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A COMPARATIVE ANALYSIS BETWEEN PERSONAL AND TERRESTRIAL LASER SCANNING FOR THE DOCUMENTATION OF HERITAGE SITES

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ABSTRACT

This paper presents a comparative analysis of mobile and terrestrial laser scanning techniques in the 3D surveying of Bashtova castle in Albania, showcasing the integration's efficacy in capturing a comprehensive and accurate representation of this historical structure. Personal laser scanning (PLS), characterized by its mobility and ability to capture data while in motion, offers advantages in terms of efficiency and coverage of large areas. Conversely, terrestrial laser scanning (TLS), with its stationary setup and high precision, excels in capturing detailed information and intricate architectural features. Thanks to the research on the case study of the Bastova Castle in the article, it can be stated that the integration of data from PLS and TLS is seamless with the help of modern software while respecting the basic photogrammetric-geodetic rules and demonstrates the possibility of creating a complex 3D model, usable for further analyses for architects and conservation professionals, as well as for restorers and civil engineers. Research has shown that the difference between point clouds from PLS and TLS is within one centimeter.

KEYWORDS

PLS, TLS, Point Cloud, Accuracy, Bashtova castle, viDOC

INTRODUCTION

In the realm of heritage preservation and archaeological documentation, the marriage of cutting-edge technologies has become instrumental in unraveling the mysteries of historical structures or objects. Among these, the integration of PLS (personal laser scanning) and terrestrial laser scanning (TLS) stands out as a transformative approach, offering a synergistic solution to the challenges posed by the intricate architecture and expansive landscapes of castles [1].

Geodetic technologies have been used for a long time for the documentation of monuments and objects of heritage conservation. With the development of computer technology and new equipment, the speed and accuracy of documentation work have increased significantly. About 150 years ago, photography began to be used for documentation, and photogrammetry was developed. Electronic systems were gradually integrated into surveying after World War II, and in the 1970s satellite data began to be used in addition to aerial photographs. A major change occurred in the 1990s with the development of commercially available computer technology and the digitization of technology. Nowadays, electronic surveying systems (total stations, GNSS equipment), airborne systems, satellite systems, terrestrial and mobile laser scanning, and automated close-range photogrammetry from the ground and drones are used. The synergy of data from different instruments is a topic of research in many workplaces today [3].

This study delves into the application of this integrated methodology, focusing on the case study of Bashtova Castle. This castle, with its rich historical significance and complex architectural features, serves as a compelling canvas to explore the capabilities and effectiveness of combining mobile and terrestrial laser scanning for the comprehensive 3D surveying of castles.

The allure of castles lies not only in their historical narratives but also in the intricate details of their construction, both inside and out. However, traditional surveying methods often fall short of capturing the full scope of these structures. TLS and PLS, stationed on the ground, specialize in acquiring detailed and precise data about the castle's interiors and architectural nuances. This integrated approach promises a holistic understanding by combining the strengths of these technologies, overcoming challenges such as occlusions, inaccessibility, and the need for comprehensive datasets [4].

Nestled within a captivating landscape, this castle presents a microcosm of challenges that the integrated approach aims to address. As we embark on this exploration of Bashtova Castle, the study not only seeks to showcase the practical implementation of Aerial Photogrammetry and TLS / PLS but also endeavors to shed light on the broader implications for cultural heritage management, archaeological research, and the preservation of historical structures [5].

Through a meticulous examination of the integration process, data acquisition strategies, and the ensuing 3D model generation, this research aims to contribute valuable insights to the evolving field of castle surveying. The findings from the case study are anticipated to demonstrate the efficacy of this integrated methodology, providing a blueprint for future endeavors in unraveling the architectural tapestry of castles and, by extension, our shared cultural heritage [10, 15].

THE CASE PROJECT

This paper uses the castle of Bashtova as a case study. The Bashtova Castle is situated north of the Shkumbini River, three to four kilometers from Vile-Bashtove settlement.

Built in the fifteenth century, this fortress is a stunning example of the various civilizations that have passed through Albania. The location is 20 kilometers northwest of Lushnjë, 15 kilometers south of Kavajë, 36 kilometers north of Fier, and 40 kilometers southwest of Tirana.

It is the only castle in the Balkans to be constructed on a field. The castle is 60 by 90 meters in size and is aligned north to south in a quadrangular configuration. In the eighteenth century, the western portion was renovated. The two round towers to the east and north are 12 meters high, and the walls are nine meters high and one meter wide.

