photogrammetry empowers researchers and scholars to preserve and study cultural heritage materials with unprecedented detail and accessibility, unlocking a future of comprehensive exploration and sharing of our rich cultural legacy.

6 Perspectives of future collaborations with the host laboratory

During my research residency at the Centre d'études supérieures de la Renaissance (CESR) at the University of Tours, I had the privilege of engaging with a dynamic academic community dedicated to exploring digital humanities (DH) approaches in studying written cultural heritage. Under the leadership of Prof. Elena Pierazzo, CESR stands as a frontrunner in this field, providing an intellectually stimulating environment for innovative research.

In the upcoming academic year, I am looking forward to contributing to the DH master's program by offering classes on photogrammetry and other techniques for digitising the materiality and structure of books. These classes aim to equip the students with essential skills for uncovering hidden insights within cultural artefacts, empowering them to approach the analysis of written heritage with advanced methodologies.

A notable collaborative project with Prof. Elena Pierazzo centred on modern manuscripts, exploring the potential of digital means to study manuscript culture after the introduction of printing. Our collective efforts led to the successful organisation of an international conference on Digital Codicology, held from 10th to 12th May 2023. The event was generously funded by le Studium and co-financed by Équipex Biblissima+, Cluster 4 (Traitement approfondi des systèmes graphiques et analyse des documents), and the Beasts2Craft ERC project of Prof. Matthew Collins. This pioneering event brought together scholars from various disciplines and established Digital Codicology as a significant and indispensable area of inquiry.

Building on the conference's momentum, we are pleased to announce the launch of a new book series published by Brepols, with Prof. Elena Pierazzo and me serving as editors-in-chief. This publication platform will facilitate disseminating cutting-edge research in Digital Codicology and related fields, fostering scholarly exchange and collaboration.

Beyond specific projects, my residency at CESR has facilitated valuable interactions and cross-pollination of research endeavours. The diverse academic community at CESR has provided fertile ground for future collaborations and promising research trajectories. These interactions have opened new avenues for exploring the material dimensions of cultural heritage through digital exploration. As we collectively delve deeper into the study of written cultural heritage, I am excited about the potential for CESR to continue playing a pivotal role in shaping the future of Digital Codicology and fostering interdisciplinary collaboration in digital humanities.

7 Conference Presentations and Research Dissemination

During the duration of this research fellowship, the findings were presented at the 19th International Seminar on the Care and Conservation of Manuscripts, hosted by the University of Copenhagen from 19th to 21st April 2023. This conference stands as one of the leading gatherings at the crossroads of conservation, manuscript studies, and digital humanities, attracting prominent scholars and experts.

The presentation was met with a positive reception from the academic and conservation community attending the seminar. Engaging discussions following the talk underscored the significance of integrating digital methodologies in studying cultural artefacts. This conference presentation served as a crucial platform to disseminate the initial research results, fostering awareness and stimulating interest in the field of Digital Codicology and the broader applications of affordable photogrammetry in cultural heritage studies.

The research outcomes from this fellowship will be further developed into a scholarly article planned for publication in the conference proceedings, to be published by the University of Copenhagen Press and scheduled for release in 2025. By contributing to the conference proceedings, this research will reach a broader audience of experts and enthusiasts, enriching the ongoing discourse in the field and facilitating cross-collaboration among scholars dedicated to preserving and exploring written cultural heritage.

8 Acknowledgements

I want to express my heartfelt gratitude to the Centre d'études supérieures de la Renaissance (CESR) at the University of Tours for allowing me to conduct my research as part of this fellowship. Prof. Elena Pierazzo's invaluable guidance and unwavering support enriched my research experience, creating an intellectually stimulating environment for exploration and discovery.

I am immensely thankful to the CESR community for their warm welcome and collaborative spirit, facilitating fruitful interactions and cross-pollination of ideas. The generous funding provided by le Studium, Équipex Biblissima+, Cluster 4 (Traitement approfondi des systèmes graphiques et analyse des documents), and the Beasts2Craft ERC project of Prof. Matthew Collins played a crucial role in the successful organisation of the international conference on Digital Codicology. I would also like to extend my appreciation to Brepols for their interest in launching the new book series.

