Static Terrestrial Laser Scanning (TLS) as an effective tool for cultural heritage survey: the case of Ahmed Bey's Ottoman Palace in Constantine, Algeria

Meriem Seghiri[a, *], Dounia Keddari[a], Yasser Nassim Benzagouta[a], Abdelaziz Debbache[a], Nadra Nait-Amar[b], Boulekdam Chaouki[a], Bahaedine Hamida[c], Mohamed Zouidi[a], Caterina Gattuso[d]

[a]Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane, Route de Ain el Bey, 25000 Constantine, Algérie.
[b]Faculté d'Architecture et d'Urbanisme, Département d'Urbanisme, Université de Constantine 3.
[c]Laboratory of Functional Ecology and Environment, Life and Nature Sciences Department, Faculty of Exact Sciences and Life and Nature Sciences, University of "Larbi Ben M'hidi", Oum El Bouaghi. November 1st 1954, Oum El Bouaghi 04000, Algeria.
[d] Department of Biology, Ecology and Earth Sciences (DiBEST), University of Calabria, Via Ponte P. Bucci, 87036, Rende (CS), Italy.
Corresponding author: meriem.seghiri@crat.dz

Abstract

The cultural heritage sector is showing great interest in developing innovative techniques to optimize the safeguarding and management of sites and monuments. The aim of this article is to illustrate the importance of 3D surveys acquired using a Terrestrial Laser Scanner (TLS). This study is the first to use this technique to valorize cultural heritage in Algeria. The approach was applied to the National Museum of Traditional Arts and Cultural Expressions, known as the Ahmed Bey's Palace, a precious heritage from the Ottoman Empire in Constantine, Algeria. The point clouds from the TLS scan were processed through the Cyclone software (RCP file) to obtain a digital replica of the monument, which will be used not only to digitally archive Algeria's cultural heritage, but also to understand the current state of the building, its evolution and the various transformations carried out during the different periods of its history. In addition, the measurements from the TLS study were compared with those acquired from a traditional survey carried out previously. The accuracy of the TLS data highlights a significant margin of error with traditional surveys. TLS is accessible and easy to use, saving time and money and making it a feasible option for heritage sites.

Keywords: *Terrestrial Laser Scanner TLS, Ahmed Bey's Palace, Cultural heritage, Safeguarding and Management, Point cloud.*

1. Introduction

The heritage of a country is often associated with its national identity. A building, a natural site, or a work of art are all testaments to human knowledge and skills, which place this heritage in a universal dimension. However, the value of these assets is further enhanced at a local level, where the cultural features and symbolism emanating from the work/site are more easily grasped by locals.

The conservation of the cultural heritage is an important subject, which it is essential for all civilizations in the world (Moussa. Wet al, 2012). In order to preserve the origins and the different stages of any civilization's progress, the preservation of the legacy of the cultural heritage, from one generation to the next one, is crucial. The objective is also to revitalize the cultural territory by revealing the potentialities that distinguish it from other sectors and other countries. Cultural sites and natural environments have been buried, abandoned, and neglected for thousands of years. As a result, they are exposed to a variety of risks, both human-caused and natural (Seghiri. M et al, 2022). Cultural heritage is also threatened by climate change, especially in the Mediterranean region. Rising temperatures, variability in air humidity, groundwater levels, the frequency of floods, wildfires, landslides, and heatwaves, as well as coastal erosion, sea level rise, and increased droughts, all appear to have consequences for the stability and conservation of historic buildings, the integrity of archaeological sites, and the durability of materials and collections, which could therefore deteriorate further (Lefèvre. R.A et al, 2011). Although there is institutional awareness of these phenomena, the response and adaptation measures do not yet seem to have been triggered.

Algeria's cultural heritage is also threatened by the risks mentioned above. This rich country has many historical sites and monuments that are testament to a great cultural diversity. The 431 monuments and sites that have been classified as such do not represent the full extent of the country's cultural and natural heritage, which is of historical, architectural, and artistic value (Aiche. B et al, 2006). The Boumerdes earthquake destroyed part of the Casbah of Dellys (old town), the disappearance of a large part of the Fogarras of Tindouf (Remini. B, 2019). The obscuration of the traits of the Ksours of M'zab by modern materials have erased a large chapter of Algerian heritage. These phenomena remain very little analysed in Algeria. Due to lack of regular maintenance, built heritage seems to be already weakened and more prone to these risks (. On another level, the inadequate appropriation of certain classified sites and monuments by users contributes to their alteration and damage. The deliberate destruction of dwellings by squatters in search of modern housing refers to this irreversible loss of the architectural, historical, and even identity traces of the country (Fantazi I et al, 2019).

One of the monuments that has undergone significant transformation, especially during the colonial period, is the Ahmed Bey Palace, the National Public Museum of Traditional Arts and Cultural Expressions, located in Constantine, in northeastern Algeria. This monument is living-proof of an ottoman architecture fragment that highlights its artistic, authentic, historic and architectonic heritage.

Fortunately, the cultural heritage sector, nowadays, is showing a great interest in the development of innovative surveying techniques. Heritage science is defined as the application of digital technology in the heritage discipline. Digitization concerns all types of cultural, natural and immaterial heritage, offering new opportunities to preserve the local, national or universal legacy. 3D laser scanning and other innovative survey techniques give a high degree of details that faithfully reproduces ancient monuments. The three-dimensional view of a monument is a useful method to document cultural heritage and can be digitally achieved via 3D laser scanning technology (Fontana. R et al, 2002). Many international institutions, like ICCROM, have already recommended the use of 3D documentation to protect, conserve and restore cultural heritage. Regrettably, academic research in Algeria have not the chance yet to apply extensively this technique for the previously mentioned purposes.

