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A STYLE GUIDE FOR THE CIVIL ENGINEERING JOURNAL USING OF MODERN TECHNOLOGIES FOR VISUALIZATION OF CULTURAL HERITAGE

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ABSTRACT

This paper explores the historical evolution and contemporary applications of photogrammetry and laser scanning in cultural heritage preservation, focusing on the restoration of the Shush synagogue in Iraqi Kurdistan. It traces the development of documentation techniques, highlighting photogrammetry's pivotal role and the impact of the digital revolution. The case study of Project Shush illustrates the practical use of geomatics techniques, advanced 3D modelling, and collaboration with NGOs and authorities. The methodology outlines the use of technologies like terrestrial laser scanners (BLK360, Zeb-Revo) and UAVs, emphasizing their mobility and accuracy. Results detail the project stages, showcasing the creation of a detailed 3D model and the use of Unreal Engine for visualization. The conclusion emphasizes the importance of 3D documentation in cultural heritage and celebrates the success of the Shush synagogue restoration as a testament to technological advancements in preservation. Our research has shown that the joining of different 3D object documentation technologies significantly improves the quality and speeds up the workflow. Comparison of partial point clouds in software CloudCompare on a case study of a smaller historic building showed differences in the internal structure in centimetres, while for the external parts that were covered with vegetation the differences reached up to decimetres.

KEYWORDS

Photogrammetry, Laser scanning, TLS, PLS, Cultural heritage, UAV, Shush, Iraqi Kurdistan

INTRODUCTION

The history of documentation in cultural heritage dates back centuries, with early civilizations employing various methods to record and preserve their cultural artefacts. The Renaissance marked a significant period in the history of documentation, as scholars and artists began to catalogize and document cultural artefacts systematically, manuscripts, and artworks, laying the foundation for modern archival practices. The 19th century saw the establishment of museums and libraries, where systematic documentation became an integral part of preserving and showcasing cultural heritage collections. With the emergence of photography in the 19th century, documentation expanded to include visual records, offering a more accurate and detailed representation of cultural artefacts. At the end of the 19th century, photography began to be used as a source of measurement information and photogrammetry was developed [1]. The early 20th century witnessed the refinement of photogrammetry techniques, especially during World War I and II, when aerial reconnaissance photography played a crucial role in mapping and intelligence gathering. Post-World War II, advancements in photogrammetry accelerated, with the development of analytical plotting instruments and stereo plotters that allowed for more precise measurements and detailed mapping of terrain. The latter half of the 20th century saw the integration of computers into photogrammetric processes, enabling the automation of measurements and calculations, significantly enhancing the efficiency and accuracy of documentation. Aerial photogrammetry continued to evolve, with the introduction of satellite imagery in the 1970s providing a new dimension to large-scale mapping and environmental monitoring [2,3]. The late 20th century and early 21st century brought about a digital revolution in photogrammetry, with the shift from analogue film to digital sensors, and the development of sophisticated software for image processing and 3D modelling [4, 5, 6]. Unmanned Aerial Vehicles (UAVs) or drones became popular tools for photogrammetric documentation in the 21st century, offering a cost-effective and flexible means to capture high-resolution images for mapping and 3D reconstruction [7,8]. Advances in computer vision, artificial intelligence, and machine learning have further streamlined photogrammetric processes, allowing for faster and more automated extraction of spatial data from images. Photogrammetry serves as a foundational 3D documentation method, utilizing overlapping photographs to reconstruct three-dimensional models. Today, photogrammetrical documentation continues to play a vital role in the interdisciplinary field of cultural heritage, bridging the gap between technology and preservation, and providing valuable insights into our shared past. High-resolution imagery obtained through photogrammetry allows for the detailed documentation of intricate features on artefacts, architectural elements, or artworks, facilitating scholarly analysis and research. Photogrammetry has become an integral part of interdisciplinary collaborations in cultural heritage, fostering connections between archaeologists, historians, conservators, and technologists for comprehensive documentation and analysis [3,4]. Laser scanning has become an important technology in the documentation of cultural heritage. Emitting laser beams to measure distances, LiDAR (Light Detection and Ranging) instrument joined with scanning device generates precise point clouds that faithfully represent the surfaces of objects and environments. This method excels in capturing fine details, making it indispensable for the documentation of complex sculptures, reliefs, and historical landscapes. Introduced in the late 20th century, laser scanning quickly gained prominence in cultural heritage due to its ability to capture precise spatial data by emitting laser beams and measuring their reflections. Today, the laser scanning involves more technologies, especially time-of-flight or structured light scanning. Each technology has its own specifics, and its application depends on the type of object and the required accuracy. Cultural heritage sites, such as archaeological ruins or historical buildings, benefit from laser scanning's ability to create detailed point clouds, offering a comprehensive digital record of the site's topography and architectural features [10]. Laser scanning excels in capturing fine details, making it an invaluable tool for documenting intricate sculptures, reliefs, and other delicate elements of cultural artefacts with minimal physical contact. Mobile laser scanning systems mounted on vehicles or drones enable the efficient documentation of large-scale cultural heritage landscapes, offering a dynamic perspective for research and management purposes. The development of hand-held mobile scanning devices has made the most progress in the last decade. These are commonly called personal laser scanners (PLS), equipped with an inertial measurement unit (IMU), a laser scanning head and often other equipment such as a camera for point cloud colouring or GNSS/RTK (Global Navigation Satellite System Real Time Kinematic) equipment [9, 11, 12, ,13]. Their accuracy is lower compared to static laser scanners (terrestrial laser scanning - TLS), but the advantages are speed of measurement, ease of operation and mobility. Advances in laser scanning technology, including multi-sensor integration and improved data processing algorithms, have enhanced the speed and accuracy of data acquisition, making it a powerful tool for cultural heritage professionals. The integration of 3D documentation methods in cultural heritage preservation has ushered in a new era of exploration, conservation, and understanding. As technology continues to advance, these methods will play an increasingly vital role in safeguarding and promoting the appreciation of our diverse cultural legacy for future generations. Today, the field of documentation in cultural heritage continues to evolve, with advancements in technology, including 3D scanning, virtual reality, and artificial intelligence, offering new tools for more comprehensive and immersive preservation of our shared cultural legacy. The integration of 3D documentation with VR (virtual reality) and AR (augmented reality) technologies allows for immersive experiences in cultural heritage. Researchers, educators, and the public can virtually explore historical sites, interact with artefacts, and engage in educational experiences that bridge the gap between the past and the present.