I am deeply grateful to all the scholars, experts, and colleagues who attended the 19th International Seminar on the Care and Conservation of Manuscripts. The engaging discussions and constructive feedback received during the conference significantly enriched the development of my work.

I thank Dr Sara Pretto and all the staff of the *Espace patrimoine* of Le Labo – Cambrai for their help and their warm and attentive hospitality.

Finally, I acknowledge the support of Le Studium Loire Valley Institute for Advanced Studies for funding my research fellowship and making this project possible.

9 References

Adams, Thomas R., and Nicolas Barker. 1993. 'A New Model for the Study of the Book'. In *A Potencie of Life: Books in Society, the Clark Lectures 1986-1987*, edited by Nicolas Barker, 5–43. London: British Library.

Adorisio, Antonio, and Carlo Federici. 1980. 'Un manufatto medievale poco noto: il codice'. *Archeologia Medievale* 7 (January): 483–506.

Beasts2Craft. 2020. 'Beasts2Craft. Biocodicology as a New Approach to the Study of Parchment Manuscripts'. 2020. http://web.archive.org/web/20201215165250/https://sites.google.com/palaeome.org/ercb2c/home.

Beckett, Jamie. 2000. 'Picturing the Past. HP Labs Technology Helping Scholars Decipher Ancient Texts'. Hp Labs - News. 6 December 2000. https://web.archive.org/web/20010414013002/http://www.hpl.hp.com:80/news/2000/oct-dec/3dimaging.html.

Campagnolo, Alberto. 2020. 'Understanding the Artifactual Value of Books'. In *Book Conservation and Digitization. The Challenges of Dialogue and Collaboration*, edited by Alberto Campagnolo, 17–48. Leeds: Arc Humanities Press.

Clarkson, Christopher. 1978. 'The Conservation of Early Books in Codex Form. A Personal Approach: Part 1'. *The Paper Conservator* 3 (1): 33–50. https://doi.org/10.1080/03094227.1978.9638508.

Duffy, Christina. 2015. 'A CT Scan of the St Cuthbert Gospel - Collection Care Blog'. *British Library, Collection Care Blog* (blog). 26 June 2015. https://blogs.bl.uk/collectioncare/2015/06/a-ct-scan-of-the-st-cuthbert-gospel.html.

Fenech, Ann, Matija Strlič, Irena Kralj Cigić, Alenka Levart, Lorraine T. Gibson, Gerrit de Bruin, Konstantinos Ntanos, Jana Kolar, and May Cassar. 2010. 'Volatile Aldehydes in Libraries and Archives'. *Atmospheric Environment* 44 (17): 2067–73.

https://doi.org/10.1016/j.atmosenv.2010.03.021.

Fiddyment, Sarah, Bruce Holsinger, Chiara Ruzzier, Alexander Devine, Annelise Binois, Umberto Albarella, Roman Fischer, et al. 2015. 'Animal Origin of 13th-Century Uterine Vellum Revealed Using Noninvasive Peptide Fingerprinting'. *Proceedings of the National Academy of Sciences* 112 (49): 15066–71. https://doi.org/10.1073/pnas.1512264112.

Fiddyment, Sarah, Matthew D. Teasdale, Jiří Vnouček, Élodie Lévêque, Annelise Binois, and Matthew J. Collins. 2019. 'So You Want to Do Biocodicology? A Field Guide to the Biological Analysis of Parchment'. *Heritage Science* 7 (1): 35. https://doi.org/10.1186/s40494-019-0278-6.

Foot, Mirjam M. 1993. 'Bookbinding and the History of Books'. In *A Potencie of Life: Books in Society: The Clark Lectures 1986-1987*, edited by Nicolas Barker, 113–26. London: British Library.

France, Fenella G. 2016. 'Spectral Imaging: Capturing and Retrieving Information You Didn't Know Your Library Collections Contained'. In *What Do We Lose When We Lose a Library?*, edited by Lieve Watteeuw and Mel Collier, 189–97. Leuven: KU Leuven University Library. https://www.goethe.de/resources/files/pdf94/streamgate.pdf.

