Integrating UAV Photogrammetry and Terrestrial Laser Scanning for the 3D surveying of the Fortress of Bashtova

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Abstract: - Through the synergistic application of Aerial Photogrammetry using UAVs and Terrestrial Laser Scanning (TLS), this paper investigates how this combination can be used for conducting a 3D survey of the Fortress of Bashtova thereby demonstrating the effectiveness of such integrated methods in acquiring an all-encompassing image of this historical building. As the efforts towards preservation become intense, there arises the urgency of precise and detailed 3D documentation that will facilitate appropriate conservation processes and further studies. Therefore, combining TLS and UAV photogrammetry offers a powerful tool that can provide accurate architectural data for the documentation of heritage areas. Moreover, the TLS component acquires ground point-cloud data with laser scanners giving a complementary alternative for aerial perspective. The merging of these datasets ensures broad inclusion since it allows the production of accurate, detailed three-dimensional models of the Fortress of Bashtova. Thanks to the research on the case study of the Fortress of Bashtova in the article, it can be stated that the integration of data from aerial photogrammetry 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. To estimate the accuracy of the point clouds derived from TLS and UAV, we compared the distances between the point clouds using CloudCompare software. We obtained a mean RMS of 2.199073 mm and std. dev was 7.356 mm. Research has shown that the difference between point clouds from TLS and UAV is within 1.7 centimeters.

Key-Words: - UAV, Terrestrial Laser Scanning, 3D Model, Heritage, Photogrammetry, Point Cloud, Accuracy.

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1 Introduction

Today, the widely accepted technologies must be in a place to uncover such historic buildings and how such mysteries have been solved as archeological documentation and conserving of historical remains cannot do without it. Among these, the combination of terrestrial laser scanning (TLS) and aerial photogrammetry stands out as a revolutionary method that provides a cooperative response to the difficulties presented by the elaborate architecture and vast landscapes of castles. Combining Terrestrial Laser Scanning (TLS) and Aerial Photogrammetry within this context emerges as one forerunning method capable of providing a complementary answer to such challenges brought about by the detailed structures and large environments found at castle sites.

Monuments and other items that are part of cultural heritage have long been documented using geodetic methods. The speed and precision of documentation work have greatly risen with the advancement of computer technology and new equipment. Photogrammetry was invented and photography started to be used for documenting about 150 years ago. Following World War II, electronic methods were progressively included in surveying, and in the 1970s, satellite data started to be employed in addition to aerial images. With the advent of widely accessible computer technology and the digitization of technology, the 1990s saw a significant shift. These days, automated close-range photogrammetry from the ground and drones, airborne systems, satellite systems, terrestrial and mobile laser scanning, and electronic surveying systems (total stations, GNSS equipment) are used. Research on the synergy of data from many instruments is being conducted at many workplaces these days.

In this paper, we will investigate the use of this integration technique using Bashtova Castle as our main example. The rich historical significance and the complex architectural features of the Bashtova

Fortress provide an interesting platform from which to test if it is possible to combine Aerial Photogrammetry and TLS for full 3D surveying of castles.

Castles are intriguing not just because of their past, but also because they are constructed with lots of fine points that residents and visitors find equally fascinating usual surveying procedures rarely take into consideration all aspects when it comes to castles. Nevertheless, aerial photogrammetry utilizing unmanned aerial vehicles (UAVs) together with high-resolution images constitutes the best method through which one can get an overview of a castle from above, [1].

At the same time, we have the terrestrial laser scanner that is based on the ground targeting detailed printouts of the inside parts of the fortress together with its structural characteristics. The combination of these methods can bring a detailed 3D survey of cultural heritage areas including all details and eliminating information gaps, [2], [3].

This study presents the integration of UAV photogrammetry and terrestrial laser scanning for the 3D survey of the Fortress of Bashtova, as well as presents a methodology for the management of cultural and archaeological areas, [4].