Case project Shush

The project's objective involved conducting historical documentation of the sanctuary through contemporary geomatics techniques and generating a digital 3D model of the structure. Following this, it became imperative to create a 3D model depicting the proposed reconstruction solution based on the acquired 3D model. The ultimate deliverable includes an all-encompassing visualization of the building post-reconstruction, incorporating alterations to the surroundings. This visualization serves as a crucial output for the reconstruction investors.

In 2020, the partnership between NGO ARCH[1] and GEMA ART International[2] broadened its scope to include the rescue mission of a shrine located in the Northern Iraqi village of Shush near Akre (Province Duhok, Figure1). Regrettably, the project, backed by US government funding, encountered setbacks during its preparatory phase due to disruptions caused by the Covid-19 pandemic. For centuries, minority religious communities in the mountainous regions of present-day Iraq have thrived, sheltered by the natural landscape. The Shush synagogue, dedicated to the prophet Ezekiel, served its purpose until 1950, when the Jewish population relocated to Israel. Subsequently, neglect and severe climatic conditions led to rapid deterioration of the monument, resulting in the collapse of sections of its exterior masonry. The interior became a refuge for local herds as the surrounding area transformed into pastureland [3], [4].

An extensive survey conducted in 2021, inclusive of detailed photogrammetric 3D documentation, provided crucial data essential for planning the restoration project. Initial groundwork began in September 2022. However, an archaeological survey in the vicinity caused a delay in commencing the actual restoration work until late February 2023, following the winter season. Restoration efforts involved various tasks such as cleaning the masonry, reinforcing perimeter stonework, grouting cracks, reconstructing the roof, conserving historic plaster, restoring the interior floor, rebuilding shrine-retaining walls, and installing an access staircase. The collaboration with the Kurdistan Region Antiquities Authority played a pivotal role in ensuring the project's success. Daily oversight by an archaeologist ensured the proper management of the site. GEMA ART made significant contributions by documenting archaeological discoveries, utilizing advanced 3D modelling techniques, and implementing historical construction methods revealed during the restoration process. Notably, ancient construction techniques inspired the integration of large ceramic vessels into the reconstructed roof, maintaining fidelity to the original methods (Figures 2-3).

