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Application of 3D Laser Scanner in Digitization and Virtual Reality of Numido-Punic Funerary Monument: The Soumaa's Mausoleum (Constantine, Algeria)

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Abstract: Algeria's cultural heritage, from ancient structures to stunning landscapes, serves as a powerful symbol of both its national identity and humanity's shared knowledge. The Soumaa of El Khroub, a Numido-Punic mausoleum in north-east Algeria, dating from the 2nd century BC, it was classified as a national monument in 1900 and recognized by UNESCO in 2002. However, despite its inestimable value, this heritage faces a number of risks, whether natural, environmental or anthropogenic. Although institutions recognize its importance, lack of proper maintenance and harmful actions are contributing to irreversible damage. The aim of this research is to develop a digital documentation, visualization of a funerary monument and data management. monument through the creation of a detailed 3D model. This involves employing laser scanning TLS 3D and point cloud processing to obtain precise measurements of the monument's components, aiming at facilitating restoration and preservation efforts. It will be also accessible to researchers, curators, architects and other professionals. To cover the entire site, 17 scanning stations have been planned, including 13 for the monument itself and 4 for the site as a whole. The end result will be a three-dimensional representation of the monument with all its dimensional details, incorporating a variety of data such as structural, architectural, historical and technical aspects. In addition, to enhance the cultural importance of the monument, the data from the 360-degree scan was used to create a virtual reality experience, enriched with descriptive texts and photographs. This initiative demonstrates a positive commitment to the use of virtual reality as an educational tool, offering visitors an interactive immersion in the history and significance of the monument. This innovative also makes it accessible to a wider audience, fostering a greater understanding and appreciation of its historical and cultural significance.

Key words*: Soumaa of El Khroub Mausoleum, Algeria, Risks, digital documentation and data management, Static Terrestrial Laser Scanning (TLS), Virtual reality.*

1. Introduction

Algeria has a rich cultural heritage, offering a trip through the eras and influences that have influenced its history. The sites and monuments bear witness to many different civilizations, Prehistoric, Roman, Islamic and colonial periods (**Mohdeb et al, 2023**), such as the Soumaa royal mausoleum of El Khroub in Constantine, a funerary monument dating back to the Punic period 2nd century BC and situated southeast of Constantine, holds significance in North African funerary architecture due to factors such as its strategic location in relation to Numidian routes, unique architectural typology, and furnishings (**Aibeche Y, 2003**).

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However, this heritage, like many others, faces physical and man-made risks, such as earthquakes, floods, neglect and pillage (**Seghiri et al, 2022**). Despite being recognized by institutions, inadequate maintenance and inappropriate measures are causing irreversible damage (**Azil & Vicario, 2023**). The Soumaa of El Khroub is facing major conservation problems. In 2008, it was listed as one of the 100 most endangered sites in the world, underlining the urgent need to preserve this jewel of history (Web site1).

Today, the cultural heritage field incorporates 3D scanning techniques (Lidar, drone, Radar, etc.) and artificial intelligence to preserve both historic monuments and sites (**Costantino et al, 2021**). This "heritage science" enables extremely accurate reproductions of cultural assets, offering new approaches to preserving our past (**Liu et al, 2023**).

Algeria faces significant challenges in this field, mainly due to the high costs associated with the equipment used for digitization and the crucial skills deficit. Accurate scans require significant investment in specialized equipment. However, these high costs represent a major obstacle to the widespread adoption of these technologies in the Algerian heritage sector (**Seghiri., et al 2024**).

Despite international recommendations, research into heritage science has not yet developed innovative techniques. This situation highlights the need for increased investment in specialist training and funding to overcome financial and skills barriers, enabling Algeria to take full advantage of technological advances in the preservation of its rich cultural heritage (**Djelliout & Aliane, 2022**).

A glimmer of hope comes from the pioneering study on El Soumaa's mausoleum. This project used 3D scanning for reconstruction and conservation, not only preserving the monument but also creating a valuable database for future research and restoration efforts. This project highlights the potential of communicating heritage to both professionals and the public through innovative technology.

2. Literature review

The imperative of a multidisciplinary approach becomes apparent in the safeguarding of 3D digital data. This approach necessitates collaboration among computer science laboratories, archaeology teams, and computing centers (**De Luca, 2006**). Its overarching goal is to ensure

the uninterrupted progression of research on archaeological heritage by preserving 3D models throughout initial investigations and for subsequent studies (**Kadi & Najem, 2019**).

In summary, 3D scanning, in tandem with other data acquisition methodologies, stands as a potent instrument for the preservation, in-depth exploration, and widespread dissemination of architectural heritage. The multidisciplinary approach and the long-term preservation of 3D data remain intrinsic to the core of this scientific evolution (**Dekeyser et al, 2003**).

Expanding on this knowledge, it is noteworthy that the Order of Architects (2024) underscores the significance of not just preserving but also enhancing architectural heritage. The concept of heritage enhancement, evolving over the last fifty years in the Western world ("Heritage Enhancement of Melanesian Architectural, Sculptural, and Pictorial Heritage, 2024), emphasizes the preservation of 20th-century architectural heritage (Heritage Values of 20th-century Architecture, 2024).