With some brick and tile woven into the structure, it is constructed out of native stone. Three of the seven towers of the Bashtova Castle—two circular and one rectangular—remain standing. This castle is believed to have had two stories, the first of which is subterranean. The shooting ports are still visible, and the castle includes an arcade-style fighting platform that is accessible by stairs. Three rows extend into the walls, while the towers have five rows.

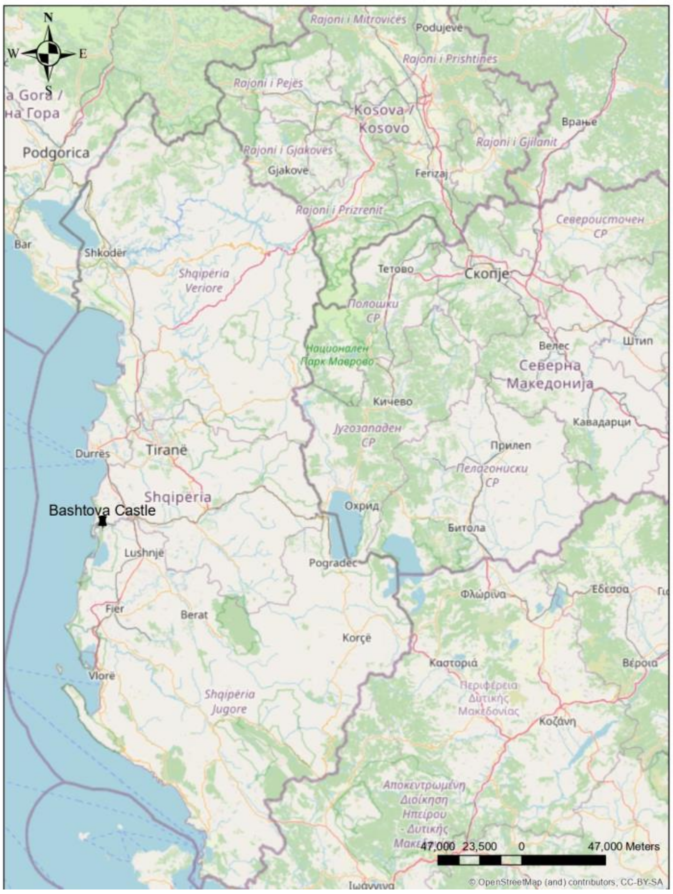

Fig. 1 – Location of Bashtova Castle

INSTRUMENTS USED AND DATA CAPTURING

Selection of Instruments

The selection of instruments for Personal and Terrestrial Laser Scanning for the 3D surveying of the Fortress of Bashtova in Albania necessitated a strategic consideration of the site's unique characteristics and surveying objectives. PLS instruments, renowned for their ability to penetrate vegetation and capture detailed elevation data, were invaluable for mapping dense vegetation within and surrounding the fortress, providing insights into ecological dynamics and historical land use. On the other hand, TLS instruments, with their high precision and ability to capture fine details of structures, were instrumental in documenting the architectural intricacies of the fortress itself. Reduced funding and transportation issues have compelled the usage of smaller instruments. Larger laser scanners mounted on tripods or traditional total geodetic stations could not be used because of this. Therefore, portable measuring devices were used in conjunction with the most advanced geomatics techniques available today [16].

Instruments used

PLS is a basic type of laser scanning and it creates a 3D point cloud with a LiDAR device (Light Detecting and Ranging). It is capable of collecting millions of points in a short time period. For this reason, it is used in many applications such as project monitoring, building diagnostics, progress control, change detection, quality control, and creating part-built, and as-built models [17].

GoSlam RS100i is a PLS instrument and it was used to perform measurements. This PLS uses SLAM technology (simultaneous localization and mapping), which is real-time positioning and mapping technology joined with the IMU /inertial measurement unit). GoSlam RS100i has a scanning radius of 120 meters and the ability to collect 320,000 points per second. It has a super large field of view angle 360 degree with a spatial point accuracy up to one cm.

Fig. 2 – GoSlam RS100i laser scanner (https://www.goslam.com/product/RS100).

