Leonid Milanov
MSc, High school teacher
SGGUGS “Zdravko Cvetkovski”- Skopje
N. Macedonia
leonmilanov32@gmail.com

Filip Kasapovski
PhD, Assistant Professor
Ss. Cyril and Methodius University in Skopje
Faculty of Civil Engineering
N. Macedonia

EVALUATION OF TERRESTRIAL AND UAV PHOTOGRAMMETRY FOR CONSERVATION AND DOCUMENTATION OF HISTORICAL HERITAGE OBJECTS

In this paper, the emphasis is placed on the implementation and integration of terrestrial and UAV photogrammetry to obtain a complete spatial model. The protection of cultural heritage is always a serious challenge for all countries, a task that requires the mobilization and coordination of many different human and material resources from several sectors. The possibility of rematerializing the data as physical three-dimensional objects requires new research and in that direction the expected results are that the final product generated with a combined approach will be a plus step towards the digital documentation of the cultural heritage and its long-term preservation.

Keywords: UAV photogrammetry, terrestrial photogrammetry, LiDAR, photogrammetric software, cultural heritage, 3D models

1. INTRODUCTION

As a task for this paper, I chose to show the modernization, refinement and power of geodesy as a scientific discipline presented through increasingly advanced and powerful technology such as drones and the many new software applications that offer fast, accurate and efficient solutions. Today, there are numerous ways and technologies for transferring any object from the real world into the digital 3D space.

From day to day to see how technology continues to develop, one of the examples of this are such drones that are widespread and as such games significant in the process of planning, designing, performing, monitoring and reconstructing all the objects around us.

The use of digital photogrammetry for documenting cultural heritage creates a dynamic database and a valuable resource for a better understanding of the meaning of cultural heritage by end users who can access the information from a digital platform at any time.

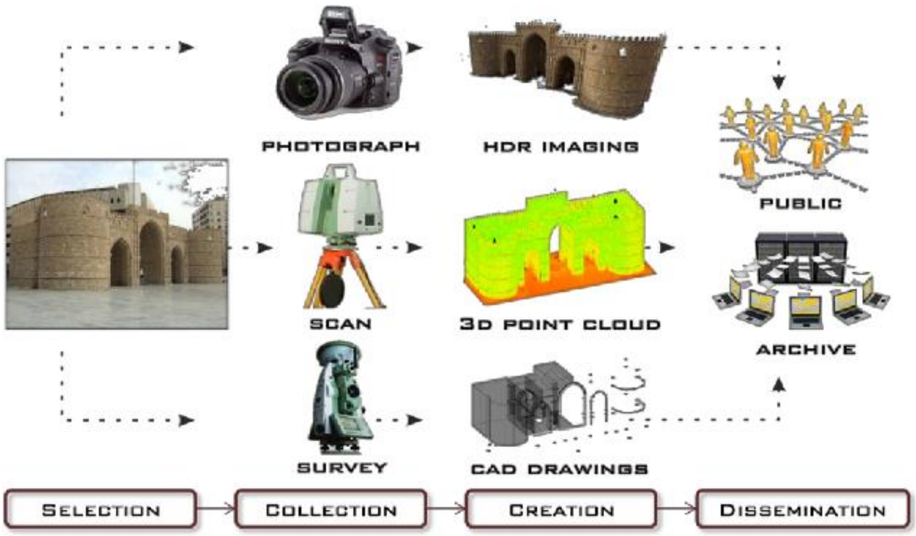

Figure 2. The process of digital reconstruction of cultural heritage objects using photogrammetry [1]

For this paper, the monitoring of a stone arch bridge from the Roman period was monitored in the village of Bogomila, Veles and it represents the cultural heritage of our country.

At the same time, a comparison and analysis of the obtained results will be made, which will be presented in this paper. The appropriate software that will be used to process the main task is of great importance, because it generates the results and data that we need to draw conclusions and opinions.

Several photo camera models with a combination of imaging and LiDAR sensors will also be implemented. In addition, more comparisons and analysis will be made of the obtained 3D models, which will also represent the final product.