The results of this scientific research show that the integration of these two methods for the 3D survey of cultural heritage areas provides an effective approach to capturing all the architectural elements and details with high accuracy and provides a comparison of the accuracy between UAV photogrammetry and terrestrial laser scanning, [5], [6].

2 Materials and Methods

2.1 Case Study

We used the Fortress of Bashtova as a case study in this paper. Bashtova castle is located at a distance of 3 - 4 kilometers near the village of Vile-Bashtove, in the north of Shkumbini river.

This castle was built in the 15th century and is a beautiful testimony to the civilizations that have passed through Albania. It is 36 kilometers north of Fier, 20 kilometers northwest of Lushnja, 15 kilometers south of Kavaja, and 40 kilometers southwest of Tirana as shown in Figure 1.

It is the only castle in the Balkans to be constructed on a field.

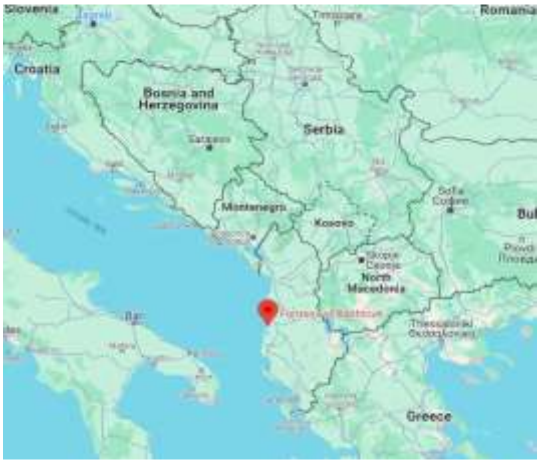

Fig. 1: Location of the Fortress of Bashtova

2.2 Architectural Analysis

The Fortress of Bashtova has a rectangular plan measuring 60 x 90 m. In the four corners and the middle of each wall, there is a tower, except for the western wall which belongs to a second construction period. The walls have a width of 1m. Between the sandstone and conglomerate in irregular shapes, pieces of bricks and tiles have been inserted here and there. From the inside, the walls are broken by a system of pilasters with a section of about 1x 1.5m at every 3m distance.

In the upper part, the pilasters relate to brick arches, 0.40 m high, strengthened with wooden ties, and create the arches over the guard path 1.20 m wide. The walls' total height, including all of the beams, was nine meters. The height of the balustraded parapet is 1.90 meters, and its width is 0.80 meters. Arrows measuring 0.50 meters in height, 0.35 meters in internal width, and 0.15 meters in external width are used to characterize each bar.

The niches, which are created between the pilasters, are also equipped with two rows of friezes. The towers have circular or quadrangular shapes. Two of the corner towers are round, and one is quadrangular, while no traces of the fourth are preserved as shown in Figure 2.

The intermediate towers are all quadrangular. They have a wall thickness of 1.25-1.40 m, while their height reached 12 m. These premises were not inhabited but served only in times of war. In a later period, some tower areas were used for living, being equipped with fireplaces.

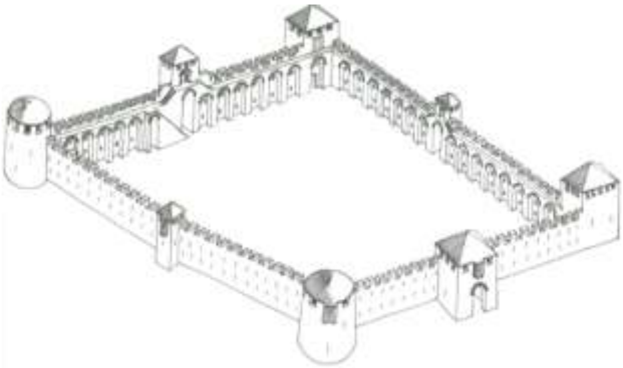

Fig. 2: The plan of the Bashtova Castle

The castle had three entrances, as can be judged from the preserved traces. The gate was covered with architraves and had a light space of 2.70 m, while in a later period, this gate was closed with a wall. The stairs are built of stone walls and rest on the inside of the walls, outside their thickness. The architecture and construction technique point to a fort built in haste, considering the greatest saving of material.