A low-cost solution for mobile mapping can be the viDOC. The viDoc RTK Rover is a vital component of the mapping process, providing real-time kinematic (RTK) location to improve the accuracy of the mapping findings in comparison to the stock GNSS receiver contained in the iPhone. To provide centimetre-level location precision, the viDoc RTK Rover uses the RTK correction signals that are continuously monitored by the CORS stations from satellites. The viDoc RTK Rover is able to improve the system's positioning and receive real-time corrections by pairing it with the iPhone 13 Pro Max over Bluetooth. The accuracy of a VIDOC RTK (Real-Time Kinematic) rover can be quite high, as RTK technology is designed to provide centimeter-level precision in positioning data. When connected to any NTRIP service, the rover synchronized with PIX4Dcatch allows the generation of real-time, RTK-accurate georeferenced photos and 3D models. Studies have indicated that 3D models with an absolute precision of less than 5 cm can be obtained using viDoc RTK.

Fig. 3 – Vidoc RTK rover paired with a smartphone (DJI Ferntech)

Terrestrial Laser Scanning is a cutting-edge technology used to capture highly detailed three-dimensional (3D) data from terrestrial environments. It employs laser beams emitted from a scanning instrument towards an object or surface, measuring the time it takes for the laser pulses to return [19].

Faro Focus S70 Laser Scanner is a TLS instrument and it was used to perform measurements. With a maximum range of up to 70 meters (approximately 230 feet), the S70 can efficiently capture data from large-scale environments, such as buildings, industrial facilities, and outdoor landscapes. Portability is a cornerstone of the S70's design, allowing users to easily transport and deploy the scanner in diverse settings. The intuitive interface and seamless integration with FARO's software ecosystem make operation straightforward, empowering users to process, analyze, and visualize captured data with ease.

The FARO S70 Laser Scanner utilizes Time-of-Flight (ToF) technology to capture highly accurate three-dimensional (3D) data from terrestrial environments.

Additionally, the FARO S70 integrates other advanced technologies such as rotating mirrors or prisms to direct the laser pulses, high-resolution cameras for capturing color information, and a positioning system (such as GPS or total station) to determine the scanner's location in space. These technologies work in tandem to ensure the scanner captures detailed and accurate 3D data efficiently and reliably.

The combination of ToF technology with these advanced features enables the FARO S70 Laser Scanner to deliver exceptional performance in terms of precision, speed, and versatility, making it a powerful tool for professionals across various industries. This device delivers a measurement accuracy of up to ±1 mm at a 10-meter range, which can slightly vary with increasing distances, ensuring minimal error margins even over its maximum range of 70 meters. The scanner's ability to capture up to 976,000 points per second allows for rapid and detailed data collection, essential for high-resolution 3D models. It performs reliably in various environmental conditions, including bright sunlight and complete darkness, thanks to its robust design and IP54 rating for protection against dust and water splashes. Operating effectively within a wide temperature range of -20°C to 55°C (-4°F to 131°F), the FARO Focus S70 is adaptable to diverse field conditions, ensuring consistent performance. This combination of precision, speed, and environmental resilience makes the FARO Focus S70 an invaluable tool for professionals in surveying, construction, architecture, and industrial applications requiring meticulous 3D documentation.

Fig. 4 – Faro Focus S70 Laser Scanner (https://www.faro.com/en/Products/Hardware/Focus-Laser-Scanners)

METHODS

Ground Control Points Marking

For geolocation of obtained point clouds, five ground control points (GCPs) as targets 60 cm x 60 cm dimensions were used. These GCP targets are easy identifiable on photos; these are placed on the ground within the boundary of the personal and terrestrial laser scanning and serve to possibility to georeference the created photogrammetrical model. For this study, five GCPs were selected and measured with GNSS Trimble R12i receiver, obtaining RTK data from the Albanian National GNSS System "ALBCORS. It is advisable to make the GCPs visible during the scanning area, which is achieved by using high-contrast colors and ensuring that the size of the control points is sufficiently visible for the flight height at which the work is being performed. The size of the control points shall be determined by the scale of the image; the GCP for the TLS and PLS shall have a clearly identifiable center or point within the accuracy of the ground measurement, in this case approximately two centimeters. The size of the target should be at least 10 pixels for sufficient detection quality. The GCPs should be placed regularly at the edge of the observed locality and at least one in the middle due to model deformation. The accuracy of the ground control points (GCPs) measured using a total station is notably high, achieving an overall precision of approximately two centimeters. This level of accuracy is essential for ensuring the reliability and utility of the geospatial data derived from these points. To enhance the robustness of the measurements, a subset of GCPs was measured twice from different survey stations, allowing for cross-verification of the data. The observed differences in the measured coordinates from these repeat measurements are around 8 millimeters, which is well within the acceptable tolerance for high-precision surveying. This minor discrepancy highlights the consistency and reliability of the total station. The workflow involved meticulously setting up the total station at designated survey stations and precisely measuring the coordinates of each GCP. For validation, certain GCPs were remeasured from alternative stations, providing a means to verify and ensure the accuracy of the initial measurements. The consistency observed in the measurements underscores the effectiveness of the workflow and the reliability of the equipment used, confirming the GCPs as trustworthy benchmarks for high-accuracy geospatial tasks.