1.1 STUDY AREA

The ancient Roman bridge (Figure 2) is located in the center of the village of Bogomila in the Azot region in the eastern part of the territory of the municipality of Čaška in the original catchment area of the Babuna river. It is placed in the northeast-southwest direction across the Babuna river, about 2 km from the railway station in Bogomila. The bridge belongs to the type of single-arch bridges and is classified as a significant cultural heritage site defined by the National Institution "Conservation Center" - Macedonia. The exact construction time of the bridge is not precisely determined. There is a belief among the people that the bridge dates back to the Roman period. It serves as a witness to the history of architectural development in our territory and as such is an important element for study in the context of scientific research on the development and peculiarities of construction in Macedonia. The bridge is a witness to the history of the development of architectural activity in our territory and as such is an important element for study in the context of scientific research on the development and peculiarities of construction in Macedonia. [8]

Figure 2. The oldest found image of the bridge [8]

1.2 PURPOSE OF RESEARCH

Of the numerous areas in which digital photogrammetry is used, I was most interested in architecture as a science that is close to geodesy in many aspects. So, the purpose of my research is to highlight the great importance of digital photogrammetry in architecture and the way it enables documentation for the needs of cultural heritage conservation. At the beginning of the research, I hypothesized that by applying digital photogrammetry, models of the objects that are categorized as cultural heritage, which are the subject of research can be obtained with satisfactory, high accuracy, and based on the models thus obtained, analyzes can be made for their possible displacements, damages and the possibility of their restoration, all in order to preserve them in

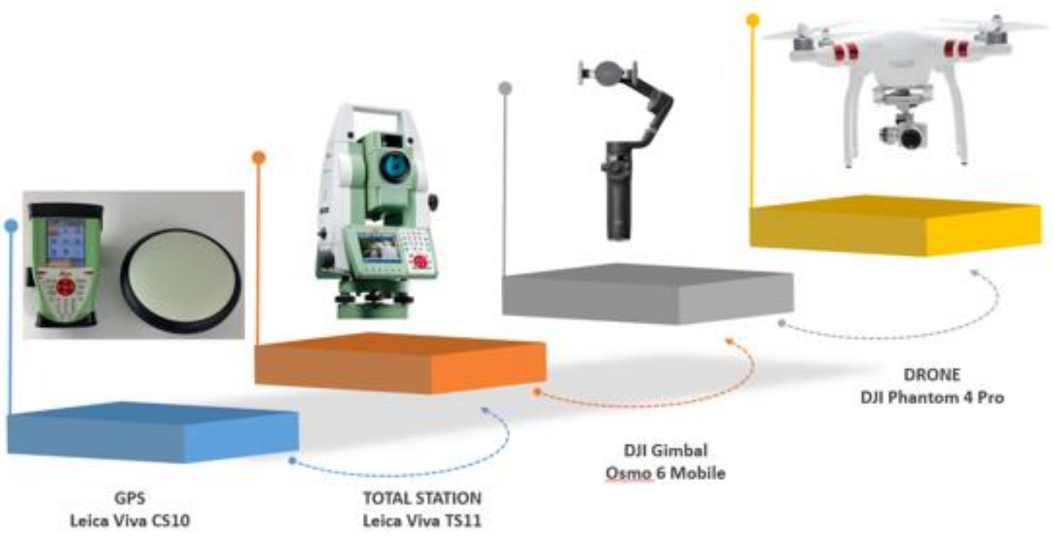

Figure 3. Geodetic measurement technology

their original state. During the creation of the practical example, several applications and software were used, such as Agisoft Metashape, Cloud Compare, Drone Deploy, etc.

2. GEODETIC MEASUREMENT TECHNOLOGY

The implementation of the practical part of the work includes field activities that include the use of various modern measurement technologies, such as the DJI Phantom 4 Pro drone with a 20 MP camera, the triple photo camera from the iPhone 14 Pro smartphone, the Leica Viva TS11 total station with a declared accuracy of 2 mm + 2 ppm and the Leica Viva CS10 GPS with a declared accuracy of 10 mm + 2 ppm for the static method and 20 mm + 2 ppm for the kinematic method. The drone is used to capture high-resolution aerial imagery of the bridge with flight paths strategically planned to achieve thorough coverage from various angles and elevations with support of Drone Deploy platform. Meanwhile, the smartphone camera is employed for capturing detailed close-up images of specific architectural features of the bridge, providing additional visual data for analysis. The GPS device and total station contribute to precise positioning and geo referencing of both the imagery and survey data, guaranteeing spatial accuracy throughout the reconstruction process.

