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EVALUATION OF SFM AND LIDAR TECHNOLOGY FOR MAPPING INSCRIBED ARTIFACTS. PRELIMINARY OBSERVATIONS STARTING FROM THE RESEARCH PROJECT 'RAVENNA AND ITS LATE ANTIQUE AND MEDIEVAL EPIGRAPHIC LANDSCAPE'

1. Introduction

The digitization of collections has become a widely adopted strategy among institutions and museums to enhance accessibility and reach a broader audience (Corona 2023, 73-74). This process involves converting physical artifacts, documents, and other items into digital formats, making them available online for the general public, researchers, students, and history enthusiasts as well. In the context of the 'Ravenna and its Late Antique and Medieval Epigraphic Landscape' project, the digitization process is a 'best practice' that has been decided upon for the implementation of late antique, Byzantine and medieval Ravenna inscriptions in a website conforming to the principles the acronym FAIR (Findable, Accessible, Interoperable, Reusable)[1].

2. Project overview

Considering the city's significance – as the capital of the Western Roman Empire in 402, following the transfer of the imperial court from Milan by Emperor Honorius – and the extensive body of scholarship dedicated to it, there currently lacks a systematic and comprehensive edition of its epigraphic evidence. This deficiency persists despite notable works that scrutinize individual texts or incorporate references to Ravenna's inscriptions within broader historical, art-historical, or archaeological contexts (the list is extensive, and by way of example see only: Bollini 1975; Rugo 1976; Fiori 2008). A recent monograph exclusively addresses Greek inscriptions up to the 7th century, leaving out Latin documentation (Bencivenni 2018). From the testimony of Byzantine and Renaissance humanistic historiography, for example, from the protohistorian of the 9th century Andrea Agnello (Deliyannis Mauskopf 2006), one can infer the loss of important epigraphic documents. Therefore, what has been published represents only a limited percentage compared to the entire epigraphic heritage, which has so far never been accurately calculated.

[1] The research is directed by Prof. S. Cosentino (Department of Cultural Heritage of *Alma Mater Studiorum* – University of Bologna) whom I thank to be involved in the project for the aspects related the 3D digitization process and the re-contextualisation of inscriptions in urban and architectural space.

Fig. 1 – Roman settlement boundary created using QGIS by the Author.

In short, the project aims to preserve and make accessible an important aspect of Ravenna's cultural heritage, consisting of the city inscriptions produced between 402 and 1411. In the context of this broad historical framework, one of the tasks of the research is to create 3D models of the artefacts and a digital platform to promote this still little-known type of documentation of Ravenna's history to the heritage community. In addition to utilizing 3D scanning, the project envisions the re-contextualization of the epigraphic artifacts, considering their interaction with the physical environment, settlements, and the social landscape. Diverse GPS data will be linked to each object, including its current location, the potential place of re-use (if applicable), and the original location of first use, if distinct. The initial GPS coordinate is acquired during the 3D scanning phase, while the second and third coordinates are obtained through the systematic mapping process utilizing QGIS (Fig. 1).

It is expected that the digital models and metadata will be accessible online upon the completion of the project (2026-2027), coinciding with the publication in open access. The collection of digitized objects will essentially serve as an archive containing the 3D data, metadata describing the objects from an archaeological perspective, and paradata detailing the digitization process, all organized within a simple database structure. All gathered information will be accessible through a web interface. Web access is an essential point in the project, as it makes possible for all target stakeholders to access at the data, fulfilling the FAIR principles. The 3D visualization component, hopefully, will be based on the ATON tool (https://osiris.itabc.cnr.it/aton/). The latter is the open-source Web3D/WebXR framework by CNR-ISPC. Within ATON each user has its own collection (3D models, 360 panoramas, audio, etc.) that contains web-ready items that will be arranged into scenes.

So far, approximately 110 epigraphs have been examined, the majority of which are stored under conditions that make it challenging to relocate and study them. The epigraphs are currently housed in the National Museum of Ravenna[2], in the Archiepiscopal Museum, and in several basilicas within the city. Some are displayed affixed to the wall using metal studs, while others are stored in storing rooms on various supports, such as shelves.

3. Challenges to SfM and LiDAR technology

The process of 3D scanning in museum storage areas is essential for managing, preserving, and documenting collections, but it comes with various challenges, particularly with regard to epigraphs stored in the National Museum. One significant obstacle is the limited space within these storage areas (Fig. 2), where a vast quantity of other objects and artworks is housed in confined environments. This spatial constraint makes it challenging to access objects for 3D scanning, often requiring the use of specialized equipment to reach remote areas. Additionally, adequate lighting is crucial for capturing precise details in 3D scans. However, in storage areas of the National Museum – problematic not only for the museum in Ravenna but also for many others – natural light is often limited. Consequently, the use of appropriate artificial lighting sources becomes imperative to ensure accurate scanning results. Another challenge is posed by the diverse size and shape of artworks within museums, ranging from small and delicate pieces to large and intricate

[2] I would like to thank the former director, Dr. Letizia Lodi, and the current director, Arch. Dr. Serena Ciliani, of the National Museum of Ravenna for granting permission for the autoptic study, surveying, and photographing of the *corpus* of Ravenna epigraphs stored at the museum. Additionally, I would like to express my gratitude for the great helpfulness and kindness of Drs. Paola Novara and Elisa Emaldi, for their assistance in accessing the museum's inventories and storing rooms.