In the Algerian context, there has been talk of digital heritage for years, in a general and theoretical way. This topic has been addressed by several profiles and specialists, including architecture, archaeology, urban planning and territorial development. However, there is a lack of research on how to digitize a monument or site, for two reasons: the equipment and processing software used are expensive, and there is a lack of mastery of the techniques and tools (Iguergaziz. W et al, 2022).

This study stands out as the first of its kind to use 3D scanner for an Algerian historic monument, the Ahmed Bey's Palace. This research aims to illustrate the importance of measuring and modelling Ahmed Bey's Palace, with 3D laser scanning technique. The approach is applied for reconstruction and conservation of this ottoman heritage; it also prevents forgetting because it helps to communicate characteristics and values with conservation professionals and general public. The use of 3D scanning is an innovative method for the detection of historical architecture, which allows the integration between the geometric dimension and the understanding of form. The survey of the Ahmed Bey Palace is the result of what can be achieved with the 3D surveying system; it must be considered as fundamental for the preparation of a database to be used to increase knowledge through its geometric description (Yastikli. N, 2007) In particular, the computerized scientific survey can be considered as a useful tool, configuring itself as a basis for obtaining new information as well as for acquiring more details, allowing interesting thematic analyses not only for restoration, but also for valorization.

The analysis of the geometries and the possible renders of the 3D survey of the Palace made it possible to obtain a detailed and informative document. In fact, this technique in itself constitutes a useful knowledge operation to better understand the current state of the building. In addition, the ability to quickly manage information allows for the possibility of designing and comparing several solutions, and therefore selecting the ones deemed most appropriate and adequate.

2. Research aim:

The aim of this article is to illustrate the importance of 3D surveys acquired using a Terrestrial Laser Scanner (TLS), for the valorization of cultural heritage in Algeria, with a particular focus on the Musée National des Arts et Expressions Culturelles Traditionnelles, known as Ahmed Bey's palace in Constantine. Our objective is to create an accurate digital replica of this Ottoman heritage site, via point cloud data obtained from TLS scan and Cyclone software. This digital archive not only contributes to the preservation of Algeria's cultural heritage, but also provides invaluable information about the current state of the monument, its historical development and the transformations it has endured over the years. TLS technology, which not only saves time and resources, but also positions it as a viable and cost-effective option for heritage sites.

3. Materials and methods

Ahmed Bey's Palace situated within the preserved Medina of Constantine (safeguarded sector), in northeastern Algeria, serves as a testament to the enduring influence of the Ottoman era in North Africa. Constructed between 1826 and 1833, it stands as a tangible reminder of this historical period.

3.1 The Ahmed Bey's Palace in its territorial context

Ahmed Bey's Palace is an ottoman building located in historic centre (Medina) of Constantine City in the Northeast of Algeria, at 1094 m of height (36.36797 N, 6.61157 E), which is granted the status of public Museum of Arts and Popular Traditions by the Ministry of Culture in 2010.

The historic centre of Constantine, which has existed for over 2500 years, is located in eastern Algeria, covering an area of 85 hectares. It is limited by:

- North, north-east and east by the gorges of the Rhumel River;
- North-west and west by the rocky escarpment;
- South-west by the cultural centre;
- South by the Bardo district.

The Medina of Constantine is classified as a protected area under Law 98-04 and a 2003 decree due to its rich history. The old city (Fig.1) houses many ancient buildings with architectural and artistic riches, representing degrees of permanence and stratified authenticity (buildings extracted from. Several civilizations have marked the history of the city and its urban landscape: Numidian, Roman, colonial, and Ottoman.

3.2 History of Ahmed Bey's Palace

The Bey's Palace in Constantine, located in the city's historic centre, is considered to be one of the most prestigious palaces of the Ottoman period in North Africa, and one of the most important for its historical significance.