3. GEODETIC MEASUREMENTS

Obtaining comprehensive and precise data, as well as creating a precise digital model with high-resolution detail, presents a challenge for every geodetic professional. It requires the use of a combination of terrestrial and aerial surveying methods, often utilizing advanced technologies like LiDAR or photogrammetry. [6] Given that it is a specific engineering object and an object where there is a greater height difference in the terrain around the object, a plan was made that included all significant changes in the terrain in terms of height in order to obtain a realistic model and a realistic representation of the field. The bridge was covered or recorded in such a way that a combination of terrestrial photogrammetry and unmanned photogrammetry was made. This method of combination gives quite accurate results as well as excellent visualization of all characteristic objects, especially objects that are under historical cultural heritage.

For geo referencing the 3D view from the photogrammetric recording, GNSS technology Leica CS10 was used in support of the MAKPOS permanent stations of the cadastre agency. After the acquisition of the data, it will be processed using different software: initially with Agisoft Metashape to obtain a cloud of points (Point Cloud), then the same cloud of points can be transferred to the software Cloud Compare, as well as to AutoCad Civil3D. It is practically shown how to get a complete 3D view of a specific object, in this case a bridge, and it is of historical and cultural importance. At the same time, to show that the same method is quite precise, accurate and economically viable, as well as to prove these claims through a series of analyzes and comparisons where data obtained by different methods will be used.

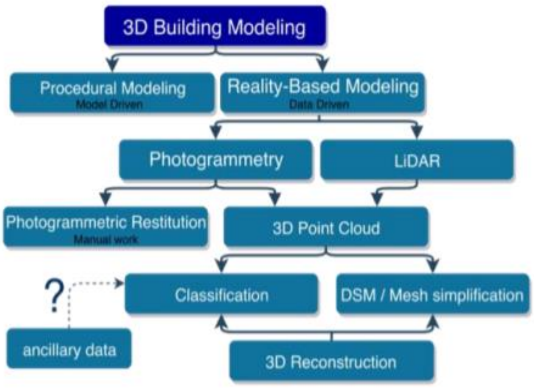

Figure 4. Process of obtaining 3D model [4]

3.1 3D MODEL FROM TERRESTRIAL AND UAV PHOTOGRAMMETRY

According to my analysis and knowledge of the terrain, I decided that the height of the flight should be 50 m, so I made a plan to place 13 markers for orientation points, namely 5 markers that are placed on the roadway of the bridge itself, that is, on the base of the bridge and around it, while the other 8 markers are placed laterally along the surface of the entire bridge and in its arc area in order to obtain better homogeneity and the most realistic display. The average longitudinal and transverse distance of the orientation points placed on the ground is about 10 m, while for the markers placed along the entire bridge it is 5 m. The markers that are placed on the ground have a square shape of 50 x 50 cm and were recorded using a GNSS Leica CS10, and the remaining 8 markers that are placed on the entire bridge were recorded using a Leica Viva TS11 total station, which will give the model coordinates in the state coordinate system.

Figure 1 Figure 5. Ground control points used in field measurements

Photogrammetry recording is supported by the Drone Deploy mobile app, which is designed and customized for the DJI Phantom 4 Pro.