Fig. 5 – Ground Control Point distributed around the castle (Google Earth).

The coordinates of GCPs were obtained with one cm absolute accuracy in ETRS89 / Albania TM 2010 coordinate system (epsg:6870).

Tab. 1 - Coordinates of 5 Ground Control Points measured with Total Station

GCP	X (m)	Y (m)	H (m)
1	4,545,881.829	457,710.367	3.474
2	4,545,937.371	457,697.870	3.246
3	4,545,944.403	457,626.342	3.224
4	4,545,864.029	457,647.027	3.012
5	4,545,906.751	457,671.135	3.491

Personal and Terrestrial Laser Scanning

Plans and cross-sections of the fortification were the intended output of the documentation. So, spatial measurement was always the basis. Regarding methodology, all three technologies—PLS, Mobile Laser Scanning (MLS), and TLS—were employed. It must be acknowledged that each has benefits and drawbacks and that the objects for which they are used vary. Larger built-up regions are best mapped using the PLS because it is quick and portable; in the instance of the Vidoc Rtk Rover, there is no texture because the scanner utilized here lacks a camera and simply produces a non-textured point cloud with an accuracy of within 5 cm. [21].

TLS requires more work, but the Faro M70 laser scanner has texture and better accuracy. The drawback is that documentation is done more slowly than with PLS. Currently, photogrammetric documentation is produced at a very high and quick level using SfM or IBMR, which creates a point cloud in a manner comparable to laser scanners. The point cloud in photogrammetric technology is invariably textured. One could argue that photography is a type of scanning as well, albeit one that uses a matrix of detectors and typically does so in an erratic order. Photogrammetry uses pixels and lines rather than metric units, thus you will need to add a scale bar or measure at least one distance on the object [22].

Measurements were conducted using the PLS instrument GoSlam RS100i. This PLS makes use of SLAM (simultaneous localization and mapping) technology, which combines the IMU (inertial measurement unit) with real-time positioning and mapping capabilities. With a scanning radius of 120 meters, the GoSlam RS100i can gather 320,000 points in a second. With a spatial point accuracy of up to 1 cm, it boasts an incredibly broad field of view, spanning 360 degrees. GoSlam took 58 minutes to acquire the data about the castle.

The iPhone 13 Pro Max's high-resolution camera and light detection and ranging (LiDAR) technology were utilized to capture images and gather depth data, respectively. Together 3738 images were collected.

The Pix4Dcatch software was paired with the iPhone 13 Pro Max to enable real-time data gathering and analysis of the LIDAR point cloud data in the field. The Pix4Dcatch program was used to handle the LiDAR sensor data and produce a point cloud. To improve the geolocation accuracy of the mapping results, data from the viDoc RTK rover acquired through the VRS network was also utilised. Using LiDAR point cloud data, the Pix4Dcatch app on the iPhone 13 Pro Max created a preliminary depiction of the point cloud; however, additional image processing was required to create a high-resolution point cloud by providing additional camera sensor data.

Subsequently, the data collected by the iPhone 13 Pro Max was transferred to a computer that was running the Pix4Dmatic application in order to undergo additional processing. Through the integration of the LIDAR point cloud data with the image captured by the iPhone 13 Pro Max, the Pix4Dmatic software generated a more accurate and comprehensive representation of the road infrastructure. Furthermore, the software employed state-of-the-art algorithms and computer vision techniques to improve the accuracy of the mapping results.