The application of science extends to the study of art history and the preservation of cultural assets. Architecture, as a discipline, assumes a pivotal role in the preservation of historical and architectural heritage. The French Ministry of Culture delves into the importance of digital technology in heritage preservation (Heritage and Digital Technology, 2024). Furthermore, information and communication technologies contribute substantially to heritage preservation (The Contribution of Information and Communication Technologies (ICT) to the Safeguarding of Contemporary Scientific and Technical Heritage.

The impactful utilization of 3D imaging in archaeology is highlighted (3D Imaging in Archaeology, 2024), along with the pivotal role of 3D scanning technology in heritage preservation (3D Scanning Technology in Heritage Preservation, 2024). Additionally, the alignment with novel approaches such as BIM or HBIM (Heritage Building Information Modelling) for heritage preservation is emphasized (Bruno et al, 2022).

In conclusion, the convergence of technology and architectural heritage has unveiled uncharted avenues for the preservation and scholarly exploration of our collective history. Digital tools, with a particular focus on 3D scanning, have not only enhanced the accessibility and comprehension of architectural heritage but have also underscored the indispensable nature of a multidisciplinary approach to ensure the ongoing trajectory of research. As we navigate through this digital era, these technologies will steadfastly remain at the nucleus of our endeavors to conserve and elevate our architectural heritage for the benefit of future generations.

3. Materials

A funerary monument built in the Punic period, located 14 km south-east of Constantine (Cirta), several factors make the Soumaa a benchmark in North African funerary architecture: its location in relation to the map of

Numidia (Fig.1), its architectural typology and its furnishings. Its location at the intersection of the routes linking Cirta to Théveste and Calama to Sitifis.

It forms part of a continuous funerary space made up of dolmens and bazinas (Fig.2.a) Ain El Arbi- Bounouara and Oum Settas (Cazeaux., 2018) It is also one of the Turriform mausoleums, inspired by the Halicarnassus mausoleum (Seghiri., 2018).

The Soumaa of El Khroub occupies a unique place in Algeria's cultural heritage. Classified as a national monument as early as 1900, the site is of undeniable historical importance. Its fame extends beyond national borders, as it was included on UNESCO's tentative list of World Heritage Sites in 2002. However, despite its prestigious status, the Soumaa du Khroub has faced major challenges in terms of conservation, even being listed in 2008 as one of the 100 most endangered monuments on the planet.

The first documented description of the site dates back to 1838, during the French occupation (Temple & Fable, 1838), the French archaeologist Adrien Berbrugger also mentioned it in 1843 (Berbrugger., 1843). However, proper excavations only took place much later, between 1915 and 1916, organized by the Archaeological Society of Constantine under the supervision of the Algerian antiquity authorities (Fig.2). The work was directed by the architect Bonnell, and although we can comment on the methods used, which were not always scientific, we owe him most of our knowledge of this mausoleum (Lahcene., 2017).