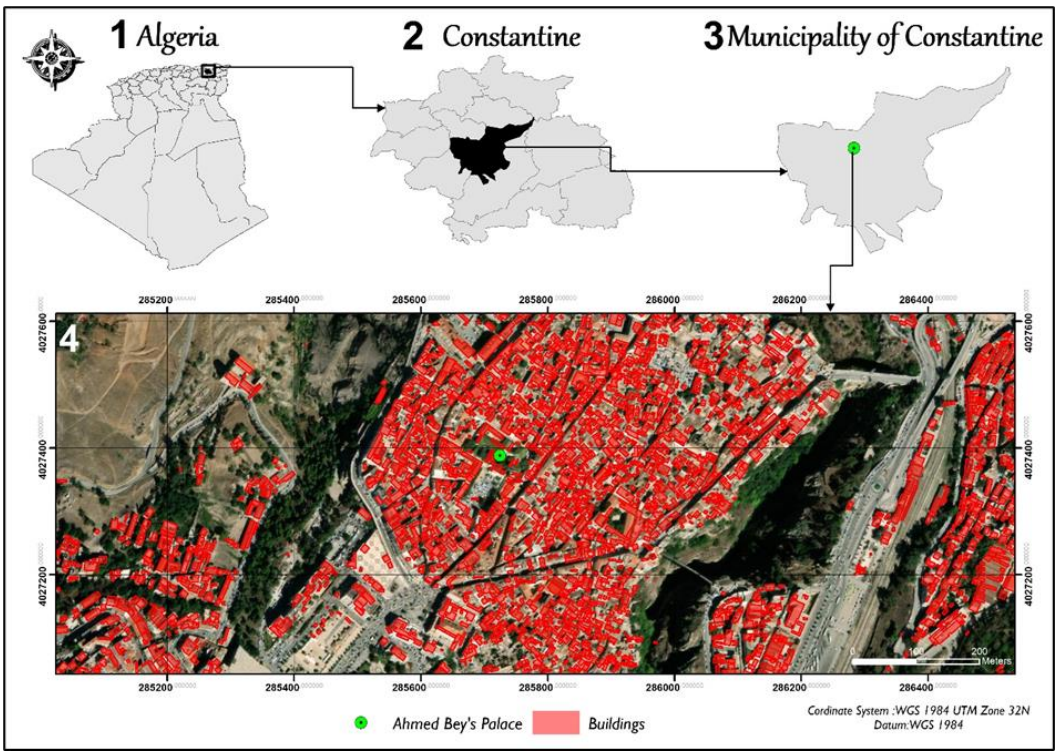

Fig.1. The Ahmed Bey's Palace in territorial context (Source: Treatment authors on Google).

The monument was the last bastion of resistance to the French occupation in 1837. The history of the palace housed the memory of Hadj Ahmed Bey, the initiator of the construction of the palace and the last Bey to have ruled the Beylik of Constantine. The architecture and artistic richness of the building are considered to be an encyclopaedia of Arab-Muslim architecture in the Maghreb (Feraud. LC, 1877).

The Bey called upon the best architects, craftsmen, and master masons to build the palace. He was inspired by his travels to the great cities of Egypt, Tunisia, Syria, Turkey, etc., built between 1826 and 1832. The basic materials for the construction of the monument were recycled materials from the surrounding environment of the palace. An approach that will lead to a distinctive character where different architectural elements belonging to multiple periods are intertwined.

3.3 Architectural description of monument

The monument covers an area of 5609 m2, occupying an entire side of the Si Haoues square into Constantine Medina, built on uneven terrain and it has an irregular form, the openings to the outside are small and the decoration is rare. As for the interior, it is much richer and more elaborate, containing two patios and two spacious gardens (Palm Garden, oriented towards south-east, 374m2, Orange tree garden, oriented towards North-West, 220m2).

The integration of the interior garden in this building makes it one of its architectural specificities, as the presence of interior gardens remains an exclusivity in Ottoman architecture in Algeria (web site 1: http://cnra.dz/atlas/palais-ahmed-bey/).

The monument's volumetry is composed of two parts; the first is oriented to the east, consisting of 3 levels; basement, ground floor and the 1st floor. The second part situated on the west side, consisting of 2 levels; ground flour and 1st floor. The access to the palace is located in the south and leads to the vestibule (skifa). On the right side of this, there are the galleries surrounding the palm garden, and on the left side, there is a gallery leading to the orange garden, total number of galleries is 22 distributed over all levels, 22 galleries, occupying 23% of total area. Ahmed Bey's palace contains 119 rooms, called Medjless and with various sizes.

3.4 spatial and functional description

Spatially, the palace is divided into two pavilions (Fig.2):

- Administrative: consisting of Diwane El Bey or the Bey's cabinet, located in the center; the choice of location is strategic, overlooking all the wings of the monument. The Diwane is lit from all sides, allowing both lighting, ventilation and permanent surveillance of the entire building.
- Family: located to the east of the palace, it includes the rooms that housed the Bey's family: his mother Hedja Rokia Benguena, known as "Umm al-Noun", his four wives from different tribes and his only daughter Fatima, who was given the largest room overlooking the two sides of the palace.

Functionally, the monument contains three large wings (Fig.2):

- Hareem wing: located to the north-east of Diwane, consisting of 5 large rooms, organised around the central patio space.
- Legal wing: situated to the south, containing a residence and a court at the same time. The Bey instituted three courts dedicated to the palace, divided up according to the Bey's wishes: Mahkma Hanafiya (Court) for Turks; Mahkma Malikiya for Algerians; Military Court for those occupying military posts.
- The patio or courtyard of the General Staff: situated to the south-east, its function was to receive the Bey's visitors. This wing was designed according to Arab-Muslim architecture, with a central courtyard surrounded by three rooms.