The aim of the project was the complete restoration of the historical monument. The first step was to create a complex model using laser scanning and photogrammetry. The precise and detailed documentation became the basis for the reconstruction. The model created by combining geodetic technologies was analysed and completed for the needs of the investor and once approved, the completed model served as the basis for the restoration work.

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[1] https://www.archfoundation.in/

[2] https://www.gemaart.com/en/restoration-of-the-shrine-in-shush/

[3] https://www.rudaw.net/english/culture/19102022

[4] https://database.ours.foundation/79E81Y8/

Fig. 1 – Iraq and location of the Shush village (www.mapy.cz)

(a) (b)

Fig.2 –Original status in 2019

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Fig.3 – Measurement with laser scanner BLK360

MATERIALS AND METHODS

Transporting large laser scanners and related equipment to remote destinations, in this case Iraqi Kurdistan, poses significant challenges, primarily due to distance, cost of transport and security, which could lead to potential damage during check-in processes and controls. However, recent technological advances in laser scanners have solved these problems. In particular, the emergence of smaller, portable laser scanners has made it easier to work in remote locations, such as the use of the TLS BLK 360 or PLS ZEB REVO in this case study. UAV / DJI Mavic Pro drone was used for photogrammetric work. The images were used to create a photogrammetric textured model not only of the building itself, but also of the wider surroundings. The BLK360 is a miniaturized laser scanner (TLS), easy to transport and easy to use. It has only one button and it can be operated using a tablet or a smartphone. This instrument takes standard panoramic scans in 6 minutes with capturing of HDR (High Dynamic Range) images; the accuracy is 4 millimetres on 10 metres, which is sufficient for most historical structural objects. A standard individual scan from the BLK360 device typically generates a data size of 600 MB. Another innovation on the market is the introduction of handheld mobile laser scanners (PLS). These scanners offer a remarkable advantage in terms of mobility as they allow scanning on the move. This contrasts with traditional land-based scanners that require a stationary position for scanning, which significantly speeds up the process of scanning objects. Initially, the accuracy of these mobile scanners was significantly lower compared to conventional terrestrial scanners. However, continuous technological advances have led to new models being released every year, which have continuously improved their accuracy. For example, FARO's latest product, known as Orbis, represents a breakthrough capability that allows operators to scan on the move as well as static scanning, marking a significant advance in the laser scanner market. Similar new models have been introduced by Trimble (Hoovermap), Leica (BLKGO), GreenValley (LiGrip) and a number of others. The new models are rapidly reducing the accuracy gap between PLS and conventional ground-based scanners (TLS), making their accuracy more comparable. The mobile laser scanner ZEB-REVO Go was used for this study. This PLS, manufactured by GeoSLAM, is a mobile handheld scanner using SLAM (Simultaneous Localization and Mapping) and IMU technology [14]. This technology seamlessly integrates newly scanned sections with the existing dataset and IMU data, reducing the need for extensive post-processing to merge individual scans, unlike ground-based scanners. This PLS operates independently of the GNSS signal, allowing mapping of large areas without signal dependency, for example in mines or building interiors. Older types had relatively low accuracy and measurement data density, but this has improved significantly recently with the advent of new laser heads and improved SLAM technology. The ZEB REVO Go used scans at a rate of 40,000 points per second and the accuracy of the scanned points is 1-3 cm per 10 meters depending on the type of object. But this is sufficient for many objects. Especially for underground historical objects or ruins it is an excellent tool. A definite drawback is that this type does not have a camera to colour the point cloud. After 32 minutes' walk the instrument generates approximately 200 MB.