Fig. 2 – A storing room of the National Museum of Ravenna in 2023.

sculptures. This necessitates the adaptability of 3D scanning equipment to capture details across this wide spectrum of objects. Overall, despite these challenges, the 3D scanning process remains crucial for the comprehensive documentation and preservation of museum artifacts.

An additional constraint exists in the Archiepiscopal Museum (Fig. 3), where the epigraphs on slabs are positioned on the walls, some at considerable heights, making it impractical to remove them for scanning purposes. This limitation adds another layer of complexity to the 3D scanning process, requiring innovative solutions or alternative approaches to capture accurate digital representations of these elevated epigraphs.

Due to these circumstances, it was decided to use photogrammetry and test LiDAR technology. The Structure from Motion (SfM) technique, a

Fig. 3 – Archiepiscopal Museum of Ravenna in 2023.

well-known procedure, is a methodology used to reconstruct the three-dimensional structure of objects or representations from a series of two-dimensional images acquired from different perspectives. This technique can be applied to the survey of small objects, such as art objects, archaeological artifacts, manufactured objects, and more (consider the following studies as illustrative examples: Aicardi *et al.* 2018; Brandolini, Patrucco 2019; Barszcz *et al.* 2021).

LiDAR stands out as a versatile and well-established technology with a broad spectrum of practical applications. It recently became accessible to smartphone users through the iPhone 12 and 13 Pro, as well as the iPad Pro (Apple Inc., Press Release March 18, 2020), which has increased public awareness of its capabilities, and has also sparked interest in the archaeology of architecture (e.g. Fiorini 2022; Vacca 2023). Introduced to the market primarily for applications in augmented reality (Nocerino *et al.* 2017; Apple 2020), the LiDAR system, deployed by Apple, comprises two essential components: a transmitting element and a receiving element. By combining transmission and reception data, along with their respective timings, a comprehensive 3D map is meticulously generated. The LiDAR sensor executes continuous scanning and operates more analogous to video footage, distinguishing itself from Time of Flight (ToF) sensor incorporated in various smartphone that is similar to capturing a three-dimensional photograph of the scene (Pezzali 2020). This functionality offers variable precision, ranging from 3 mm to 9 mm, while adhering to a predetermined scanning depth.

4. Data acquisition

In this study, a dynamic acquisition was conducted within the indoor confines of the National Museum storing rooms (Fig. 4). The primary objective was to perform a comparative analysis of the processing time associated with

Fig. 4 – Workspace setup at the National Museum of Ravenna in 2023.

Object A Measurement (ID 6)	Length measured manually (mm)	SfM length (mm)	LiDAR length (mm)	LiDAR Error (%)	File size SfM (.obj - MB)	File size LiDAR (.obj - MB)
1	235	234	220	0.15	17	15.1
2	-	235	230	0.05	24	18.8
3	-	235	235	0	19.3	17.4

Object B Measurement (ID 42)	Length measured manually (mm)	SfM length (mm)	LiDAR length (mm)	LiDAR Error (%)	File size SfM (.obj - MB)	File size LiDAR (.obj - MB)
1	350	351	340	0.1	23.2	17.8
2	-	354	350	0	28	20.0
3	-	350	360	0.1	32	18.6

Object C Measurement (ID 97)	Length measured manually (mm)	SfM length (mm)	LiDAR length (mm)	LiDAR Error (%)	File size SfM (.obj - MB)	File size LiDAR (.obj - MB)
1	420	422	430	0.1	19.9	18.0
2	-	420	420	0	20.1	21.3
3	-	421	425	0.05	18.5	19.7

Fig. 5 – Comparison of direct, SfM, and LiDAR measurements.

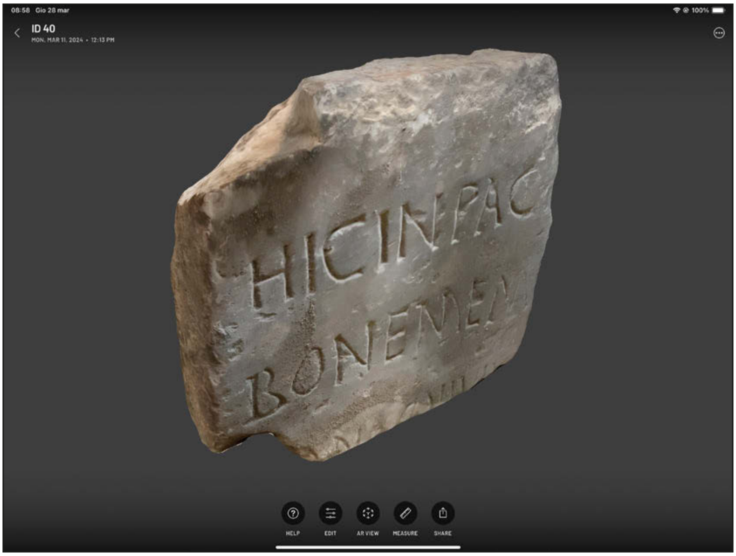

Fig. 6 – A screenshot displaying one of the 3D models, showcasing the application being used on the screen.