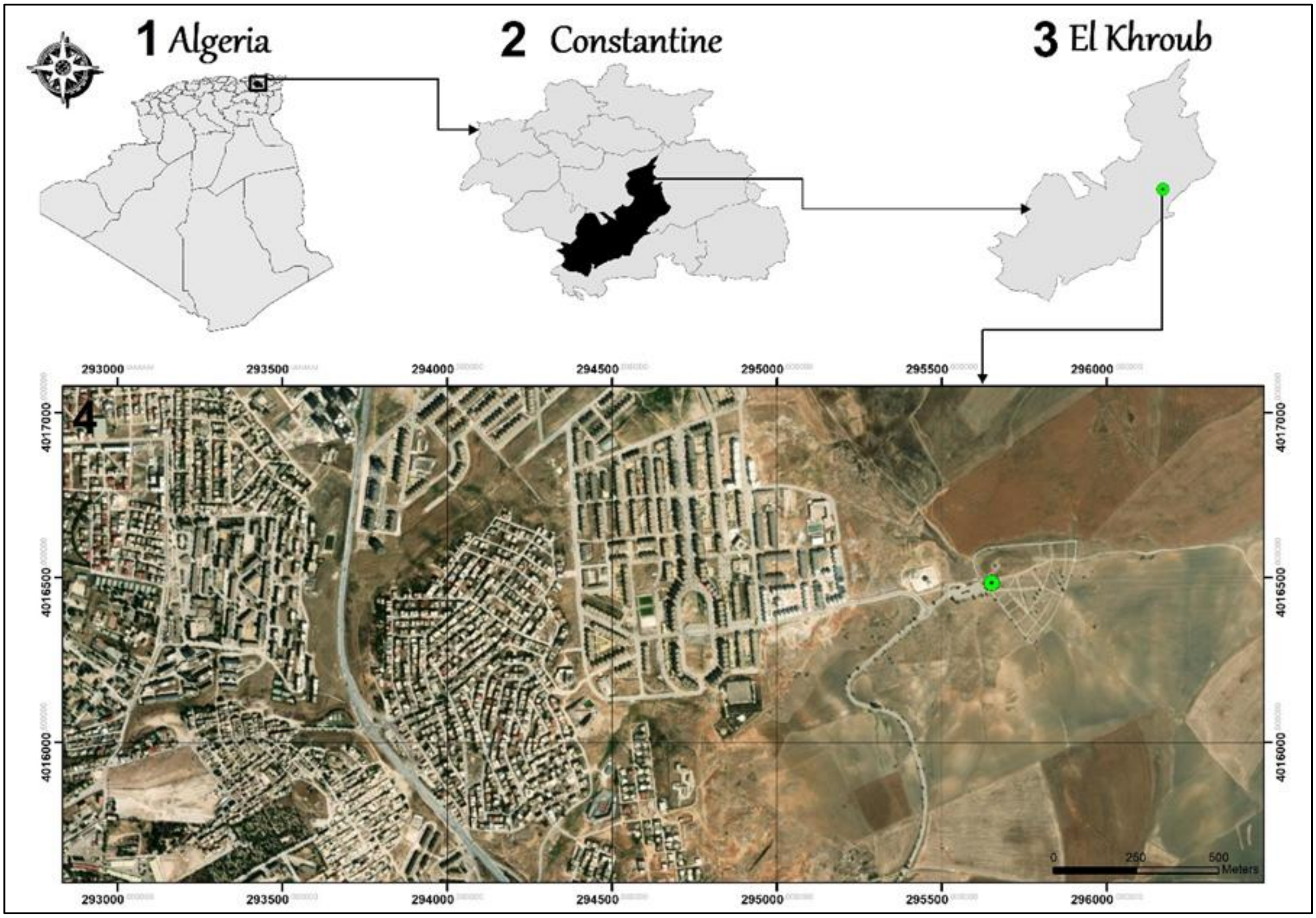

Figure 1. Situation of Soumaa’s mausoleum, Constantine Algeria

Source: Authors 2023

Figure 2. (a) Image of Soumaa's Mausoleum (b) Archaeological site of Soumaa

Source: Authors 2023

3.1. Archaeological and historical study

The mausoleum at Khroub dates back to the end of the 2nd century BC, according to the dating of the funerary furnishings. It is probably the tomb of Micipsa and his son Hiempsal (F. Rakob); according to Camps, it is that of Massinissa (Camps., 1960). The first explorations and excavations were begun in 1861 by the Archaeological Society of Constantine, where part of the funerary room was discovered and several architectural elements, such as the columns and cornice, were identified. In 1915-1916, F. Bonell's team (from la Société des Monuments Historiques) revealed the presence of a funerary vault in the basement, as well as significant funerary furnishings in good condition (Bonnell, 1915), which are currently preserved in the Cirta Museum (Constantine) as showing in figure 3 (a, b). According to a study by G. Camps, the arms in the funerary furnishings are Punic. He said: "The spear, the oval shield, the pointed helmet, the bow and above all the sword make up a panoply that would not have been surprising in Carthage or in the East, but which differs from the usual equipment of the Numidian or Moor" (Citra's Museum collection 2013).

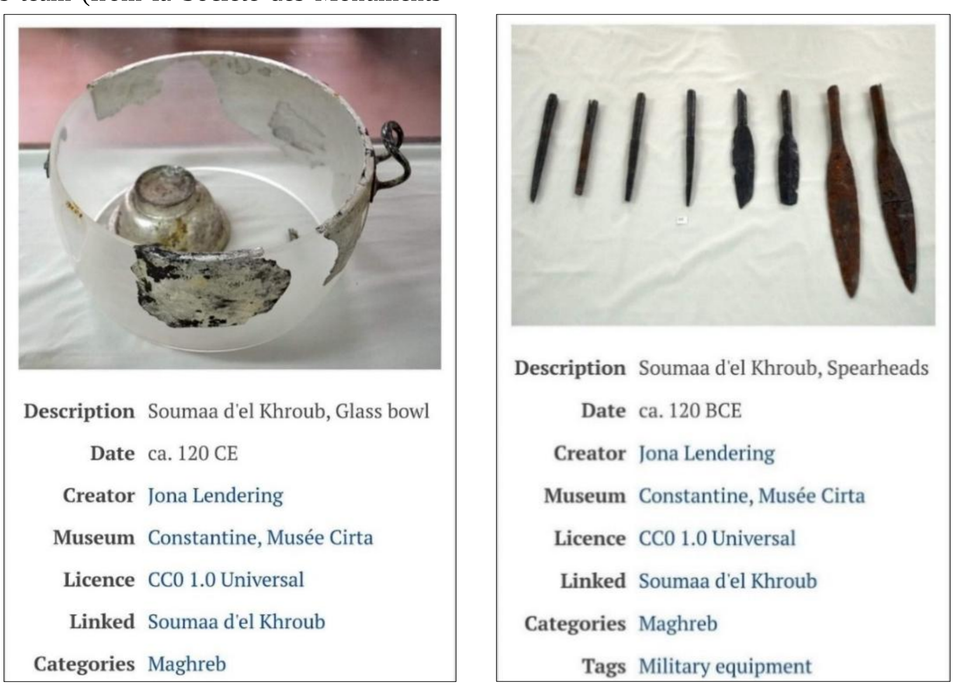

Figure 3. funerary objects found during the excavations and preserved in the Cirta museum

a. Glass blow b. Spearheads

Source: Cirta's Museum collection 2022

3.2. Architectural description

The entire structure, built on the outside with large, perfectly-fitted, dry-laid stone, is made up on the inside of unsquared blocks (Fig.4.a), placed in a blocking position without taking into account a bed for laying or waiting. The natives called the monument the Souma (tower), the mausoleum consists of many parts (Bouchareb, 2007) as showing in Fig.4.b:

The vault (caveau): positioned 1.50 meters below natural ground, has a rectangular base measuring 2 m by 1.5 m and a height of 1 m. Built in a north-easterly direction with 9 keystones, it is embedded in the massif.

The outer party: of the monument features large, well-fitted ashlar stones, exceeding 2 meters in length, forming a plinth of 10.50 meters on each side supporting three steps.

The basement: measuring 10.50 m by 10.50 m and 2.80 m high, consists of five courses of dressed stone with raised faces and joints. Above, forming steps with a 0.40m setback, two 0.50m high courses receive the pedestal.

The pedestal: comprises a 1-metre-high base formed of two courses, the second of which is moulded and 0.65m high with a straight face; the moulded cornice, the profile of which contains the Egyptian groove in place of the straight Greek Doric drip moulding.

Plinth: has a 1-meter-high base with a moulded cornice containing an Egyptian groove. Above it, a 0.50m high plinth served as the paving for the first floor. Levelling revealed a 20-centimeter difference in level between the north-east face and the north-west corner. An upper floor, partly preserved, featured three angles with dimensions of 1.75m by 1.75m and a height of 3.20m, adorned with specific decorations.

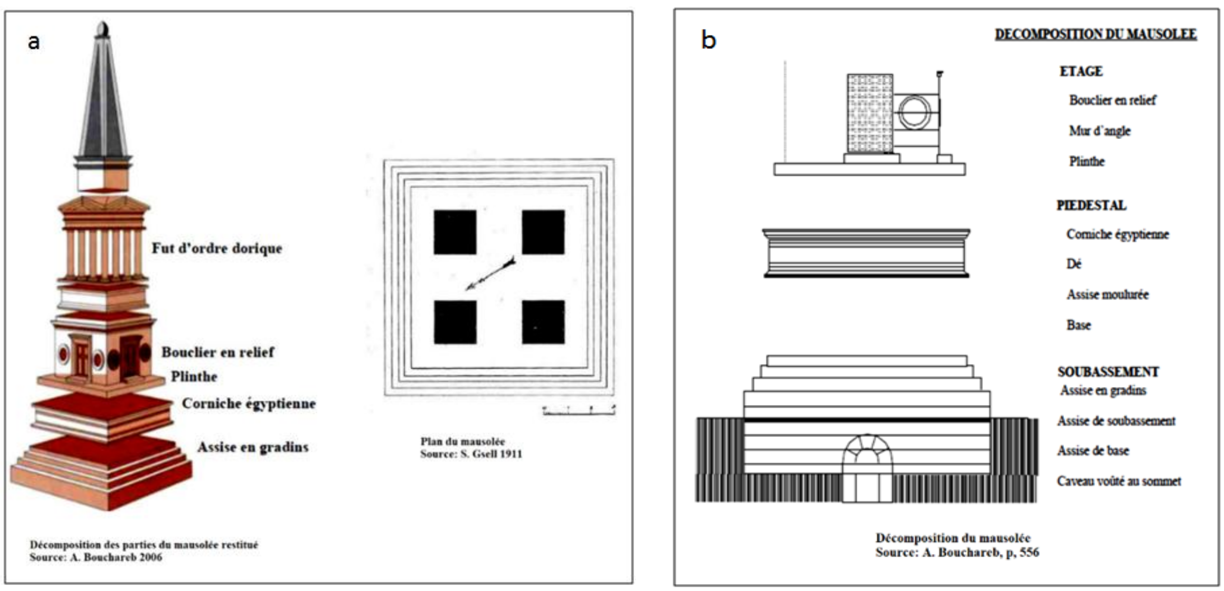

Figure 4. Architectural description

a. decomposition of the restored mausoleum b. decomposition of the mausoleum

Source: Bouchareb 2006

3.3. State of conservation of mausoleum

The Soumaa's archaeological site features a pile of stones, including parts of ancient-style columns such as capitals, shafts and bases, laid directly on the ground. These elements, potentially scattered or damaged over time by natural events, disasters, human activity or lack of maintenance, bear witness to the changes undergone by the monument over the centuries. Visible columns in the pile suggest the past existence of a larger architectural structure.

The current state of the site reveals advanced deterioration, despite the presence of a fence limiting man-made alterations, with signs of vandalism such as tags and graffiti. Restoration work should focus on the stones on the ground, which are exposed to various biological and natural alterations, with fractures, perforations and deposits. Various cracks in the stones compromise their resistance, while plant growth indicates favourable humidity. In addition, algae and crusts on the cornice alter the aesthetic appearance and architectural legibility. Studies suggest a complex tectono-gravitational dislocation of the Oum Settas massif, potentially of seismic origin, with Massinissa's tomb aligned on a line of collapse, which could explain its collapse observed in 1845 (Benabbas, 2006).