Methodology

Based on all the captured data presented in the previous chapter, it was possible to create an accurate and complete 3D model of the object including its cascading surroundings by combining them. The mapping of the surroundings was an essential part of the assignment, as the terrain is very complex, made up of cascades and platforms that need to be considered when planning the reconstruction and creating a new path to the object. Basically, each technology was used to make the most of their efficiency, i.e. laser scanning with a BLK 360 terrestrial scanner was done on the inside of the building and the outside of the garden with emphasis on the transition - outside / inside where the most problems could arise and at the same time there was a need to have these things documented most accurately, because of the thickness of the walls, the interior condition and the position of the interior in relation to the exterior. 8 terrestrial scans were performed. The SLAM technology for the ZEB-REVO mobile laser scanner was beneficial in its fast-scanning process time compared to terrestrial position scanning, so it was possible to scan the object itself including the surroundings to obtain a measurable quality model. A DJI Mavic Pro drone was used to obtain detailed texture and overall view of the area of interest, with a total of 158 images taken from different angles and directions.

Unreal Engine

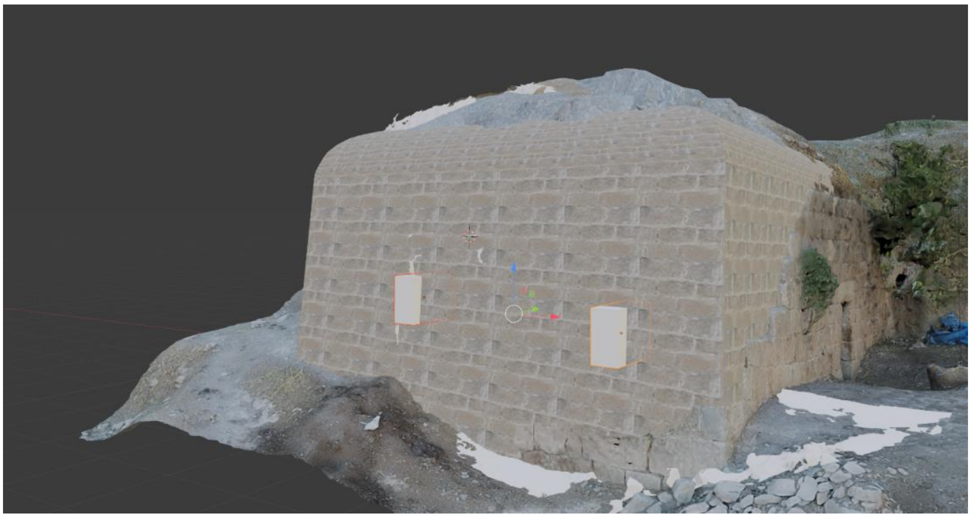
Unreal Engine (UE) is a game engine created by Epic Games. The game engine includes a set of tools and resources that make it possible to create realistic 3D visualizations, standalone virtual reality applications, and weather simulations, realistic object shading, and more. It is thus a comprehensive software that has almost unlimited visualization possibilities. All final visualization outputs have been processed in this software.

RESULTS

The creation of digital documentation, documents and final design were divided into 3 stages. The first stage consisted of an initial detailed model of the building and a drawing of the required output, i.e. the modifications that needed to be made. Initially in the digital model, and later the basis of this output, the reconstruction of the object. This phase was also based on a thorough consultation with the restoration company, where a consensus had to be found between the possible scope of work and the financial plans for the reconstruction. Several proposals were therefore made, as shown in Figures 4-7.

The main pillar of the first stage was the creation of a detailed and accurate complex 3D model of the object. Here, it was necessary to correctly follow the thickness of the walls and to correctly intersect the windows of the tomb, which were not visible from the outside because they were overgrown with weeds and thorns. However, the partial outlines made it at least clear where they were located. Thanks to the laser scan from the inside of the tomb, where the windows were uncovered, and thanks to the preserved panes, it was clear what the scale of the windows was, then the process of blending with the outside was accurate.

(a)



(b)

Fig.4 – Modelling of the object and filling missing parts

In Figures 4 a and b it is possible to see which technology was used to create the windows. The models were superimposed on each other, making it clear from the visible walls on the outside of the tomb where the walls originally ran. Thus, blocks were created from the inner part of the tomb to follow the outline of the window openings. These blocks were interlocked and stretched to go through the whole building, then made transparent to the rest of the model structure, giving us the exact location of the two window openings from the outside.