two methodologies. The aim was to evaluate the feasibility and efficiency of the proposed methodology within the context of relatively low-cost workstation solutions. The focus centered on assessing the time required for data processing, aiming to gain insights into the practicality and viability of the proposed approach in scenarios where cost-effective workstation solutions take precedence. Concurrently, a preliminary assessment has been initiated to ascertain the level of definition of the 3D model and the size of the generated files (Fig. 5).

The 3D model was generated using the free app Scaniverse (version 2.1.8) and the photogrammetric software Agisoft Metashape Professional (version 1.8.4). The data processing of the acquired images was performed on two portable workstations: an iPad Pro (12.9-inch, 5^{th} generation) and a laptop ASUS Vivobook Pro 16X OLED (N7600, 11^{th} Gen Intel: CPU Intel(R) Core™ i7-11370H, 32GB 3200 MHz DDR4, 1TB PCIe® SSD, NVIDIA GeForce® RTX™ 3050).

The workflow time was calculated excluding the creation of the shooting set, thus not considering the arrangement of the LED lighting essential for the success of the two methods – within the museum's storing rooms – and the time for the handling of the objects, not all of which can always be removed.

A typical work session using the Apple LiDAR sensor lasts for 2 hours, focusing on 15 objects with dimensions ranging from a minimum of height

0.16 m; width 0.135 m; depth 0.052 m to a maximum of height 0.73 m; width 0.51 m; depth 0.09 m. With an average of 8 minutes of LiDAR scanning per artifact. The survey is performed at less than 0.20 m by walking around the objects (Fig. 6). At the conclusion of the scanning process, the models become promptly accessible, georeferenced, and uploaded to the cloud.

The working session involving the same objects, albeit employing the SfM technique, spans a duration of 3 hours, during which the photographs destined for post-production are captured, with an average of 12 minutes of LiDAR scanning per artifact. The processing duration for photogrammetric shots, encompassing tasks such as downloading and configuring software parameters culminating in the generation of the final model, is estimated to be approximately 20-30 minutes.

5. Conclusion

An observable improvement in workflow efficiency and hardware/software optimization, especially in terms of time, is evident when comparing LiDAR to SfM. The LiDAR process typically takes only a few minutes, ranging from 5 to 8 minutes, inclusive of object handling. Repeated focusing on the same point from different angles enhances scanning precision. Unlike SfM, LiDAR scan accuracy and file size are not limited by distance but rather by the resulting file size. In contrast, SfM, accounting for image downloading and hardware/software processing, may take between 35 to 45 minutes for each object.

LiDAR sensors on smartphone and tablet can serve as valuable tools for creating 3D models of architectural and cultural heritage of disclosure databases. This capability offers an opportunity to contribute to the minimal metric documentation required for comprehending and preserving these assets, all at a relatively low cost. Furthermore, this development signals an imminent era where the precise capture of even the smallest engravings on epigraphs will be achievable at a low cost, addressing the current limitation in digital epigraphy, presently confined to the digitization of inscriptions through the creation of databases.

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ABSTRACT

Focusing on Late Antique epigraphic and architectural artifacts preserved in Italian and Greek contexts – starting from the research project 'Ravenna and its Late Antique and Medieval Epigraphic Landscape' – this study assesses the effectiveness of Structure from Motion (SfM) and Light Detection and Ranging (LiDAR) in generating 3D models suitable for sharing as open data within digital collections. The analysis compares the speed and accessibility of SfM and LiDAR in producing reconstructions, as well as their precision in capturing engravings and decorations. In fact, the research project on Epigraphy from Ravenna, under the guidance of Prof. S. Cosentino at the Department of Cultural Heritage of the *Alma Mater Studiorum*, Università di Bologna, aims to digitize inscriptions in Ravenna spanning from 402 to 1441. A key project objective is to establish a digital platform that

supports heritage communities, thus unveiling the yet undiscovered heritage of Ravenna. To date, approximately 110 epigraphs have been examined, most of which are situated in challenging-to-access locations. Given these circumstances, the feasibility of leveraging SfM and LiDAR technologies was explored. The study endeavours to underscore the paramount significance of advancing LiDAR technology in the realm of cultural heritage preservation and mapping.