4. Methodology

The methodological approach adopted for the study of architectural heritage follows a comprehensive three-phase process, commencing with an in-depth analysis of its history. This methodology unfolds with data acquisition, followed by the exploitation of this data to generate a 3D model reflecting the current state of the structure. Finally, it delves into the exploration of various hypothetical scenarios.

4.1. Static Terrestrial Laser Scanning (TLS) of the soumaa of El Khroub

The terrestrial laser scanner is used for 3D mapping, the LEICA BLK 360 laser scanner from BLK is one of the 3D mapping tools available in industry that is used for land surveying and 3D documentation. Objects up to 60 meters away can be scanned with LEICA BLK 360. Fewer scans are required to survey this kind of monument. which speeds up project scanning completion, capable of capturing up to 360.000 points per second. The laser scanner is particularly well adapted to surveying applications, due to its ability to correlate individual scans during post-processing (Fig.5). The BLK 360 acquires data accurately during laser scanning, delivering high-quality scanning results even at great distances, with extremely low noise. It provides good quality scan data at extended range (Web site1). The registration process begins once the data has been collected, with the aim of stitch the laser scans (Seghiri et al,2024). A complete 3D scene requires scanning from different angles, followed by registration of the individual point clouds into a single point cloud, using attachment points or objects such as spheres or cylinders. This technology has a variety of applications, including topographical surveys, detailed archaeological studies, preservation of historical buildings, environmental monitoring and urban mapping, the instrument (TLS) is used for the heritage mapping application (Girya et al, 2022).

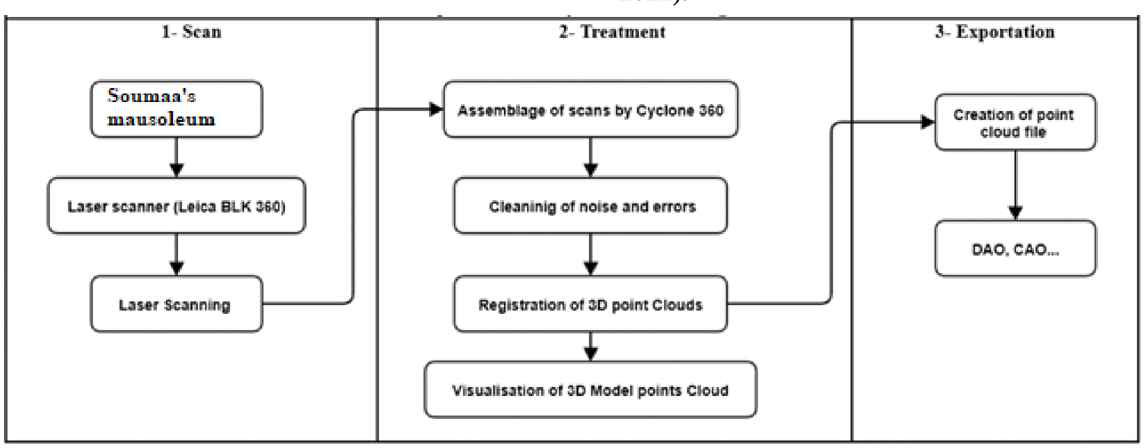

Figure 5. Overall methodology flowchart.

Source: Authors 2023

4.2. Data collection

15 scans were taken for complete 3D mapping of the selected monument (Fig.6.a). 2 scans were taken to acquire the whole site (from the outside of the monument), and 13 scans was taken from the inside of the mausoleum to cover the entire interior geometry (Fig.6.b), the duration of each scan varies from 4 to 6 minutes with a resolution of 5 mm / 10 m. Millions of measurements have been taken and contain several noises and errors. The choice of several locations was aimed at obtaining maximum detail of the monument as a whole, as well as optimizing the 3D scan.

The spaces scanned of the mausoleum are: the fronts (4 fronts), east, west, north and south. The choice of station positions was based on the shape and complexity of the space, and the detail required. the scans taken of the site were based on the pile of stones that had fallen from the mausoleum.