Now a comprehensive 3D model of the building has been obtained, including all important peripheries such as window openings, existing preserved walls, etc. Now we need to start creating options for the future state, or the final state after the future reconstruction, based on historical photographs and suggestions from structural engineers and architects. The solution was limited by the historic appearance, so the goal is to get as close to the historic condition as possible after reconstruction but strengthening the important sections that caused the couple. The cause of the destruction of the building was of course also the time itself and the lack of interest in the management of the building.

Fig. 5 – Preliminary 3D model

In second stage, the garden space was reduced to approximately half the planned extent in phase 1. The basic initial visualisation was therefore redesigned to meet the new requirements. In addition, a pathway for incoming visitors and caretakers was required at this stage, as currently there was only an inaccessible pathway leading to the building along a cascading slope and this was not a comfortable access.

The final design was therefore a staircase made of boulders available on the slope that did not copy the shortest route but the best one, i.e. cascading up the platforms that the slope contains. It is thus also much more efficient in terms of construction than building a straight staircase and a completely new path. The development of Stage 2 can be seen in Figures5-6.

In this phase, we started to work with the prepared model in Unreal Engine, which is an ideal environment for detailed visualizations including materials, shadows and more. The Unreal Engine gave the project a whole new dimension, including making the tomb and its possible state after reconstruction available in virtual reality [15, 16].

Fig.6 – Preliminary model with a modelled staircase that was finally created as a more natural.

The third and final stage was the final visualisation, which was done exclusively in Unreal Engine. Here, it was necessary to fine-tune the material used for the staircase and the tomb itself to make the visualization of the planned state of the building after reconstruction as realistic as possible.

Fig.7 – Final model with natural staircase

Data processing

The captured data needed to be processed and cleaned of outliers. The data cleaning was largely done in Geomagic Wrap software, which is an ideal tool for minor cleaning of point clouds. By taking dates from different devices, the data could be combined freely to create a detailed model of the synagogue and the surrounding area. As part of the study, a detailed comparison of the output from the instruments used was also carried out. The comparison of the outputs (point clouds) was done in CloudCompare software (Figure 8).

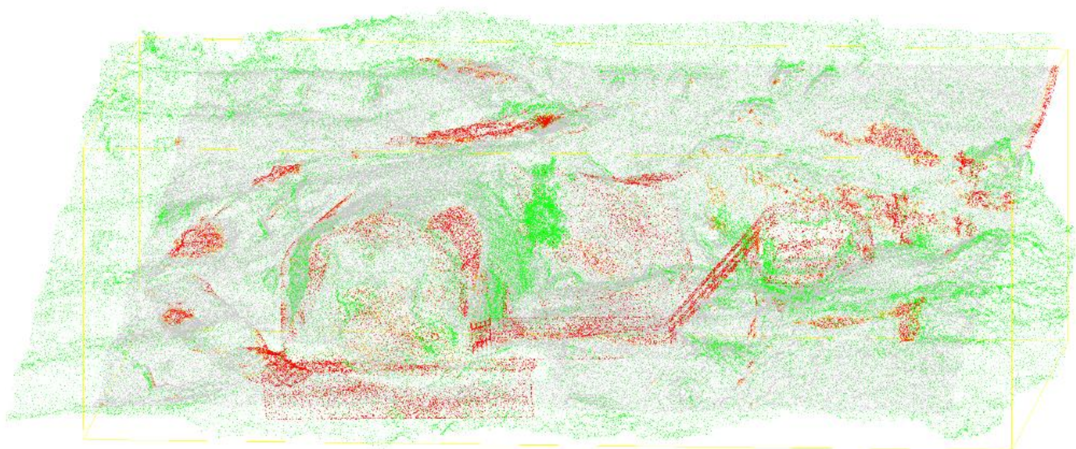


Fig.8 – Representation of the areas that have been added and processed in the final visualisation and VR (red colour shows the added areas - comparison of the UE model and the point cloud from the geodetic survey); however, the UE model is not in point form and therefore the differences are mainly in the parts that have been added to the model.