The Pix4Dmatic application includes control points that were acquired by field-based georeferencing using GNSS receivers in addition to RTK GNSS data. This information was used to reference the locations in the point cloud that the user had marked and could easily differentiate. Pix4Dmatic's 3D model of the object space is extremely accurate and detailed thanks to its usage of photogrammetric image processing. The software automatically aligned the LIDAR point cloud and picture data, used the RTK GNSS and georeferencing data, and increased the accuracy of the mapping findings.

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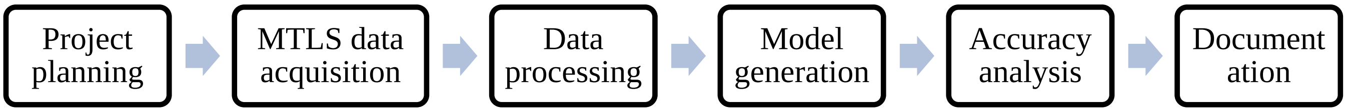

Fig. 6 – The workflow adopted for the study

The FARO S70 Laser Scanner collects extremely precise three-dimensional (3D) data of terrestrial environments using Time-of-Flight (ToF) technology. In order for ToF technology to function, laser pulses are directed at surfaces or objects, and the time it takes for the pulses to return is measured. The scanner generates point clouds, which are accurate three-dimensional depictions of the scanned area, by computing these distances. By working with Faro S70 laser scanner, only five scanner position were used, located in the center and in the corners of the fortress. The integration of ToF technology with these sophisticated functionalities empowers the FARO S70 Laser Scanner to yield remarkable results in terms of accuracy, velocity, and adaptability, rendering it an invaluable instrument for experts in several fields. It took 43 minutes to capture the data for the castle using the Faro S70 [24].

Fig. 7 – Laser Scanner Faro S70 during measurements inside the castle.

RESULTS

Personal Laser Scanning (PLS)

The GoSLAM Studio Flagship Version software was used to process personal laser scanning data. This software is specially designed and developed for the GoSLAM series of mobile 3D scanners, integrating device application and point cloud processing. It is also compatible with third-party device point cloud processing.

The program has eight fundamental features: coordinate transformation, automatic horizontal plane fitting, point cloud splicing, forward photography, automatic point cloud data report production, one-click point cloud denoising, shadow rendering, and point cloud encapsulation. To facilitate data access, GoSLAM incorporates one-click heap data production into bulk metering. Using GoSLAM Studio Flagship, the independently registered PLS point clouds of the castle were aligned. We combined all the data after this alignment to create a single point cloud. A set of spatially measured points is called a point cloud. Each pixel in digital photogrammetry is made up of two coordinates, X and Y. By using photogrammetric processing, it is possible to compute the point cloud from at least two overlapping photos of the same object. A typical point cloud is composed of millions of points, which together form a 3D shape or view; the points can be coloured by a camera in laser scanning or directly from images in digital photogrammetry.

Fig. 8 – Point Cloud generated from PLS

viDOC

The LiDAR sensor created a point cloud of the region, which gave us a complete 3D representation of the object space and allowed us to understand the road infrastructure, while the camera took pictures of the road infrastructure. The mapping procedure was made more accurate and efficient by using the Pix4Dcatch app for image processing and automated alignment between the photos and LiDAR data. Pix4Dcatch software was used to process the data collected by the RTK Rover and iPhone 13 Pro Max, as depicted in Figure 2, and create a 3D reconstruction of the road infrastructure. The application used RTK data, LiDAR, and image alignment to improve the geolocation accuracy of the mapping results. The precision of the mapping results was further improved by the iPhone 13 Pro Max's capability to receive real-time modifications from the RTK Rover via Bluetooth connectivity.