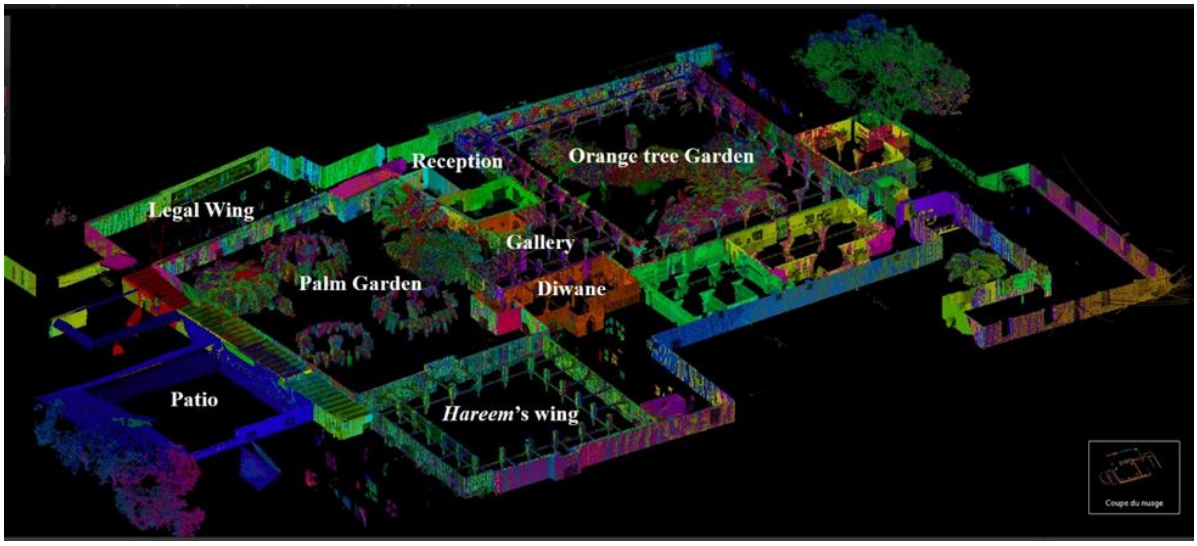

Fig.2. Spatial and functional distribution of the Palace obtained from Scan (Source: Authors, 2023).

4. Method

This study uses the TLS 3D BLK 360 Laser Scanner to carry out a complete scan of the Ahmed Bey Palace. The scanning process involves several steps and relies on software.

4.1 The 3D laser scanner as investigation tool

A laser scanner collects a large range of data representing three-dimensional coordinates, called point cloud data, which is a collection of coordinates (x, y, z) in a Cartesian system that portrays to the viewer an understanding of the spatial distribution of an object. For most laser scanning instruments, the point cloud can be regarded as the raw product of a survey. They may also include additional information, such as return intensity or even colour values (Costantino. D et al, 2021).

“LEICA BLK 360” laser scanner 3D has been used to survey the Palace (Fig.4). The tool is a phase shift TLS with superb portability and dimensions Height 165 mm/ Diameter 100 mm, with wireless communication integrated wireless LAN (802. 11 b/g/n).

The instrument allows measurements with horizontal and vertical resolution of 0.009°, point measurement speed 3min for complete full dome scan, rate up to 360,000 points/sec, with a distance range from 0.6 m to 60 m and a 3D point accuracy 6mm @ 0m/ 8mm @ 20m. Furthermore, the presence of the integrated 15Mpx 3-camera system, 150Mpx full dome capture, HDR, LED flash calibrated spherical image 360°x360° assurances the option of automatically obtaining the faithful colouring of the point cloud (web site 2: https://leica-geosystems.com/products/laser- scanners/scanners/blk360).

Fig.4. LEICA BLK360 Scanner in situ (Source: Authors 2022).

4.2 Survey methodology

In order to scan the monument and have a point cloud file, we proceeded with several steps, which are displayed orderly in the following flow-chart (Fig.5).

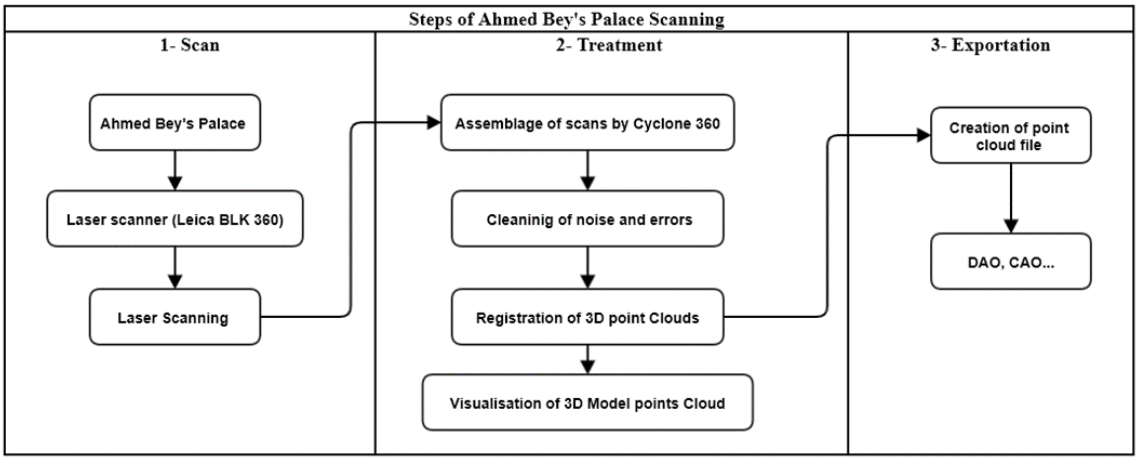

Fig.5. Steps of Ahmed Bey's Palace Scanning (Source: Authors, 2023).

The survey of the Ahmed Bey's Palace was performed with LEICA BLK 360 Laser Scanner, capable of capturing up to 360.000 points per second. The maximum captured range for this scanner is 60 meters. The scanning operation took place in four locations: the interior of the palace (85 number of scans), as showing in figure6, the alleyways bordering the palace (12 stations), the Si El Houaes square (3 stations) and the minaret of the El Bey's Mosque (4 stations), as showing in figure7. The choice of several exterior locations was aimed at obtaining maximum detail of the monument as a whole, as well as optimizing the 3D scan. A total of 104 scans were required to scan the palace (Fig.8).