———. 2020. 'Spectral Imaging to Aid Preservation and Conservation of Cultural Heritage'. In *Book Conservation and Digitization. The Challenges of Dialogue and Collaboration*, edited by Alberto Campagnolo, 169–78. Collection Development, Cultural Heritage, and Digital Humanities. Leeds: Arc Humanities Press.

France, Fenella G., Doug Emery, and Michael B. Toth. 2010. 'The Convergence of Information Technology, Data, and Management in a Library Imaging Program'. *The Library Quarterly: Information, Community, Policy* 80 (1): 33–59. https://doi.org/10.1086/648462.

Frost, Gary L. 1996. 'Mobility and Function in the Codex Bookbinding'. In *Roger Powell, the Complete Binder: Liber Amicorum*, edited by John Lawrence Sharpe, 92–106. Bibliologia: Elementa Ad Librorum Studia Pertinentia 14. Turnhout: Brepols.

Garside, Paul, Mariluz Beltran de Guevara, and Christina Duffy. 2016. 'The Repercussions of a Historic Library Fire: The Benefits of a Multidisciplinary Approach to Treating Fire-Damaged Parchment from the Cotton Collection'. In *What Do We Lose When We Lose a Library?*, edited by Lieve Watteeuw and Mel Collier, 199–205. Leuven: KU Leuven University Library. https://www.goethe.de/resources/files/pdf94/streamgate.pdf.

Giacometti, Alejandro, Alberto Campagnolo, Lindsay MacDonald, Simon Mahony, Stuart Robson, Tim Weyrich, Melissa Terras, and Adam Gibson. 2017. 'The Value of Critical Destruction: Evaluating Multispectral Image Processing Methods for the Analysis of Primary Historical Texts'. *Digital Scholarship in the Humanities* 32 (1): 101–22. https://doi.org/10.1093/llc/fqv036.

Heng Siong, E. H., M. F. M. Ariff, and A. F. Razali. 2023. 'The Application of Smartphone-Based Structure from Motion (SfM) Photogrammetry in Ground-Volume Measurement'. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XLVIII-4-W6-2022 (February): 145–52. https://doi.org/10.5194/isprs-archives-XLVIII-4-W6-2022-145-2023.

Kirschenbaum, Matthew, and Sarah Werner. 2014. 'Digital Scholarship and Digital Studies: The State of the Discipline'. *Book History* 17 (1): 406–58. https://doi.org/10.1353/bh.2014.0005.

Korthagen, Ilse, Femke Prinsen, Lieve Watteeuw, and Bruno Vandermeulen. 2019. 'Digitization of Manuscripts. Checklist 2.0'. Metamorfoze. http://web.archive.org/web/20201227215121/https://www.metamorfoze.nl/sites/default/files/publicatie_documenten/Checklist%20for%20the%20digitisation%20of%20manuscripts%20-%202.0%20-%20Ilse%20Korthagen,%20Femke%20Prinsen,%20Lieve%20Watteeuw%20and%20Bruno%20Vandermeulen%20-%202019.pdf.

Luhmann, Thomas, Stuart Robson, Stephen Kyle, and Jan Boehm. 2019. 'Close-Range Photogrammetry and 3D Imaging'. In *Close-*

Range Photogrammetry and 3D Imaging. De Gruyter. https://doi.org/10.1515/9783110607253.

Malzbender, Tom, and Dan Gelb. 2001. ‘Polynomial Texture Mapping (Ptm) Research’. Hp Labs. 3 May 2001. https://web.archive.org/web/20010503142438/http://www.hpl.hp.com/ptm/.

McKitterick, David. 2013. *Old Books, New Technologies: The Representation, Conservation and Transformation of Books since 1700*. Cambridge; New York (NY): Cambridge University Press.

Micheletti, Natan, Jim H. Chandler, and Stuart N. Lane. 2015. ‘Investigating the Geomorphological Potential of Freely Available and Accessible Structure-from-Motion Photogrammetry Using a Smartphone’. *Earth Surface Processes and Landforms* 40 (4): 473–86. https://doi.org/10.1002/esp.3648.