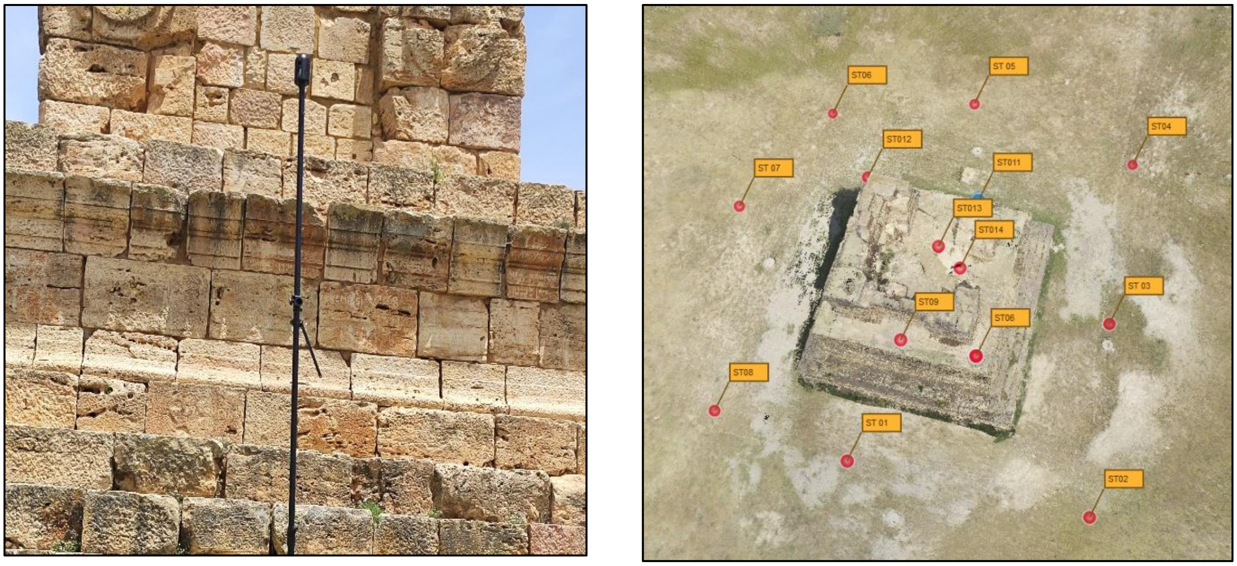

Figure 6. (a) BLK 360 in *situ*, (b) scan stations

Source: Authors 2023

4.3. Point cloud processing

The acquired scan data underwent integration into the software to consolidate the information from the 17 scans while eliminating any potential noise or errors. The chosen software for processing the point clouds is "Cyclone Register 360 (BLK Edition)," a powerful tool that facilitates various stages of data processing. This includes alignment and indexing of the clouds, displaying the point cloud model alongside photographic archives, employing measuring tools for accuracy assessment, and ultimately exporting orthophotos (Ulvi, 2021). To achieve a comprehensive visualization model of the monument's point clouds, it is crucial to register these clouds into a unified coordinate system. This process ensures the accurate alignment of data from different scans. Figure 7 showcases the essential features of the software, as provided by the manufacturers.

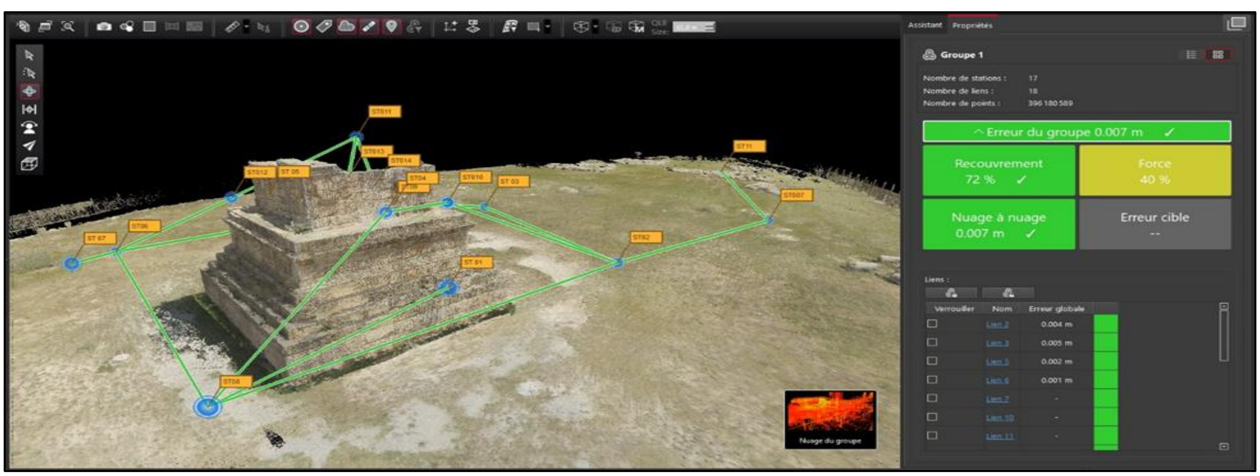

Figure 7. data processing by Cyclone Register 360

Source: Authors 2023

5. Results and discussions

5.1. Digital archiving

The survey point cloud of the palace is a large 9.5GB file with around 400 million coloured points, utilising variable decimation thresholds for detail preservation. The minimum decimation threshold is set at 1mm. The dataset shows a 37% average overlap, ensuring comprehensive coverage. Despite careful consideration of decimation and overlap, there's a 6mm average error in the points, highlighting the need for ongoing quality control for precise reconstruction and analysis (Elbshbeshi et al, 2023).

Digital archiving highlights significant advances in the preservation of cultural heritage, particularly in the creation of a 3D model of the monument using laser scanning and point cloud processing techniques (Fig.8). This approach offers a detailed virtual representation of the monument, enabling not only immersive visual exploration, but also precise measurements of the various constituent elements of the site. These measurements are of crucial importance to restoration and conservation efforts, providing accurate data that facilitates the planning and execution of targeted preservation work (Shi et al, 2020).