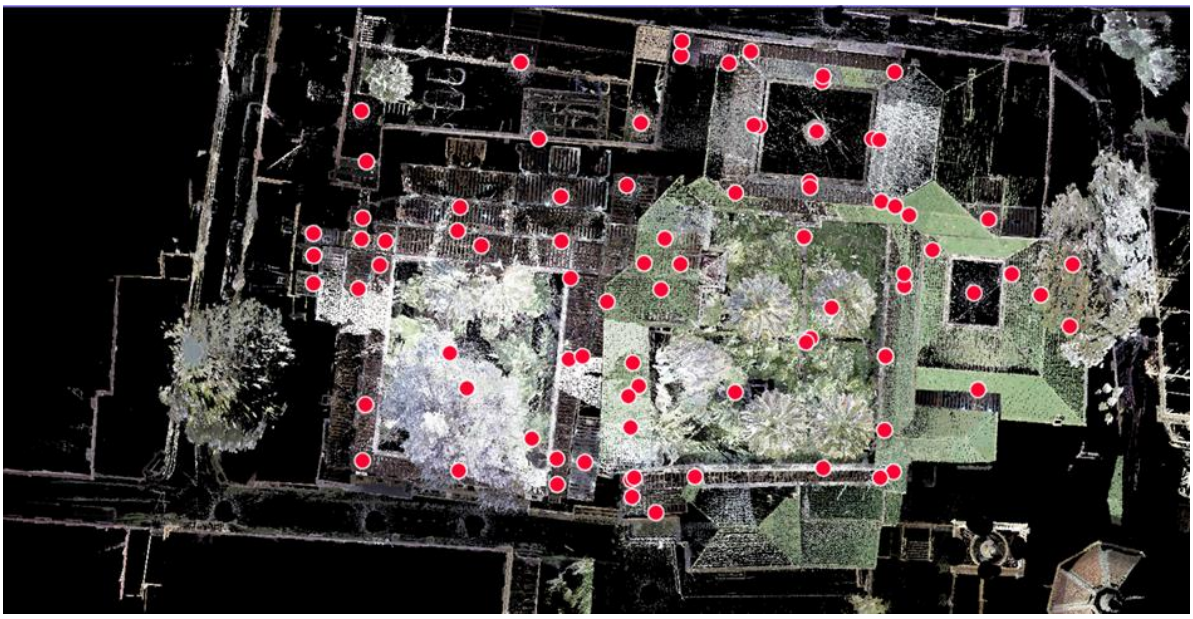

Fig.6. scan station inside the palace (Source: Authors, 2023).

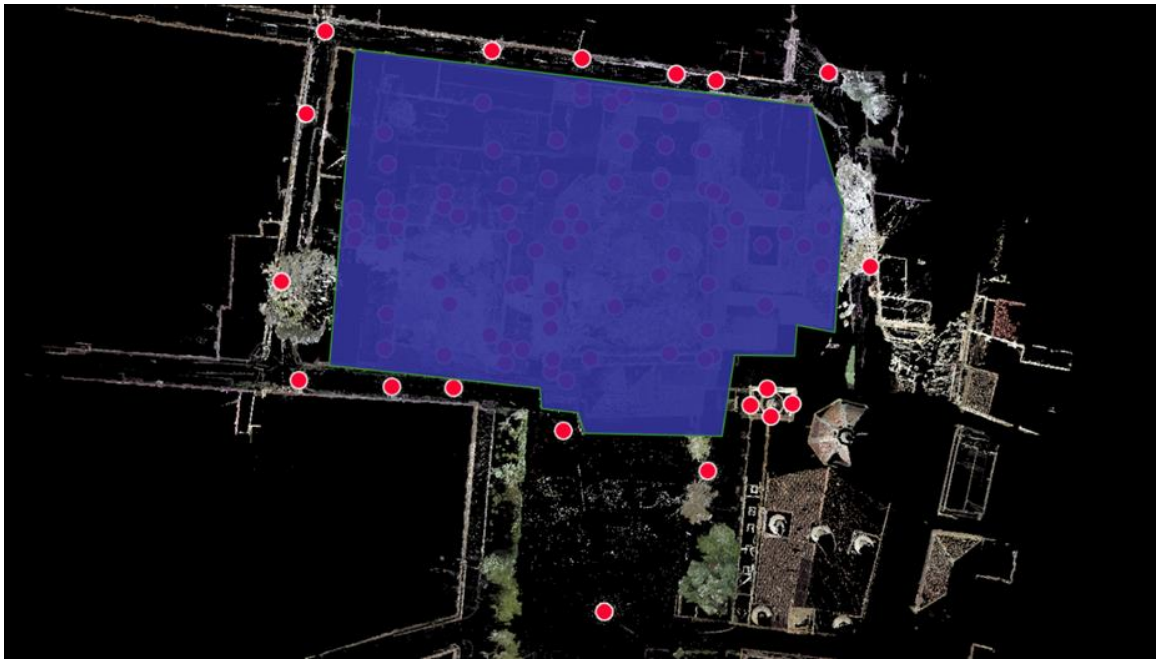

Fig.7. scanning station outside the palace (Source: Authors, 2023).

4.3. The monument

The spaces scanned inside the monument are: the showrooms (5 rooms), open to receive visitors; the galleries, gardens and patio. The choice of station positions was based on the shape and complexity of the space, and the detail required.