Monterisi, Cristina, Alessandra Capolupo, and Eufemia Tarantino. 2023. ‘Crowdsensing Close-Range Photogrammetry for Accurately Reconstructing a Digital Twin of a Cultural Heritage Building Using a Smartphone and a Compact Camera’. In *Computational Science and Its Applications – ICCSA 2023 Workshops*, edited by Osvaldo Gervasi, Beniamino Murgante, Ana Maria A. C. Rocha, Chiara Garau, Francesco Scorza, Yeliz Karaca, and Carmelo M. Torre, 234–50. Lecture Notes in Computer Science. Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-37114-1_16.

Perre, Athena van der, Hendrik Hameeuw, Vanessa Boschloos, Luc Delvaux, Marc Proesmans, Bruno Vandermeulen, Luc van Gool, and Lieve Watteeuw. 2016. ‘Towards a Combined Use of IR, UV and 3D-Imaging for the Study of Small Inscribed and Illuminated Artefacts’. In *Lights On… Cultural Heritage and Museums!*, edited by Paula Menino Homem, 163–92. Porto: LabCR, Laboratory for Conservation and Restoration; FLUP, Faculty of Arts and Humanities, University of Porto.

Pickwoad, Nicholas. 1995. ‘The Interpretation of Bookbinding Structure: An Examination of Sixteenth-Century Bindings in the Ramey Collection in the Pierpont Morgan Library’. *The Library* 17 (3): 209–49. https://doi.org/10.1093/library/s6-17.3.209.

———. 2014. ‘The structures and materials of commercial bookbindings in the Arcadian Library’. In *The Arcadian Library: bindings and provenance*, 233–78. Studies in the Arcadian Library, no. 9. London: Arcadian Library in association with Oxford University Press.

———. 2015. ‘Binding’. In *The St Cuthbert Gospel: Studies on the Insular Manuscript of the Gospel of John (BL, Additional MS 89000)*, edited by Claire Breay and Bernard Meehan, 41–63. London: The British Library.

Pollard, Graham. 1975. ‘Some Anglo-Saxon Bookbindings’. *The Book Collector* 24 (1): 130–59.

Saif, Wahib, and Adel Alshibani. 2022. ‘Smartphone-Based Photogrammetry Assessment in Comparison with a Compact Camera for Construction Management Applications’. *Applied Sciences* 12 (3): 1053. https://doi.org/10.3390/app12031053.

Strlič, Matija, Jacob Thomas, Tanja Trafela, Linda Cséfalvayová, Irena Kralj Cigić, J. J. Kolar, and May Cassar. 2009. ‘Material Degradomics: On the Smell of Old Books’. *Analytical Chemistry* 81 (20): 8617–22. https://doi.org/10.1021/ac9016049.

Terras, Melissa M. 2015. ‘Cultural Heritage Information: Artefacts and Digitization Technologies’. *Cultural Heritage Information*, 63–88.

Vandermeulen, Bruno, Hendrik Hameeuw, Lieve Watteeuw, Luc van Gool, and Marc Proesmans. 2018. ‘Bridging Multi-Light & Multi-Spectral Images to Study, Preserve and Disseminate Archival Documents’. In *Archiving 2018 Final Program and Proceedings*, 64–69. Washington (DC): Society for Imaging Science and Technology. https://doi.org/10.2352/issn.2168-3204.2018.1.0.15.

Watteeuw, Lieve, Hendrik Hameeuw, Bruno Vandermeulen, Athena van der Perre, Vanessa Boschloos, Luc Delvaux, Marc Proesmans, Marina van Bos, and Luc van Gool. 2016. ‘Light, Shadows and Surface Characteristics: The Multispectral Portable Light Dome’. *Applied Physics A* 122 (11): 976. https://doi.org/10.1007/s00339-016-0499-4.

Watteeuw, Lieve, and Bruno Vandermeulen. 2016. ‘RICH Project’. Illuminare. 19 October

2016. https://web.archive.org/web/20161019214848/http://www.illuminare.be/rich_project.