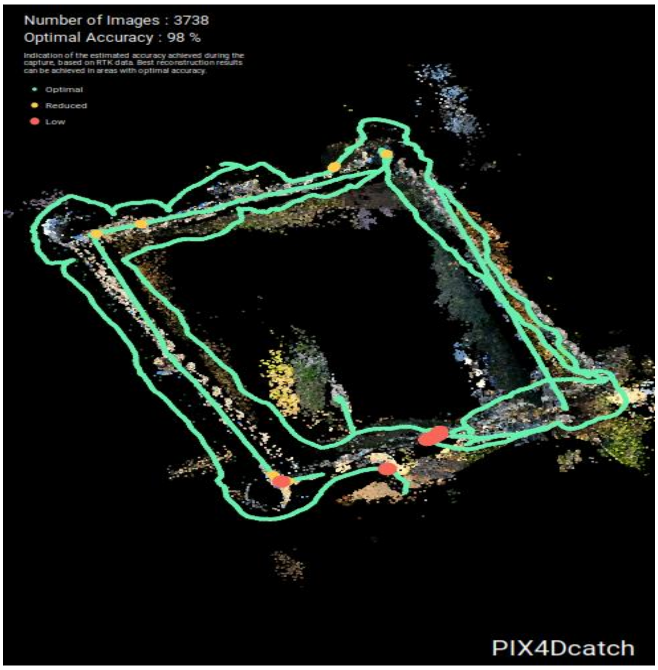

Fig. 9 – Results obtained in Pix4Dcatch

Fig. 10 – Point cloud generated in Pix4Dmatic

Accuracy assessment of viDOC

The absolute correctness of the point cloud data was assessed by contrasting manually measured RTK-GNSS ground control points with the digital relief model (DRM) created from the data. Point clouds created by mobile handheld terrestrial laser scanning need a common reference in order to be compared. In this instance, we used a standard digital relief model (DRM) for evaluation and chose to interpolate the data sets with irregular spacing, like point clouds, using the inverse distance weighting (IDW) technique. The optimal grid resolution for this experiment was determined using Equation 1, which can accurately compute the lowest grid resolution (p) based on the data density. Different DSM surfaces were generated at various grid resolution calculations for each dataset.

$$p = 0.5 * \sqrt{\frac{1}{D}} \quad (1)$$

where D is the average point density (number of points/dm2)

Every RTK-GNSS GCP elevation (ZGCP) and the elevation of the point at the same position (ZDRM) in DRM were compared to determine the elevation difference. ZGCP represents the GCP points with their elevation (Z), while ZDSM represents the points identified in the digital relief model along with their elevation. Additionally, using the vertical differences between the observed RTK-GNSS control points (ZGCP) and the points on the DRM surface at corresponding coordinates, the root mean square error (RMSE) and standard deviation (SD) were calculated. These points are dispersed over the research region and unrelated to the point cloud and DRM creation. This is how the RMSE and SD were computed:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Z_{GCP}\,(X_i - Y\mathrm{i}) - Z_{DRM}\,(X_i - Y\mathrm{i}))}{n}} \quad (2)$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(Z_{GCP}\,(X_i - Y\mathrm{i}) - Z_{DRM}\,(X_i - Y\mathrm{i}) - \mu)}{n-1}} \quad (3)$$

To evaluate absolute accuracy, manually measured RTK-GNSS data were employed. The calculated error statistics for DSM surfaces with respect to each ground control point are shown in Table 1. The table shows that all statistical values are below five centimeters barrier. There were not many changes between the point cloud data that came from each system, according to an analysis of the error statistics of the two systems.

Tab. 2 - Error values of point cloud data

Min (m)		Max (m)	SD (m)	RMSE (m)
-0.08		0.021	0.026	0.048

Terrestrial Laser Scanning

The Faro Scene software was used to process terrestrial laser scanning data. This software is a versatile and robust platform developed by FARO Technologies, renowned for its excellence in 3D measurement and imaging technology. Designed to process, manage, analyze, and visualize 3D point cloud data from various sources, including laser scanners and drones.

Terrestrial laser scanning has become a common tool for documenting monuments, but it has also resulted in a significant surge in data. In two days, more than 16 GB of data—including photographic ones—were collected. In the best-case scenario, a report is generated, and the scans are automatically merged based on the correlation. However, a significant overlap of scans is required, and this can only be done with expertise. For less complicated items, sets of connected scans are formed that need to be manually linked into one using tie points. For more complex objects, the scans join well automatically based on overlap, usually more than 50%. Still, the end product is a 3D model with texture that is of a respectable caliber.

FARO Scene offers a comprehensive suite of tools and features. From efficient data import and management to advanced registration and alignment capabilities, the software empowers users to seamlessly integrate and manipulate large datasets with ease. Its powerful visualization and analysis tools enable precise navigation through point cloud environments, allowing for detailed measurements, annotations, and modeling directly within the software. With seamless export options and compatibility with industry-standard formats, FARO Scene facilitates interoperability with other software applications, ensuring flexibility and efficiency in diverse workflows across industries such as architecture, engineering, construction, and forensics.

After the expedition, all five scans were processed using the Faro Scene program. The totally automated "cloud-to-cloud" technique of joining the gathered scans was based on correlation.