104 scans positions were necessary to detect the whole monument (except closed spaces); 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 noise and errors.
The acquired scanned data have been added into the software, to assemble the 104 scans and clean up the noise and errors. “Cyclone register 360 (BLK Edition)” is the software used to process the point clouds.

This software allows the management of all data processing phases’ alignment and indexing of the clouds, display of the point cloud model and related photographic archives measuring tool, and finally, the export of orthophotos. These point clouds have to be registered into one coordinate system in order to achieve a complete visualization model of point clouds of the monument. The main characteristics provided by the manufacturer are shown in the following Figure 8.

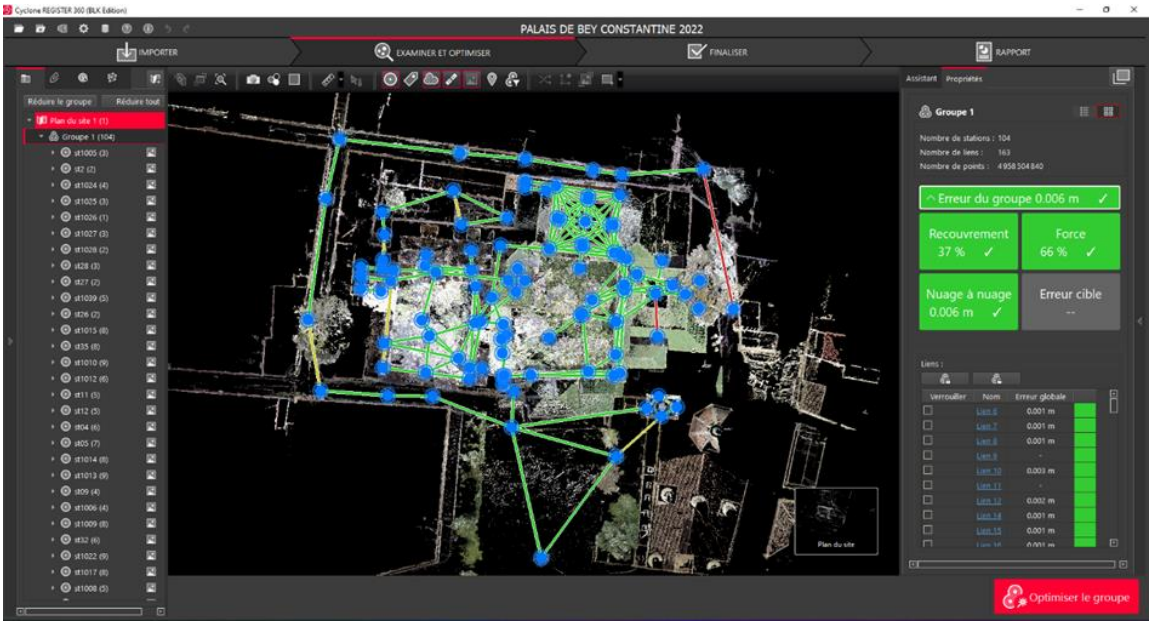

Fig.8. Treatment of 104 stations of scan by Cyclone register 360
(Source: Authors, 2023).

5. Results and discussion

The whole palace survey point cloud is a huge file 130GB, consisting of about 5 billion colored points with a variable decimation threshold, with a minimum value of 1 mm, with average overlaps 37%, while the overage error of the points is 6 mm.

5.1 Point Cloud

The Point Cloud is a volumetric representation of the scanned monument, creating a real-life scale 3D digital replica. This is to provide visual and dimensional information about the Ahmed Bey's Palace. The file is composed of millions of points, placed according to a reference frame with Cartesian coordinates (Fig.9), in RCP format; it combines a number of scanned files of the monument. RCP can be inserted, viewed and modified in CAD (computer aided design). It will be exploited by professionals of cultural heritage conservation (Liu.J, et al 2023).

The Point Cloud provides precise documentation of the monument's current state, and can be used for restoration, renovation and management projects. It is also used for studies on the structure, architecture, architectural elements, history and evolution of the monument over time (Pepe. M et al 2023).

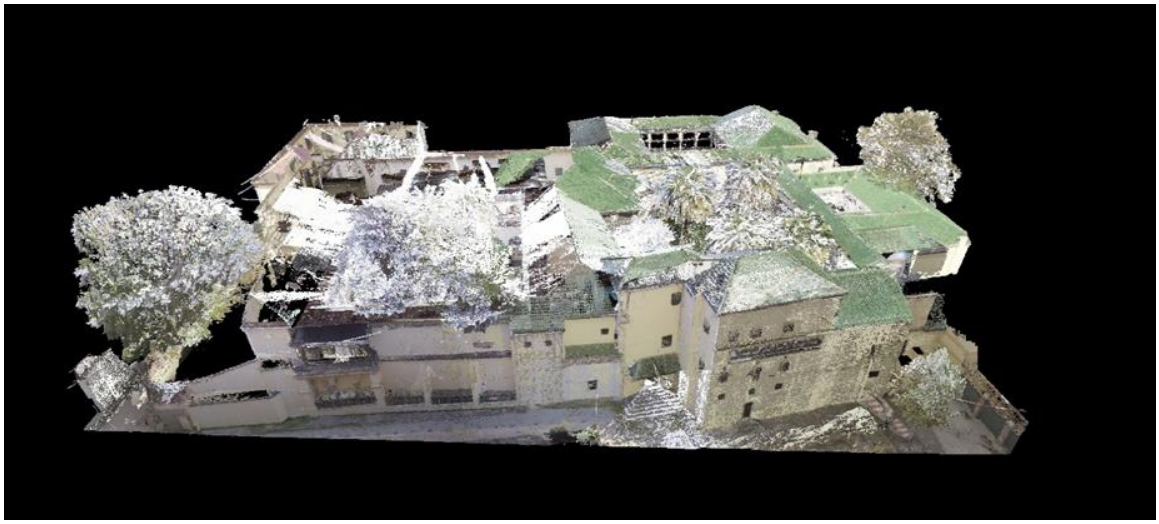

Fig.9. 3D Point Cloud model of the Ahmed Bey's Palace viewing in Cyclone software (Source: Authors, 2023)