Watteeuw, Lieve, Bruno Vandermeulen, Jan van der Stock, Frederik Truyen, Marc Proesmans, Luc van Gool, and Stefan Gradmann. 2014. 'Imaging the Topography of Illuminations and Bookbindings with Reflectance Transformation Imaging'. In *ICOM-CC 17th Triennial Conference. Building Strong Culture through Conservation*. Melbourne: ICOM. https://lirias.kuleuven.be/retrieve/282651.

Zhang, De-hai, Liang Jin, Cheng Guo, Jian-Wei Liu, Xiao-Qiang Zhang, and Zhi-Xin Chen. 2010. 'Exploitation of Photogrammetry Measurement System'. *Optical Engineering* 49 (3): 037005. https://doi.org/10.1117/1.3364057.

Notes

[1] A codex refers to a specific format of a book that has become the standard in Western culture. It consists of pages bound together on one side, resembling the modern book format we are familiar with today. The codex format replaced earlier forms, such as scrolls, and revolutionized the way information was organized and accessed. The codex format played a significant role in shaping the development of written knowledge and has remained the dominant form of book production for centuries.

[2] Spectral imaging refers to a specialized imaging technique that captures and records the interaction between materials and different wavelengths of light across the electromagnetic spectrum. It involves the acquisition of multiple images, each corresponding to a specific wavelength or narrow band of wavelengths. By analysing the spectral response of materials, spectral imaging enables the recovery and visualization of hidden details, such as faded or obscured features, pigments, and inks that may not be perceptible to the human eye or traditional imaging methods. This technique plays a crucial role in the non-destructive examination, analysis, and preservation of cultural heritage objects, providing valuable insights into their composition, condition, and historical context (Giacometti et al. 2017, 101).

[3] High-resolution digital microscopy is an imaging technique that utilizes advanced optics and digital sensors to capture highly detailed and magnified images of objects at a microscopic level. It enables the visualization of small-scale features, such as microfractures, loss of pigments or inks, and other signs of degradation that may not be visible to the naked eye or traditional microscopy methods. With its ability to provide enhanced resolution and clarity, high-resolution digital microscopy is a valuable tool for examining and documenting the material characteristics and condition of cultural heritage objects, aiding in conservation and research efforts (Garside, Beltran de Guevara, and Duffy 2016, 202–3).

[4] Photogrammetry is a technique that uses overlapping photographs and computational algorithms to create three-dimensional digital models of objects or environments.

[5] Reflectance Transformation Imaging (RTI) is a specialized photographic technique used to capture and reveal the shape and surface information of objects. It involves capturing a series of images of an object illuminated from different directions using a fixed camera position. These images are then processed using computational algorithms to create an interactive and manipulable digital representation of the object. RTI allows for the exploration of fine surface details, such as textures, brushstrokes, and surface irregularities, that might otherwise go unnoticed (Malzbender and Gelb 2001; Beckett 2000).

[6] In the commercial market, there are various professional scale bars available, but they can be expensive, costing approximately 500 EUR each. Cultural Heritage Imaging offers a set of more affordable scales; however, purchasing the complete set of 12 costs 569 USD, and most of these scales are too large to be practical for a library setting (https://culturalheritageimaging.org/What_We_Offer/Gear/Scale_Bars/index.html). An excellent alternative is provided by Heinrich Mallison of Palaeo3D (http://palaeo3d.de/WP/?page_id=23), where scales can be purchased individually for as little as 10 EUR (plus shipping). (All website links have been checked in July 2023 and are available on the Wayback Machine of the Internet Archive: http://web.archive.org/).

[7] Masquerade only allows saving the new files in the native 3DF Zephyr format (*.bim), but it does works seamlessly, and it is very intuitive. 3DF Zephyr guides the user through the steps to generate the 3D model, and Masquerade can be called within the workflow by selecting 'Additional imports: Image mask' at the beginning of the New Project Wizard.

[8] It should be noted that 3DF Zephyr now accepts video input as well, but photography quality (for archiving and reusing the same dataset at a later stage) is better in still image capture.