First, the markers that are needed to perform the aerial photogrammetric recording are placed and they are later used as orientation points for geo referencing the model. Two markers were placed on the roadway, two before and after the bridge, and one marker was placed in the canal next to the bridge, that is, at the lowest point of the bridge, which made a correct layout and the average distance from marker to marker is about 10 meters. After the markers for the aerial photogrammetric survey are provided, the markers for the needs of the terrestrial surveys are placed next. Those markers can be said to have been placed laterally along the entire lateral surface of the bridge as well as inside the arch (arch) of the bridge. For that whole, 8 markers were placed and their average distance was about 5 meters. The coordinates of these markers were obtained by measurements using a Leica TS11 total station, thus the station and orientation points were obtained with a GNSS device. The dense network of markers placed on the surface of the bridge and around the bridge is all in order to get the best possible accuracy, that is, to be visible as many markers as possible from as many camera positions as possible. With that, the model gets more power and reliability. The coordinates of these markers were obtained using a GNSS device Leica Viva CS10 with the help of the permanent stations from the MAKPOS system, using a set of parameters for that area.

After recording the orientation points with the GNSS device and the total station, the same markers remain in their positions and the aerial photometric recording is started with the help of the drone. The flight is supported by the Drone Deploy mobile application (Figure 6), which is compatible with DJI drones, and the application itself offers many possibilities and recording methods. With the given parameters, the application gives the recorded pixel size of 1.1 cm/pix, which is sufficient for the required

Figure 6. Flight plan and parameters

research. The flight lasted about 6 minutes and 82 photos were collected. With these phases, the aerial photogrammetry recording is completed and the acquisition of terrestrial images is moving on. The terrestrial photos were provided using a triple camera with a fairly high resolution from the iPhone 14 Pro smartphone. At the same time, the smartphone was fixed to a DJI Gimble Osmo 6 hand-held movable tripod, which provides stability and fixation of the camera during photography. This gives better insight into the camera positions from which the recording is being made and care is taken to have a satisfactory overlap between all subsequent images. In this way, 100 photos were taken for which the geographical coordinates determined through the GPS of the smartphone itself are known.

3.2 3D MODEL FROM LIDAR SCANNING WITH SMARTPHONE

The other example of obtaining a 3D model of the bridge is by collecting scans that will serve to form a dense cloud of points. This was realized with the help of the LiDAR sensors that are present in the iPhone 14 Pro smartphone. The goal is to analyze what accuracy would be obtained in this type of data acquisition by using the orientation points placed on the bridge that were recorded with a total station for georeferencing this cloud of points. Collecting the scans was quite simple and was done from multiple positions. As we mentioned, for this example it was enough for us only the iPhone 14 Pro smartphone fixed to a DJI Gimble Osmo 6 handheld mobile tripod. The smartphone camera itself has built-in LiDAR sensors that can be used through the 3D Scanner application (Figure7) to collect scans and form on a cloud of dots. Two independent scans were made, that is, the entire bridge was covered but in two parts with two scans and they are in a local coordinate system. Interestingly, the app instantly generates a dense cloud of points based on the images at the moment. The same scans can be exported in .las format and processed in appropriate software.

Figure 7. Use of 3D Scanner App

4. RESULTS AND DISCUSSION

To start the process of obtaining a 3D model through the software, it is necessary to go through several stages that we have already mentioned. Each stage of production must take place in a certain order, step by step. Agisoft Metashape is an advanced image-based 3D modeling solution that aims to create professional and quality 3D content from photos. Based on the latest multi-view 3D reconstruction technology, it works with arbitrary images and is effective in both controlled and uncontrolled conditions. Photographs may be taken from any position, provided that the object to be reconstructed is visible in at least two photographs. Both image alignment and 3D model reconstruction are fully automated. [3] CloudCompare is a 3D point cloud editing and processing software. Originally the software was designed to perform direct comparison between dense 3D point clouds. It relies on a specific octree structure that allows excellent performance when performing such a task. In addition to the fact that most point clouds are obtained with terrestrial laser scanners, the software can handle huge point clouds - typically more than 10 million points. The software also allows comparison of a cloud of points with a network of triangles. [5]

4.1 PHOTOGRAMMETRIC PRODUCTS

The Agisoft Metashape software was used to process the data collected from the field, i.e. the images from the drone and the terrestrial photo camera, as this software provides a very clear and detailed view of the 3D model of the object.