The archives that we were able to consult, reveal the transformations carried out by the French in 1837. The palace (and its immediate surroundings) underwent transformations during the colonial period, which led to the alignment of streets and impasses in accordance with the Haussmannian model. As a result, the new occupiers demolished whole sections of the palace and destroyed the Bey's family properties, in order to create wider streets and better control the city. In 1836, the building complex consisted not only of the parts still visible today, but also of the Bey's family apartments, including three traditional houses with patios, which disappeared in the course of the transformations carried out by the occupiers (Feraud. LC, 1877).

After the colonial period, the palace was subjected to restoration and other interventions, but there are no traces or documents detailing these interventions. This may be due to the loss of files, bad conservation and limited access to archives (Table 1).

Kind of operation	**Period**	**Year**
Creation	Ottoman period	1826-1835
Transformations	French period	1837-1962
Many uses	From independence	1962-1982
Restoration Expertise and research	-	1982-1986
Interventions	-	April 1991- June 2003
Interventions	-	Since June 2003

Table 1: Transformations carried out on the Palais (Source: Archives of Ahmed Bey's Palace).

Digitization of the palace is becoming a necessity. Having this digital replica obtained from the BLK scanner will not only enable it to be archived, but also to understand the palace's evolution and the transformations carried out during the different periods of its history.

The point cloud file will be made available to researchers and conservators, to be exploited according to the needs of each profile (Zhenrao. C et al, 2021).

The digitization of the palace has never been carried out before, and is a first in Algeria's cultural sector. It could serve as a model for other cultural heritage preservation projects.

5.2 Survey and measurements

The 3D scanner offers millimetric precision, enabling heritage experts to gain precious time in surveying the building compared to the use of a laser rangefinder or tape measure, surveying techniques still used in restoration and rehabilitation sites in Algeria.

This is the most suitable method for monuments with complex architectural and decorative elements, such as the Ahmed Bey’s Palace. The measurement carried out by the 3D scanner makes it possible to take measurements of any desired object without touching it (non-destructive measurement), which contributes to the preservation of the monument and its elements. Adding to all these advantages, the possibility of surveying inaccessible or collapsed parts and spaces (Mauranges. L, 2009).

The BLK 360 scanner used to scan the Bey’s Palace produced a highly accurate point cloud, which made it possible to measure the dimensions of every architectural element in the building with minimal error. In 2015, during the event of Constantine Capital of Arab Culture, the Bey’s Palace underwent a valorization project. Complete architectural surveys were carried out to create a comprehensive technical file including plans, sections, and facades of the monument (Web site 3: https://www.m-culture.gov.dz/index.php/fr/liste-des-biens-culturels, Ministry of Culture, Algeria).

The measurements were taken using the triangulation method, which is the traditional method (Alby. E et al, 2007). For the Diwane room, for example, a team of 4 members, including 2 architects and 2 technicians, worked for 4 days at a rate of 6 hours a day to complete the survey of the room (Fig.10 a, b). After this stage, the measurements were transferred to computer-aided design software for the design phase (CAO).

Fig.10. Comparison between two techniques of survey
(a) Diwane architectural survey hand measurement (Source: Authors 2015); (b) Part of the Diwane survey (arc), measurement table obtained from the Cyclone software (Source: Authors, 2023).

6. Conclusion

Cultural heritage sites, which bear witness to history and cultural wealth, are exposed to a multitude of risks, whether from unrelenting natural forces or human activities. This study highlights the crucial importance of 3D laser scanning technology in preserving and protecting these cultural gems. In the Algerian context, characterised by the diversity of its heritage, the adoption of this innovative approach is essential for the creation of an integrated platform to manage all of Algeria's cultural treasures.

The 3D digitization of the prestigious Palais Ahmed Bey has yielded exceptionally accurate information, creating an invaluable archive for future generations. These digital files will serve as invaluable resources for meeting the many restoration, management and reconstruction requirements inherent in this exceptional cultural heritage.

The three-dimensional data resulting from this digitisation offers a variety of media, such as 3D models, panoramic photos, detailed plans, façades and 3D sections. This innovative technique stands out for its time efficiency, rationalisation of human resources and substantial financial savings. Its geometric precision far surpasses traditional methods, making it the way forward for documenting historic monuments.

The complete digitisation of the Palais Ahmed Bey required the installation of 104 digitisation stations, meticulously selected according to specific objectives.

However, this undertaking was not without its challenges, as the monument's vast surface area, complex shape and many architectural details required meticulous planning. The surrounding environment, with its overhangs, trees (palm and orange gardens), and constant flow of visitors (over 200 a day), added a layer of complexity. These factors can generate noise and errors during scanning, prolonging the processing phase due to the multitude of point clouds obtained and the increased size of the RCP file.