The Point Cloud serves as a volumetric representation of the scanned monument, forming an accurate 3D digital replica to offer both visual and dimensional insights into the Soumaa's mausoleum. Comprising millions of points arranged within a reference frame with Cartesian coordinates (Fig.9a), the file is in RCP format and consolidates various scanned files of the monument. RCP files can be seamlessly integrated, examined, and modified in Computer-Aided Design (CAD) software.

Figure 8. Top view of the Soumaa's mausoleum in the form of 3D point cloud.

Source: Authors 2024

Primarily intended for use by professionals in cultural heritage conservation, the Point Cloud offers precise documentation of the current state of the monument. It proves valuable for restoration, renovation, and management projects (fig.9b), enabling detailed studies on the structure, architecture, architectural elements, history, and evolution of the monument over time (Pepe et al, 2023).

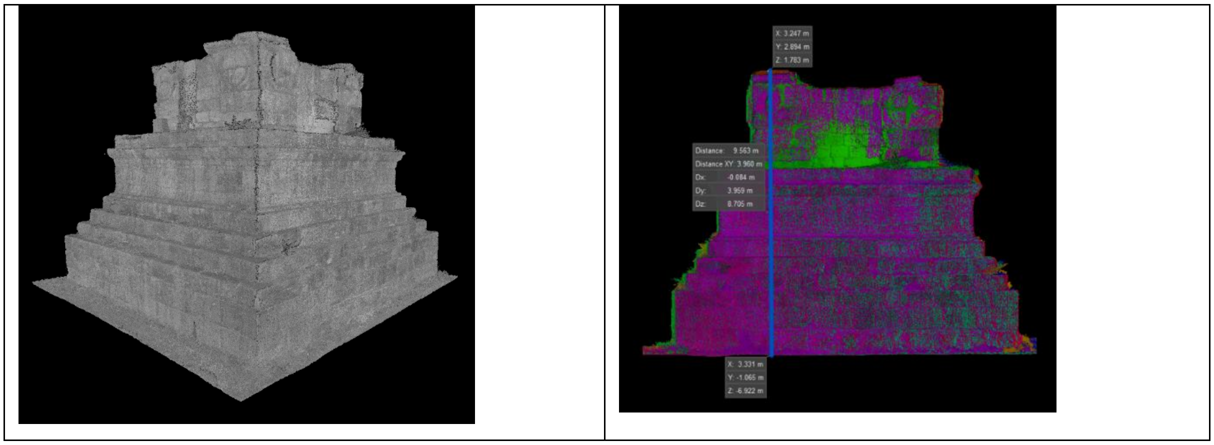

Figure 9. (a) Model of the monument represented in terms of its point cloud, (b) Measurement of the height of monument from its base

Source: Authors 2024

The TLS treatment for managing built heritage focuses on analysing methods applied to the transformation between image space and object space. Data acquisition and archiving are also explored, with specific experimentation on surveying a heritage mausoleum in Constantine. This approach underscores the importance of digital photogrammetry in producing quantitative data in three-dimensional space, incorporating aspects of topography, computer-aided design (CAD), and photogrammetry (Zeroual et al, 2019).

Finally, the importance of digitising-built heritage is discussed in a process that highlights the use of a laser scanner to acquire 3D data to millimetre accuracy (Fig.10). 3D data with millimetre-level accuracy (Dore et al, 2017). This approach integrates semantic enrichment beyond basic geometric information, exploring innovative approaches such as Building Information Modelling (BIM). such as Building Information Modelling (BIM) and Heritage-BIM HBIM. The methodology highlights the evolution of techniques for collecting, storing, organising, processing and disseminating data of heritage documentation (Hallot, 2018).