In general, based on known facts and parameters, the most accurate data should be from the BLK360 terrestrial laser scanner. In the normal case, very close-range photogrammetry would be more accurate, but the photogrammetric model was only processed from drone photos and our equipment did not include a total station or GNSS/RTK to make the photogrammetric model more accurate due to its size based on control points. Therefore, for our purposes, the laser scanner and the model created from its data replaces the total station and the control points, which is a certain trend in geodesy nowadays. But here we only mention absolute accuracy, the photogrammetric model is essential for this project, as it is the only instrument used that can produce a good quality textured polygon model. The laser scanner measurements here were mainly used for accurate dimensions, model checking and modelling of the interior of the synagogue. The inner part of the synagogue is almost devoid of light, so the use of laser scanners was a logical choice here.

However, it is important to note that there are other parameters besides accuracy and texture generation that need to be considered when comparing the use of equipment and technologies. One of the important factors for this project was device compactness and measurement time (Tab 1).

Tab. 1 - Comparison of technologies used.

	Measurement time	accuracy	output
DJI Mavic pro	20 minutes outside	1 cm	Images only, 1.5 GB
BLK360	1 hour (inside / outside)	4 mm	images and scans, 3.6 GB
ZEB-REVO	10 minutes (inside / outside)	2-3 cm	Scans only, 80 MB, 4,687,083 points

To make an adequate comparison, a more accurate scale had to be given to the photogrammetric model. The scale was calculated from the drone sensor only, which uses the World Geodetic System (WGS84). The unit in the drone without the use of the RTK module is not accurate and thus there are deviations when comparing the model with the laser scanner data. In addition, it was necessary to remove WGS84 system from the model data and use only the local coordinate system of Agisoft Metashape software, which was used to process the photogrammetric data and calculate the texture. Data with WGS84 coordinates cannot be opened in Geomagic Wrap and CloudCompare software, only a straight line is usually shown instead of the model.

On the other hand, laser scanning has a precise scaled model (BLK360 and ZEB-REVO data used here) but no orientation in space. The orientation was done in Geomagic Wrap software, as was the registration (first manual and then global), which merged the models. Scale adjustment of the photogrammetric model was also performed in the same software. Subsequently, all three models were uploaded to CloudCompare, where the actual analysis of each model was performed. First, only the exterior parts were compared, and in the case of the data from both laser scanners, the interior of the synagogue was also compared.

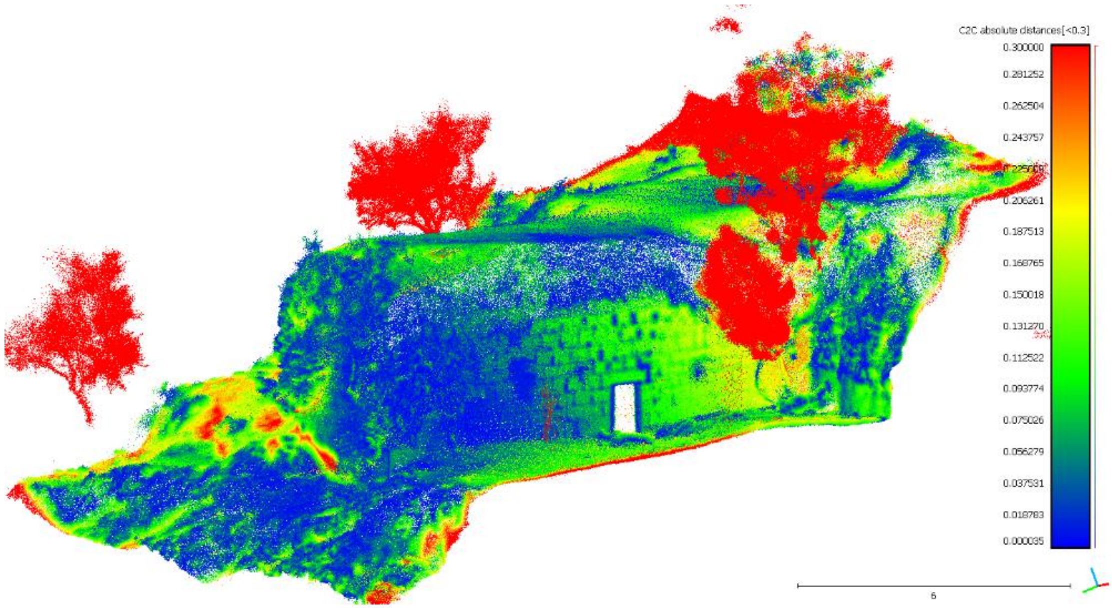


Fig.9 – Comparing of BLK360 and ZEB-REVO data (BLK360 as a reference model)