3D laser scanning technology is proving to be an invaluable asset for the preservation, management and enhancement of Algeria's rich cultural heritage. Its widespread adoption should be strongly encouraged in order to ensure adequate protection and optimum management of these historical treasures, veritable witnesses to the nation's past.

7. Acknowledgments

The authors would like to acknowledge the support of the Centre de Recherche en Aménagement du Territoire in Algeria and the Office de la Gestion et de l'Exploitation des biens culturels OGEBC in Constantine, Algeria.

8. Reference

[1]. W. Moussa, M. Abdel-Wahab, D. Fritsch, Automatic fusion of digital images and laser scanner data for heritage preservation, Lecture Notes in Computer Science. (2012) 76-85, doi: 10.1007/978-3-642-34234-9_8.

[2]. M. Seghiri, I. Kehal, M. Zouidi, D. Keddari, L. Kehal, C. Guittard, Impact of environmental factors on the alteration of funerary heritage stones: case study of Medracen (Algeria), J. Ponte. 78 (2022) 43-52, doi : 10.21506/j.ponte.2022.4.3.

[3]. R.A. Lefèvre, D. Martin, Le patrimoine culturel bâti face aux risques du changement climatique, La Météorologie. 74 (2011) 15-22.

[4]. B. Aiche, F. Cherbi, L. Oubouzar. Patrimoine architectural et urbain des XIX éme et XX éme siècles en Algérie « Projet Euromed Héritage II. Patrimoines partagés», Research Review of Sciences and Technologies. (2006) 34-45.

[5]. B. Remini, The foggaras of Sahara: the sharing of water the work of Oasian genius, Larhyss Journal. 39 (2019) 25-57.

[6]. S. Cartier, K. El Assad, Enjeux et procédures de protection sismique du patrimoine historique : La réhabilitation des ex-Galeries de France en Musée d'Art moderne d'Alger, Les Annales de la Recherche Urbaine. 106 (2010) 166-175.

[7]. I. Fantazi, B. Zehioua-Hecham, A. Ionut Petrisor, The impact of the absence of communication on the success of rehabilitation projects of the built heritage: the case of the old city of Constantine, Present Environment and Sustainable Development. 13 (2019) 226-239, doi.10.2478/pesd-2019-0018.

[8]. R. Fontana, M. Greco, M. Materazzi, E. Pampaloni, L. Pezzati, C. Rocchini, R. Scopigno, Three-dimensional modelling of statues: the Minerva of Arezzo, Journal of Cultural Heritage. 3 (2002) 325–331, doi.org/10.1016/S1296-2074(02)01242-6.

[9]. W. Iguergaziz, Y. Boulifa, Le patrimoine immatériel algérien classé par l'UNESCO, International Journal of Multidisciplinary Studies in Heritage Research. 5 (2022) 29-68, doi: 10.21608/ijmshr.2022.271574.

[10]. N. Yastikli, Documentation of cultural heritage using digital photogrammetry and laser scanning, Journal of Cultural Heritage. 8 (2007) 423-427, doi.org/10.1016/j.culher.2007.06.003.
[11]. L.C. Féraud, Histoire des villes de la province de Constantine, Hachette Bnf, Paris, 1877.
[12]. web site 1: http://cnra.dz/atlas/palais-ahmed-bey/
[13]. D. Costantino, M. Pepe, A.G. Restuccia, Scan-to-HBIM for conservation and preservation of Cultural Heritage building: the case study of San Nicola in Montedoro church, Applied Geomatics. 15 (2021) 607-621, doi.org/10.1007/s12518-021-00359-2.
[14]. web site 2: https://leica-geosystems.com/products/laser- scanners/scanners/blk360).
[15]. J. Liu, D. Willkens 2023. Comparative analysis of point clouds acquired from a TLS survey and a 3d virtual tour for HBIM development. (2023) 959-968 doi:10.5194/isprs-archives-xlviii-m-2-2023-959-2023.
[16]. M. Pepe, V. Saverio Alfio, D. Costantino, Assessment of 3D Model for Photogrammetric Purposes Using AI Tools Based on NeRF Algorithm, Heritage. 6 (2023) 5719-5731, doi.org/10.3390/heritage6080301.
[17]. Zhenrao Cai, Chaoyang Fang, Qian Zhang & Fulong Chen 2021. Correction to: Joint development of cultural heritage protection and tourism: the case of Mount Lushan cultural landscape heritage site. Herit Sci (2021) 9:86, https://doi.org/10.1186/s40494-021-00558-5
[18]. W. Boehler, A. Marbs, 3D Scanning instruments. Proceedings of the Cipa wg 6 International workshop on scanning for cultural heritage recording. (2002) http://www.isprs.org/commission5/workshop/
[19]. L. Mauranges, Étude et définition de spécifications pour le relevé (par lasergrammétrie et photogrammétrie) du patrimoine architectural, Mémoire de travail de fin d'études en vue de l'obtention de diplôme de l'ESGT, (2009) École Supérieure des Géomètres et Topographes, Le Mans, p73
[20]. Web site 3: https://www.m-culture.gov.dz/index.php/fr/liste-des-biens-culturels, Ministry of Culture, Algeria.
[21]. E. Alby, P. Grussenmeyer, E. Meyer, M. Rampazzo, Gestion d'ouvrages architecturaux : de la saisie photogrammétrique à l'interface 3D d'accès aux données patrimoniales, Revue XYZ. 110 (2007) 45-53. https://shs.hal.science/halshs-00264412/document.