This is evidenced by the thin walls, the harbor combined from the inside with pilasters and arches, the open towers that are less resistant as well as the low floors of the towers designated only in case of wars.

Over the years, several conservation interventions have been undertaken in the Bashtova Castle, relying on the materials found in the Cultural Monuments archive.

2.3 UAV Photogrammetry

Drones are unmanned aerial vehicles (UAVs) that operate without a pilot. The mapping, monitoring, and military sectors have seen widespread utilization of unmanned aerial vehicles (UAVs) due to their ability to click high-resolution data stagecoach versatility. In theory, the UAV system comes with sensors (such as a camera, LiDAR, or thermal sensor), navigational aids, and communication tools, [7], [8].

A DJI Matrice 300 RTK with a Zenmuse P1 camera was utilized during an aerial review of Bashtova Castle in this probe. The DJI Matrice 300 RTK is powered by a quadcopter propulsion system with four rotors for lifting and propulsion. These motors are high-performance, brushless, and are designed to provide the best power and efficiency whilst remaining reliable and silent. Additionally, the DJI Matrice 300 RTK has an integrated obstacle avoidance technology that makes use of advanced sensors and algorithms to detect and avoid things blocking its way, while at the same time being equipped with a strong GPS for accurate positioning and steering, [9].

We used 5 GCP with a width of 60 cm and a length of 60 cm as shown in Figure 3. These points served us to increase the accuracy of the images taken during the photography of the castle with both methods. Ground Control Points (GCPs) are large, easily recognized photo targets that are positioned on the ground inside the drone survey's perimeter. Their purpose is to make sure that each point's coordinates in the images most closely match the GPS coordinates with high accuracy, [10].

For this study, we marked 5 GCPs and measured them with a Trimble R12i receiver, obtaining RTK data from the Albanian National GNSS System "ALBCORS.

Ground control points must always be visible during aerial photography and this is achieved by using high-contrast colors and making sure the size of the control points is visible enough for the flight altitude we are working at.

Fig. 3: Ground Control Point distributed around the castle

Ground Control Point coordinates were acquired in the UTM Zone 34N coordinate system (epsg:32634) with an absolute precision of 1 mm as shown in Table 1.

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

GCP	X (m)	Y (m)	H (m)
1	4545029.727	373683.198	3.474
2	4545085.396	373671.341	3.246
3	4545093.246	373599.915	3.224
4	4545012.658	373619.673	3.012
5	4545055.091	373644.263	3.491

We used DJI Matrice 300 RTK with Zenmuse P1 which has the largest image sensor with the highest resolution ever. The Zenmuse P1 camera also supports prime lens swapping. These lenses are capable of producing 45-megapixel aerial photos, and the camera is mounted on a 3-axis gimbal. The DJI Zenmuse P1 with a 35mm focus lens was tested for this study.

For UAV Photogrammetry was performed oblique mission using DJI Pilot 2 which involves a main flight path to collect nadir photos in addition to multiple subpaths facing towards the center of the site to collect oblique photos. This method requires more flight time and battery power than a standard 2D Area Route mission of the same site, [11], [12].

For the oblique area route, 5 different missions were performed to capture all the details of the castle, with different camera angle positions. All 5 missions, then were merged into a project, to generate a Point Cloud with high accuracy, [13], [14], [15].

We choose 50 m height and 3 m/s speed of DJI Matrice 300 RTK to perform this flight path as shown in Figure 4. A front overlap of 85% and a side overlap of 80% were set.