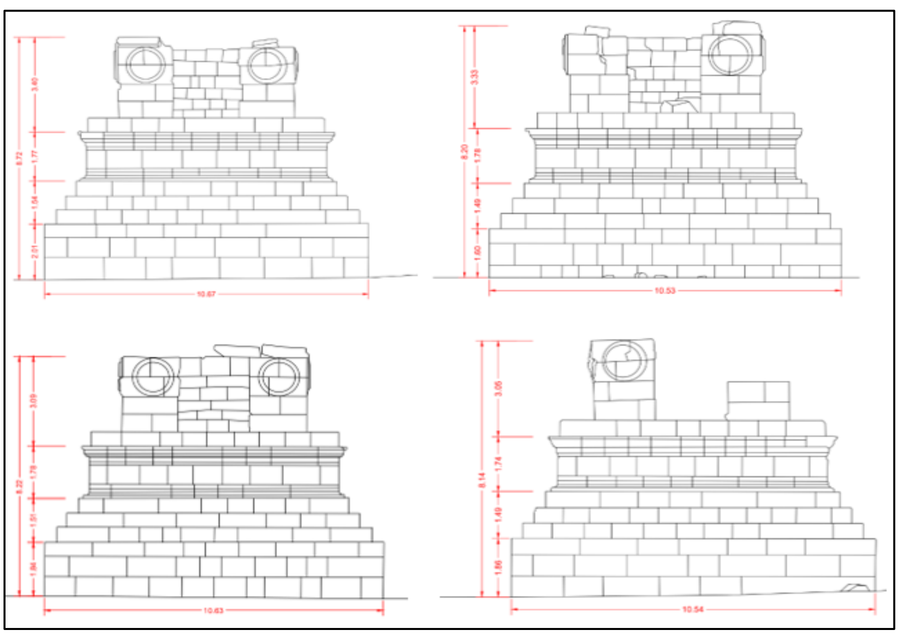

Figure 10. the 4 fronts of the mausoleum drawn from the TLS

Source: Authors 2023

5.2. Virtual reality

The virtual reality of the mausoleum has been achieved through a fascinating compilation of 360° images (Fig.11), meticulously captured using the BLK 360 scanner and then subtly crafted using 3D Vista software (Fig.12). This technological feat is crystallised in the creation of a virtual tour dedicated to the tomb of Soumaa, with the primary ambition of awakening public interest in the cultural diversity and historical depth of our country (Wen et al,2023). By transcending physical barriers, this immersive experience offers Internet users the unprecedented opportunity to virtually explore ancient remains, creating a platform for education, research and appreciation of Algeria's rich cultural diversity, as illustrated in Figure 13.

The singularity inherent in this initiative resides in its documented character, lending exceptional depth to the virtual visit. Indeed, this experience goes far further than simple visual immersion, offering virtual visitors exhaustive access to a diverse collection of scientific documents. These documents include a huge range of elements, including detailed sections on the history (Benali et al, 2020) period photographs, in-depth archaeological studies and detailed architectural analyses. To discover this immersive experience, we invite you to visit our website (Web site3).

Figure 11. 360° photo obtained from the scanner BLK

Source: Authors 2023

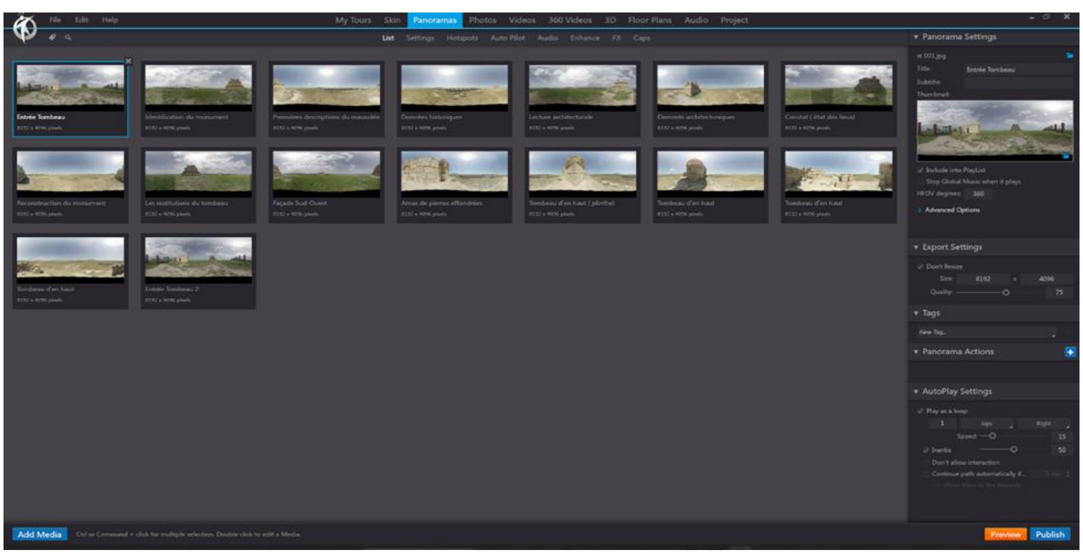

Figure 12. virtual reality project of Mausoleum viewing in 3D VISTA software

Source: Authors 2023

Figure 13. virtual reality project of Mausoleum on line

Source : https://www.crat.dz/visitevirtuellemausoleeroyalsoumaa/

Conclusion

Algeria's cultural heritage reveals the historical layers of the Soumaa d'El Khroub, a place charged with memory and history. This structure has endured the challenges of time, becoming much more than just a physical edifice: it also embodies a symbol of resilience. However, the current threats facing the monument require immediate attention to ensure its preservation for future generations.

The multidisciplinary approach adopted in the exploration of the Soumaa, which integrates the fields of archaeology, history and technology, reflects a holistic vision of heritage preservation. The use of innovative technologies such as Terrestrial Static Laser Scanning (TLS) has breathed new life into documentation, enabling the creation of a digital representation that transcends spatial and temporal boundaries. This harmonious combination of tradition and innovation testifies to the fundamental importance of preserving cultural heritage in the digital age.

This transition to digital technology not only facilitates access to data and historical, technical and structural information relating to the monument, but also enables it to be managed.

The virtual tour of the site has been a significant success for the monument, arousing public interest in the cultural diversity and historical depth of the country. VR offers Internet users an unprecedented opportunity to virtually explore all the components of the monument, as well as its site, transcending physical barriers. The technique has also created a platform for education, research and appreciation of Algeria's rich cultural diversity.

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