Between four scanner stations, eight linkages were discovered. Due to the Faro S70 laser scanner's ability to make measurements that are reasonably accurate across short distances, the final combined point cloud it produced was designated as the reference measurement.

Fig. 11 – Point Cloud generated from TLS

Comparison of PLS and TLS

Point clouds were generated and transferred to the CloudCompare program from laser scanners. The TLS measurement was chosen as the reference point cloud because, out of the three approaches, it was the most accurate and complicated. According to the computational report, the average overlap is more than 78%, and the differences after automatically connecting four observed point clouds approach only 1 cm. The final point cloud produced by TLS and the point cloud produced by PLS were compared.

Comparing point clouds in CloudCompare software involves a systematic process to analyze and visualize the similarities and differences between multiple datasets. After importing the point clouds into the software, users can utilize various tools and functionalities to conduct the comparison. Cloud-to-cloud distance analysis allows for the measurement of the discrepancy between corresponding points in different datasets, enabling the identification of areas of divergence or alignment. Additionally, registration algorithms can be employed to align the point clouds for accurate comparison, utilizing features such as Iterative Closest Point (ICP) or manual point picking. Visualization tools such as color mapping and slicing enable users to visualize and interpret the comparison results effectively. By leveraging these capabilities, CloudCompare empowers users to conduct comprehensive analyses of point cloud data, facilitating informed decision-making in various fields such as archaeology, geology, and engineering. The point cloud obtained from TLS measurements was used as the reference point cloud. As can be seen from figures 12 and 13, both point clouds are very similar; the peripheral parts are different, which is logical. They contain dissimilar parts. We obtained a mean RMS of 1.15 cm and std. dev was 1.56 cm.