Figure 8. 3D textured model

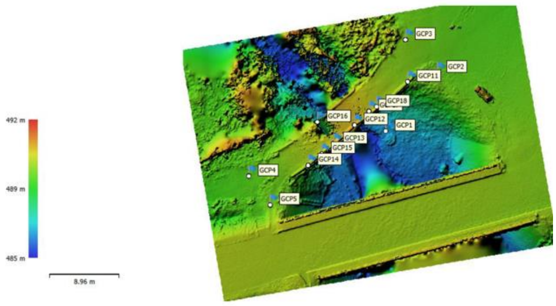

Figure 9. Digital elevation model of the site with all GCP

In general, the ultimate goal of photo processing with Metashape is to build a 3D model, orthomosaic and digital elevation model. (Figure 8)

A digital elevation model (DEM) is a 2.5D model of a surface represented in the form of a regular grid grid, with elevation values stored in each grid cell. (Figure 9) In Metashape, a DEM can be rasterized from a point cloud, anchor points, mesh, or generated directly from depth maps. Metashape also allows to create a digital surface model (DSM), i.e. a 2.5D model of the Earth's surface with all objects on it, and a Digital Terrain Model (DTM) that represents the surface of the bare Earth without any objects such as plants and buildings. [2]

Markers	East err (m)	North err (m)	Alt. err (m)
GCP13	0.000028	-0.000469	0.000888
GCP14	-0.000983	-0.004101	0.001290
GCP1	-0.011707	0.022760	-0.001920
GCP3	-0.012701	-0.010956	0.000895
GCP5	-0.018497	-0.003515	0.010458
Total Error			
Control points	0.008605	0.007257	0.003858

Figure 10. Results of geo referencing in Agisoft Metashape

As we mentioned earlier, Agisoft Metashape is a software that can export a variety of file formats for its processed products. The software supports export of anchor points, point cloud, camera calibration parameters, camera orientation data as well as all models according to user requirements.