Fig. 4: Oblique mission performed with DJI Matrice 300 RTK

2.4 Terrestrial Laser Scanning

Terrestrial Laser Scanning, otherwise described as TLS, is a version of laser scanning that uses Light Detection and Ranging for the creation of a 3D point cloud. In a brief amount of time, it can gather millions of points. Because of this, it has been applied to a wide range of tasks, including part-built and as-built model creation, progress control, change detection, building diagnostics, and project monitoring, [16], [17].

Static TLS and mobile laser scanning (MLS) are the two types of TLS. To gather high-precision information, static Terrestrial Laser Scanners (TLS) involve locating a tripod-mounted laser scanner within a fixed region and scanning over the surrounding area using multiple aspects. In engineering, architecture, and construction, static TLS is common when exact measurements are needed for buildings and sites. However, MLS deploys a handheld scanner like a laser scanner which is hand-held or even a moving platform such as a car, drone, backpack, or any other item. MLS scanners can collect 3D data of the surroundings, enabling rapid and effective data collection as it moves around the area. MLS is common among surveying, mapping, and infrastructure management applications, [18], [19].

There are benefits and drawbacks to every static TLS and MLS. When it comes to obtaining more detailed data for smaller areas, static TLS is always the best option. It also offers better accuracy and resolution. On the other hand, MLS is advantageous for fast and accurate mapping of large regions or large-scale mapping because it can cover more areas in a shorter period. Similarly, hazardous, or hard-to-reach sites such as tall buildings and cliffs can also be accessed through MLS. By comparing the MLS technology with static TLS technology, some of its drawbacks can be noted too. For example, the speed at which a scan is made may make MLS data less detailed compared to TLS while other things can affect how accurate it is also.

Terrestrial laser scanning, or TLS, for static data capture is vital. It has major benefits like wide coverage as well as high precision. Nonetheless, using TLS also has some negative aspects like the large initial investment needed for equipment and software, the time-consuming process of capturing a large or complex project, and the environmental sensitivity of TLS. To avoid these constraints, a properly planned TLS survey program can be implemented, increased using the Reality Capture (RC) technology's additional aid during the data collection procedure, [20].

A well-designed TLS survey plan can save time on-site, limit self-occlusions, and provide maximum coverage of aqueduct surfaces with adequate point density. Typically, TLS is employed in conjunction with other RC technologies, such as photogrammetry or SfM (Structure-from-Motion). By combining TLS with photogrammetry, practitioners can benefit from both photogrammetry's flexibility and TLS's high accuracy, [21].

GoSlam RS100i as shown in Figure 5 was used to perform Laser scanning measurements. This Slam laser scanner employs Simultaneous Localization and Mapping (SLAM) technology which provides real-time positioning and mapping capabilities.

The GoSlam RS100i can gather 320000 points per second and has a scanning radius of 120 meters. Its 360-degree range of view and 1-centimeter point accuracy make it extremely large.

The data collection for the castle with GoSlam was 58 min.

Fig. 5: GoSlam RS100i laser scanner

3 Results

3.1 UAV Data Processing

Five processing steps are typically involved in the generation of a dense, georeferenced 3D point cloud from a block of overlapping photographs: 1) Identification of features; 2) matching those features, among which geometric verification takes place; 3) SfM sparse 3D reconstruction; 4) GCPs optimize the bundle adjustment by georeferencing the scene geometry and adding camera self-calibration; 5) multi-view stereo dense matching for dense 3D reconstruction.

There is constant use of the A Scale Invariant Feature Transform (SIFT) algorithm for detecting features, i.e., important locations in every image in the first stage. Important spots are partially invariant to photometric distortions and 3D camera viewpoint, and they are scale and rotation invariance. The texture and resolution of each image mostly determine how many critical points are present. In the second stage, an approximate nearest neighbor (ANN) method is typically used to match the important locations, which are identified by a unique descriptor, across many images.

After that, each matched picture pair's key point correspondences are filtered using a RANdom SAmple Consensus (RANSAC) algorithm to impose a geometric epipolar constraint.