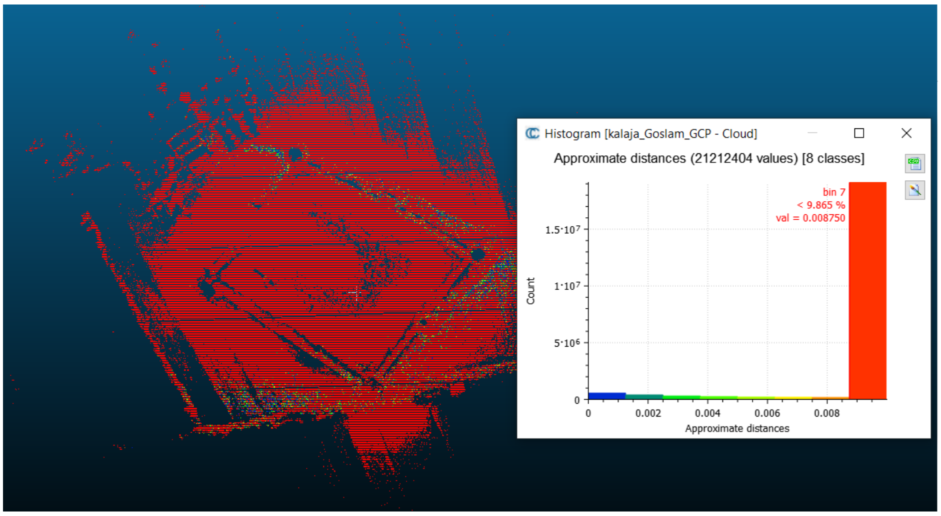

Fig. 12 – Distance computation and histogram in Cloud Compare

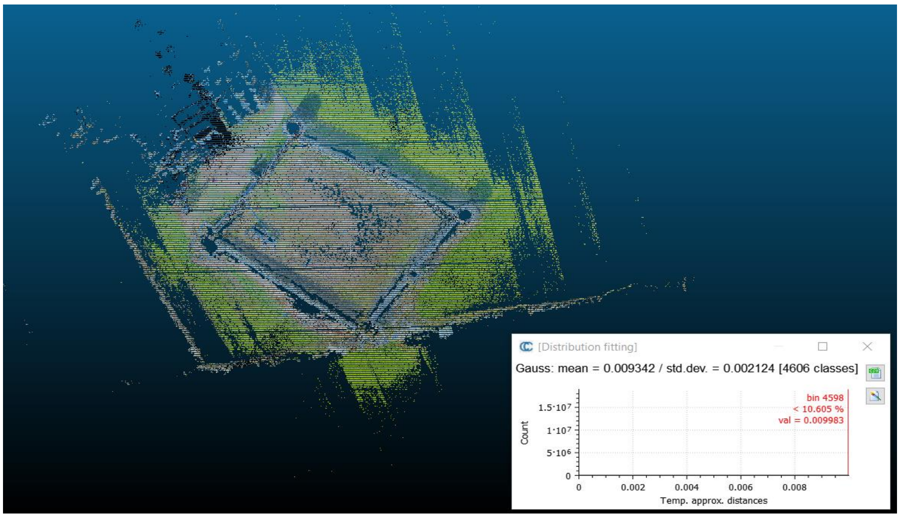

Fig.13 – Results obtained in Cloud Compare

CONCLUSION

TLS and PLS offer distinct advantages and should ideally be selected or combined based on the desired level of accuracy, data coverage, and visual detail needed to preserve and study cultural heritage areas effectively.

PLS technology generate direct point measurements. This makes it the preferred choice when precise dimensional information is critical, such as for intricate architectural elements. It is also economical and perfect for the detailed scanning of objects. The precision is based on IMU and the time of measurement, and of course on complexity of movement; the absolute accuracy can be 1-3cm based on using of GCPs.

Using of iPhone 13 Pro Max with a viDoc RTK Rover was easy to use and sufficiently accurate. The absolute accuracy of the point cloud data was evaluated by hand measurements acquired from a GNSS device. The results demonstrate that the vertical precision of the iPhone-viDoc point cloud data was substantially higher, with error values approaching the centimeter level. The georeferencing of the dataset was completed satisfactorily at the centimeter scale. This suggests that all three approaches may be used to extract road borders and evaluate cross-slopes with a high degree of accuracy. The exact correctness of the point cloud data is determined by comparing manually measured RTK-GNSS ground control points (GCPs) with digital relief models

(DRMs) created from the point cloud data.. The results also show that the iPhone-viDoc point cloud data can be used in place of UAV-LiDAR data for these reasons. PPK application on the viDoc RAW data may be investigated in future studies in an effort to improve the testing and reach even higher georeferencing accuracy. The study provides useful information regarding the mapping and appraisal of heritage sites using low-cost mobile mapping techniques like viDOC.

Personal laser scanning systems, such as handheld or backpack-mounted devices, often provide high-resolution point clouds with exceptional detail, particularly in confined or inaccessible areas. However, the accuracy of PLS may be influenced by factors such as operator skill, motion artifacts, and limited range. In contrast, TLS systems offer superior precision and accuracy over larger areas due to their fixed position and advanced scanning capabilities. Despite this, TLS may struggle with capturing intricate details in complex environments or areas with occlusions. One of the primary advantages of PLS is its portability and flexibility.

PLS systems can be easily transported and deployed in diverse settings, allowing for rapid data collection and on-site processing. This agility is particularly advantageous for documenting heritage sites with challenging terrain or restricted access, where TLS may be impractical or time-consuming to set up. However, the mobility of PLS comes at the cost of reduced scanning range and potential limitations in coverage compared to TLS. The cost of equipment, software, and personnel training is a critical factor in choosing between PLS and TLS for heritage site documentation.

PLS systems generally have a lower initial investment compared to TLS, making them more accessible to smaller organizations or projects with limited budgets. However, ongoing expenses related to maintenance, calibration, and data processing may offset these initial savings over time. In contrast, TLS systems require a larger upfront investment but offer economies of scale for large-scale projects and long-term data archival. Both PLS and TLS generate point cloud datasets that can be integrated with other surveying techniques, such as photogrammetry or ground-based measurements, to create comprehensive 3D models of heritage sites. The complementary nature of these methods enables researchers to combine the strengths of each approach and mitigate their respective weaknesses. For instance, PLS may be used for capturing fine-scale details and textures, while TLS provides accurate geometric data for structural analysis and conservation planning.

The results of the study showed that the TLS offers a constant accuracy than PLS for the documentation of cultural heritage areas. After analyzing our results, we found that there is a one centimeter difference between the point clouds obtained from TLS and PLS. It should be added that the PLS and TLS will not deliver data from the upper parts of the object if it is used as a mobile device carried by the operator. By comparing the point clouds derived from TLS and UAV in CloudCompare software, we obtained a mean RMS of 1.15 cm and std. dev was 1.56 cm. In general, we can recommend both technologies for the documentation of the heritage sites.

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