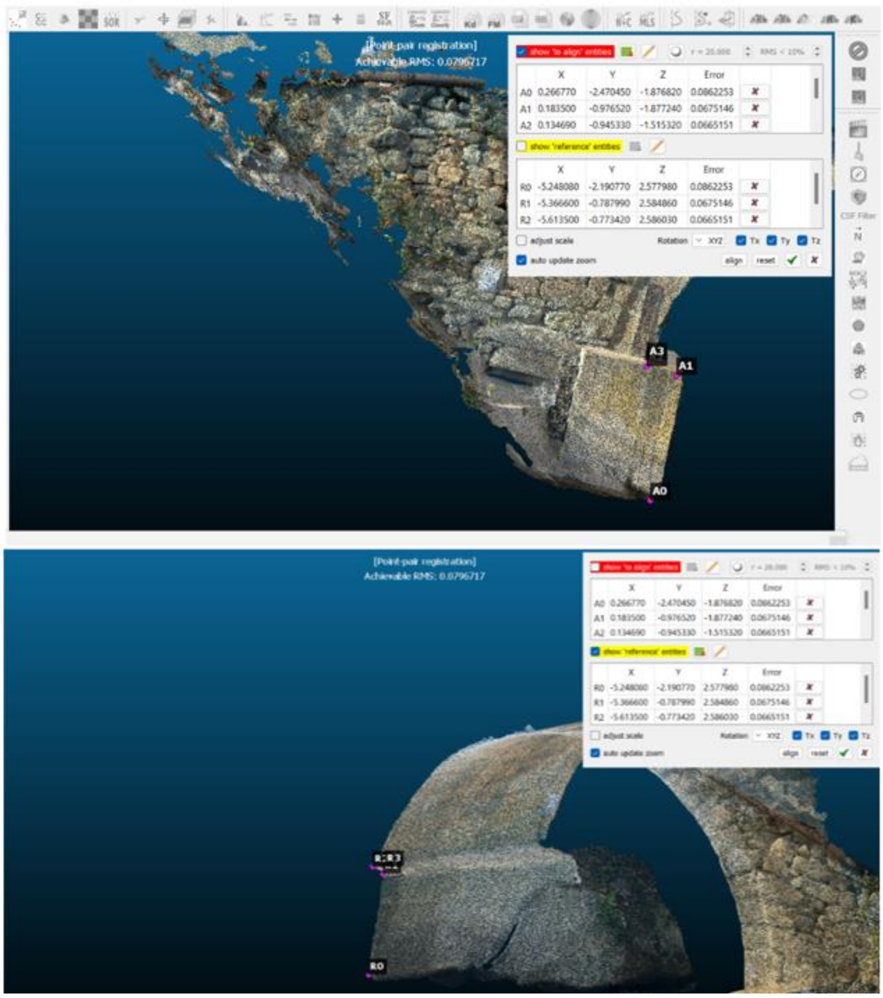

Figure 11. Process of scans alignment

4.2 LIDAR PRODUCTS (SCANS)

Cloud Compare software is software for better visualization and manipulation of models and point clouds with many additional functions such as comparing two models. A range of different tasks and analyzes such as scan alignment, geo referencing, classification and the like can also be performed. We exported the made field scans collected with LiDAR sensors through the 3D Scanner application in .las format and imported them into the Cloud Compare software. It is about two independent scans that are in a local coordinate system and each represents one part of the bridge. The goal is to merge the two scans, that is, to align them and to place them in a state coordinate system based on the previously recorded orientation points placed on the surface of the bridge. [9] Cloud Compare offers the possibility of aligning two clouds of points, i.e. fitting them by picking the same points that are on both shores and they represent natural "virtual" markers for alignment. In this case, 4 pairs of points were used, which turned out to be enough, and it is important to note that in order for this process to succeed and be precise, the same points from both clouds should be picked in parallel in order to have an insight into which point is picked exactly all in order to avoid mistakes as much as possible. [10] Because as we mentioned, the scans are in a local coordinate system and after their alignment they still remain so. The next step is to fit this model into the state coordinate system based on orientation points placed on the surface of the bridge. We'll do this by importing a portion of the points and repeating the same process with one entity being the points themselves while the other entity represents the entire new model.

That way the scans collected by LiDAR sensors are aligned properly and the point cloud is georeferenced and ready to perform any measurements, readings or analysis.

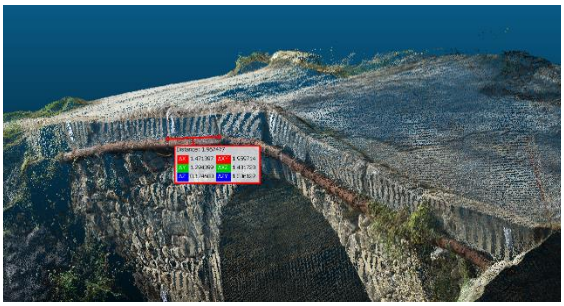

Figure 12. Geo referenced point cloud in Cloud Compare

4.3 ANALYSIS

The purpose of the analysis is to show what final product can be obtained at the end of processing, a product that has perfect visualization and satisfactory accuracy and a product that can be used in multiple areas for all kinds of cases. During the analysis of the obtained results, point clouds processed in Agisoft Metashape and Cloud Compare were taken. The goal was to see what the relationship is between the two models, one of which was obtained as a combination of terrestrial and unmanned photogrammetry, while the other only from smartphone LiDAR sensors, and both are georeferenced through the same orientation points. The analysis that I conducted consists of comparing the coordinates of two identical points from the two models in both software, lengths (Table 1), areas as well as a comparison of the complete clouds of points also known as C2C Distance in the Cloud Compare software. (Figure 13)

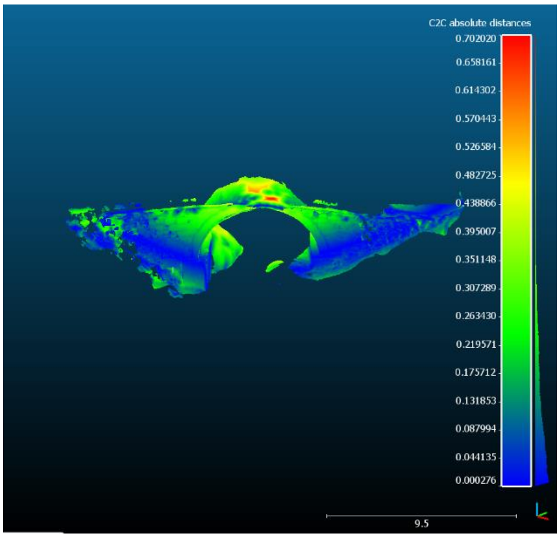

Figure 13. Graphic display of the final result of the comparison of two clouds of points with a scale of deviations from the two models expressed in meters