The third phase includes reconstructing the 3D geometry of the scene and the geometry of the picture network together using iterative bundle adjustment and geometrically corrected correspondences (tie points). This further estimates values that relate to the calibration of a camera—internal camera (intrinsic) parameters (IOP)—as well as position and attitude of each given image in an arbitrary coordinate system—external orientation (extrinsic) parameters (EOP), with only the tie points image coordinates acting as observations.

In step 4, the sparse 3D point cloud is scaled and georeferenced using a seven-parameter 3D similarity transformation in the GCP coordinate system. The GCP coordinates are then obtained as observations and are typically measured using dual-frequency GNSS receivers. To enhance the EOP, IOP, and 3D coordinates of the tie points, further GCP measurements and markings of where they occur on the images can be included during bundle adjustment. Rerun the bundle adjustment with appropriate weights on coordinates of ground (GCP) and image (tie points and GCP) measurements to reduce reprojection and georeferencing inaccuracies, [22].

Stage 5, is often a case of boosting the point density of the sparse point cloud by several orders of magnitudes - two or three - using a multi-view 3D surface reconstruction algorithm. From this reduced general cloud, in which we have both exterior and interior orientations which were determined previously as the best one, it performs the computationally intensive dense matching technique that creates, initially in image space, depth maps of every image batch, after which they are combined into the specified area.

The Pix4DMapper software was used to process UAV images. This software automatically transforms the images taken by the drone and delivers high-precision products such as orthophotos and Digital Surface Models (DSM). Pix4DMapper uses the SfM (Structure from Motion) technique to reconstruct the scene based on many overlapping photos.

For the processing of aerial images in Pix4DMapper, initial processing was performed first. Before beginning the initial processing, PIX4Dmapper computes the pictures' key points.

This software uses these key points to find the similarities between the photos. After this initial match was found, Automatic Aerial Triangulation (AAT) and Bundle Block Adjustment (BBA) were then carried out by the software.

In this study, the coordinate system for final products was chosen UTM Zone 34N (epsg: 32634). Then, in the Pix4DMapper software, the corresponding template was defined as 3D maps, which gives us the products mentioned above.

A digital elevation model (DEM) and an orthophoto of the surveyed region were produced by this technique.

The creation of the Point Cloud and 3D mesh was the second stage of image processing in Pix4DMapper, following the first processing.

Point clouds are generally produced using 3D scanners or photogrammetry software that measures a huge number of points on the external surfaces of surrounding objects. Point clouds are produced via 3D scanning procedures and are utilized in a wide range of applications such as mass customization, animation, visualization, metrology, and 3D computer-aided design (CAD) models for manufactured parts.

The model shown in Figure 6 has a high accuracy with about 303,289 points, 298 pictures, 2.41-pixel size, 5472 x 3648 resolution, and a camera centering error of 1.2 cm.

After this process, we were able to get the DSM in 2 cm pixel resolution.

Fig. 6: Point Cloud generated from UAV Photogrammetry

3.2 Laser Scanning Data Processing

Three primary stages are involved in administering raw TLS survey scans: (1) register the scan; (2) clean and optimize point cloud data; and (3) reduce the point cloud dataset. Scan registration is the first step in processing scan data. This step will involve aligning the scans to a single reference system to generate a point cloud showing the whole heritage site. Target-based registration, which uses pre-established targets, or targetless registration, which uses homologous features, is the usual method for manually or automatically doing scan registration in pairs, [23].

Once the scans have been registered, the point cloud needs to be cleaned to ensure that the final model is accurate and useful for further research and documentation. Essentially speaking, point clouds are collections of three-dimensional data points, which show the scanned geometry of some environment or item. However, a variety of factors, including reflecting surfaces, occlusions, and sensor noise, might impact these data points, leading to inaccurate and inconsistent point cloud data. Cleaning the point cloud means removing any noise and undesired data points that may have been gathered, and also correcting any errors that may have occurred during the scanning process.