Table 1. Comparison of distances

Serial number	Agisoft Metashape	Cloud Compare	GCP
	Distance(m)	Distance(m)	Distance(m)
1	1.14	1.10	/
2	5.40	5.40	/
3	9.24	9.19	9.24

Cloud-cloud distances can be processed by selecting both point clouds and calling the appropriate command. The usual way to calculate the distance between two clouds is through the 'nearest neighbor distance' method: for each point of the compared cloud, the software searches for the nearest point of the reference cloud and calculates their distance. The two clouds are selected, and it is necessary to choose which of the two will be the reference model. It is recommended to take the larger or denser cloud of points as the reference cloud. [11]

5. CONCLUSION

At the very beginning of the research, a hypothesis was put forward that by applying exactly this method, which was developed throughout, it is possible to obtain models of the objects that are categorized as cultural heritage, and which are the subject of research with satisfactory, high accuracy and based on such the obtained models to be analyzed for their possible displacements, damages and the possibility of their restoration, with the aim of preserving them in their original state. However, the choice of measurement method depends a lot on the need for the measurements in terms of accuracy, precision, cost-effectiveness, etc. From what has been shown so far and according to the field measurements and their processing, it can be concluded that this method, which consists of a combination of unmanned and terrestrial photogrammetry with classic geodetic measurements, can give very good and precise results when it comes to the reconstruction of cultural and historical objects. Of course, classic measurements for this type of objects are irreplaceable and this is proven by their very inclusion in the field measurements in this paper, which are of great importance, their accuracy was and will be a benchmark for obtaining quality results. However, the method that was used in this paper also has many advantages, such as the visualization of the object, which is a very important item for objects of cultural heritage. At any moment, we can see which part of the object we want to analyze it, make different measurements, comparisons, and this is possible because we have a precise 3D model that is easily manipulated and that is integrated into a state coordinate system. We know that objects that are of historical and cultural importance are quite important and have great significance for a nation, society. They are under constant risk of collapse due to their age, weather effects, atmospheric effects, human factors and the like, and therefore I think that by establishing such projects, their soul would be preserved throughout their existence.

REFERENCES

[1] A. T. Albourae (2021), Accuracy assessment of terrestrial laser scanning and digital close range potogrammetry for 3D cultural heritage.

[2] "DEM, DSM & DTM: DIGITAL ELEVATION MODEL – WHY IT'S IMPORTANT" by Aevex Aerospace, 2020.

[3] "Agisoft Metashape User Manual: Professional Edition, Version 1.5" by Agisoft LLC, 2019.

[4] Charles Thomson, "What are point clouds? 5 easy facts that explain point clouds", May 13, 2019.

[5] "Cloud Compare User Manual" by CloudCompare, February 2015.

[6] Lynn (2021), "LiDAR vs Photogrammetry: Which is better for point cloud creation? in Mosaic51, accessed December 18, 2023.

[7] Milanov L. (2024), Digital reconstruction of cultural heritage objects on the base of terrestrial and UAV photogrammetry, master thesis, Faculty of Civil Engineering, Skopje.

[8] NU National Conservation Center, Skopje (2020), Elaborate on the revaluation of an old stone bridge on the river Babuna, village Bogomila.

[9] Nicola Maiellaro (2015), Laser scanner and camera-equipped uav architectural surveys.

[10] Vitali Diaz (2024), Comparison of Cloud-to-Cloud Distance Calculation Methods - Is the Most Complex Always the Most Suitable.

[11] Nufus Fithrotin (2018), COMPARING THE PERFORMANCE OF POINT CLOUD REGISTRATION METHODS FOR LANDSLIDE MONITORING USING MOBILE LASER SCANNING DATA.