To find and eliminate undesirable points, this procedure usually combines automatic and manual methods like filtering, segmentation, and classification.

We used GoSLAM Studio Flagship Version software to process laser scanning data. This software integrates point cloud processing and device application specifically for the GoSLAM line of mobile 3D scanners. Additionally, it works with third-party cloud processing devices and point systems.

The software 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.

GoSLAM adds one-click heap data generation to bulk metering to make it easier to access data.

The individually registered TLS point clouds of the castle were aligned using GoSLAM Studio Flagship. We combined all the data after this alignment to create a single point cloud as shown in Figure 7.

A collection of points, similar to pixels in a digital image, is called a point cloud. While the points of the point cloud are made up of three coordinates—X, Y, and Z—each of which represents a distinct location in the three-dimensional space, each pixel is made up of two coordinates, X and Y. Millions of points come together to form a 3D shape or view in a point cloud, [24].

The maximum point error was 2.8 mm and the mean point error was 2.1 mm.

Fig. 7: Point Cloud generated from Terrestrial Laser Scanning

3.3 Comparison between UAV and Laser Scanning

This section contains the findings of our comparison of accuracy in the chosen field using two different methodologies. Based on the results shown, GoSlam laser scanning is more accurate than UAV photogrammetry when it comes to documenting cultural heritage sites, particularly castles.

The point clouds produced by these techniques were compared using Cloud Compare software. After importing the clouds into CloudCompare, we were able to determine their separation from one another. The point cloud that was selected as a reference came from measurements made with a laser scanner.

The largest distance between these point clouds according to Cloud Compare is 67.727 meters and the average distance is 2.095 m.

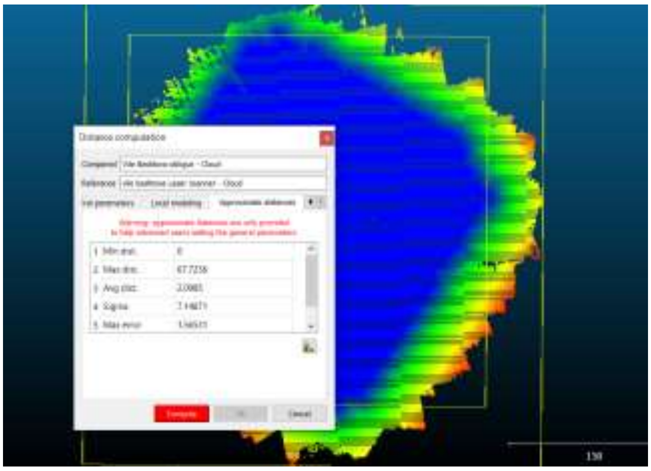

Fig. 8: Distance Computation in Cloud Compare

Figure 8 illustrates how errors and noise can be found in the point cloud produced by UAV photogrammetry. The point cloud acquired using laser scanning has better geometric accuracy.

We obtained a mean RMS of 2.199073 mm and std. dev was 7.356 mm.

By taking advantage of one technology's benefits over the other, TLS and photogrammetry can work together. Compared to photogrammetric surveys, TLS is a more costly technology, and performing laser scans requires more expertise than taking photos for 3D photo reconstructions. However, photogrammetry is more efficient, adaptable, quick, and able to gather high-quality, precise data for intricate things. Combining these two technologies allows for the utilization of the TLS's precise and dense point cloud acquisition capabilities and photogrammetry's adaptability to work under extreme circumstances.

It has been shown that the best approach to recording big and complex heritage sites for purposes such as documentation, structure evaluation, texture mapping, feature extraction, etc. is to combine TLS with photogrammetric approaches.

4 Discussion

This study investigated the combination of Aerial Photogrammetry and TLS for conducting a 3D survey of the Fortress of Bashtova. TLS and UAV photogrammetry are best understood as aggregated because of the differences in data quality between them.

Thus, by obtaining the point cloud data along with their attributes, we were able to recognize risks in the heritage site documentation. In conclusion, this gives the approach a perfect starting point for the documentation of heritage areas. We used CloudCompare to perform an accuracy analysis of each remote sensing point cloud to address the significant issue that was brought up. As a result, we attempted to compare the point clouds produced by TLS and UAV.

After analyzing our results, we found that there is a 1.7-centimeter difference between the point clouds obtained from TLS and UAV.

Our study presents a workable framework for the integration of TLS and UAV-based photogrammetry with applications to heritage areas. This framework includes TLS and UAV image acquisition, point cloud processing, and 3D mapping of heritage areas. Indeed, UAV photogrammetry has been widely used in a variety of fields, with some work in heritage areas documentation having been recorded.

Our study's findings show that unmanned aerial vehicles (UAVs), which require authorization to fly, may be deployed swiftly and often, can fly at low altitudes with less cloud interference, and are less expensive than manned planes and satellites. Nevertheless, there are a few drawbacks to the suggested strategy. First, it can occasionally be challenging to locate ground-characteristic features in historical places. The second is that to cover a greater area, a UAV campaign needs more fly routes due to the length of the battery. Due to the aerial photos' angle of view and distance, the UAV's point cloud does not have information on the fortress's entrance. However, it provides a comprehensive model of the fortress's uppermost section. The TLS point cloud makes it possible to more precisely and in detail represent the entrances and facades.

5 Conclusion

To effectively protect and research cultural heritage locations, aerial photogrammetry and terrestrial laser scanning offer various advantages that should best be chosen or combined based on the required level of accuracy, data coverage, and visual detail. It should be highlighted that while researching cultural heritage sites, high-resolution methods like TLS and UAV photogrammetry are the best options because they make it possible for us to gather accurate data for the documentation of heritage sites.

Laser scanning technology consistently delivers higher spatial accuracy due to direct point measurements. After analyzing our results, the maximum point error of the point cloud derived from TLS was 2.8 mm and the mean point error was 2.1 mm. 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.

UAV photogrammetry excels in providing broad coverage efficiently, making it suitable for documenting larger cultural heritage areas. Its aerial perspective can capture extensive terrains and architectural layouts swiftly.

According to the study's findings, the TLS offers a more accurate accuracy than UAV Photogrammetry for the documentation of cultural heritage sites. Results showed that there is a 1.7-centimeter difference between the point clouds obtained from TLS and UAV. By comparing the point clouds derived from TLS and UAV in CloudCompare software, we obtained a mean RMS of 2.199 mm and std. dev was 7.356 mm.

While the accuracy gained via UAV photogrammetry was 2 cm, the accuracy obtained from the Terrestrial Laser scanning approach for creating the point cloud was 2.8 mm. It should be noted that the TLS will not deliver data from the upper parts of the castle if it is used as a device carried by the operator. Therefore, it is always advantageous to use a combination of aerial photogrammetry and TLS to create a comprehensive model of the object.

This study offers a useful and simple research proposal for deterioration analysis, TLS measurements, and UAV photogrammetry in addition to 3D modeling. It is evident from the research and findings provided in this article that the approach discussed in the article is appropriate for architectural and conservation investigations.

In general, we can recommend both technologies for the documentation of the heritage sites.

It is crucial to remember that the UAV approach might need more specialist tools and knowledge, and it might be impacted by things like air anomalies or poor image processing. UAV photogrammetry is more advantageous than Terrestrial laser scanning in terms of cost and time since it takes less time to photograph the region that needs to be measured.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors used ChatGPT to enhance the clarity and coherence of the text. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Arli Llabani carried out the UAV and TLS measurements and their comparison using CloudCompare software.
- Otjela Lubonja was responsible for the architectural analysis of the Fortress of Bashtova.

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Conflict of Interest

The authors have no conflicts of interest to declare.