In Figure 9 it can be observed the difference between the data from the PLS Zeb-Revo and TLS BLK360. The model from BLK360 was always used as reference data. Errors up to 15 cm in position are marked in different colour, larger errors are marked in red. On the structure itself, in the parts that are not covered with vegetation, the error ranges from 2 to 8 cm. In the parts where there is vegetation, including the surroundings with a moraine of fallen masonry and stones, the deviations sometimes exceed 20 cm, which is due to the hidden parts and the density of the points, which is an order of magnitude lower for ZEB-REVO.

Another model compared is the photogrammetric model (Figures 10,11). Since the surveying was done only from drone images, it can be assumed that the model will not be as accurate in space, especially in the parts around vegetation. This assumption was confirmed by comparison. Especially the frontal part that was covered by shrubs was inaccurate compared to the laser scan from BLK360. In Figure 10, points with deviations up to 15 cm are shown in colour (Figure 10), points with larger deviations are shown in red (Figure 11). The areas without points that were created around the model are due to trees that were mostly in that area, shading the terrain. Thus, classically, a digital surface model (DSM) can mainly be generated from aerial photographs.

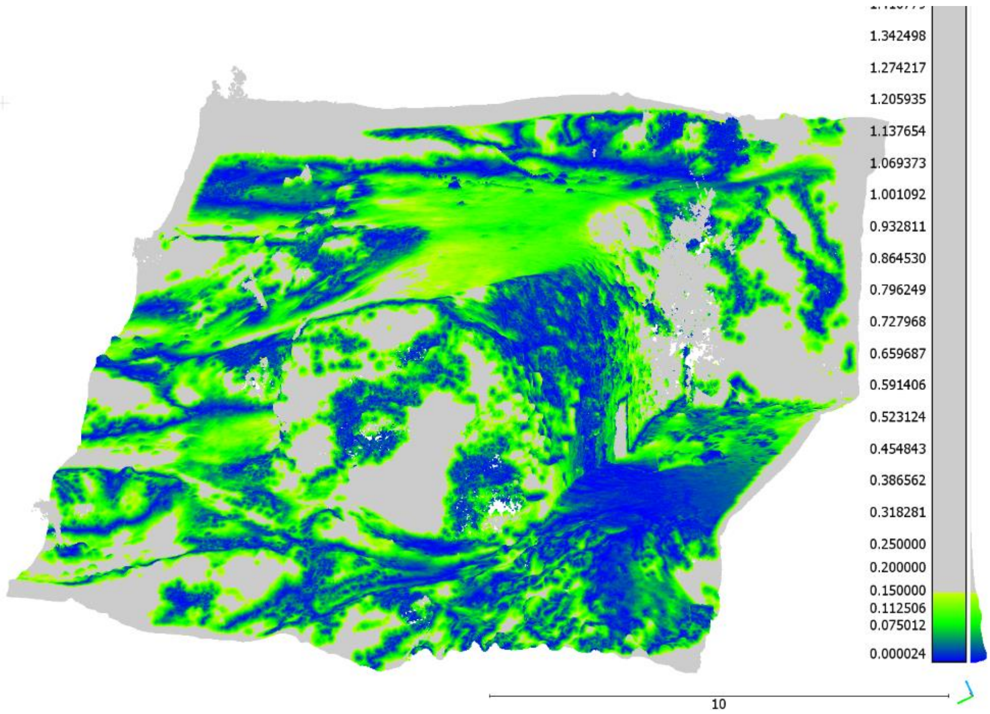


Fig.10 – Comparing of BLK360 and drone photogrammetry (BLK360 as a reference model, points with deviations up to 15 cm)

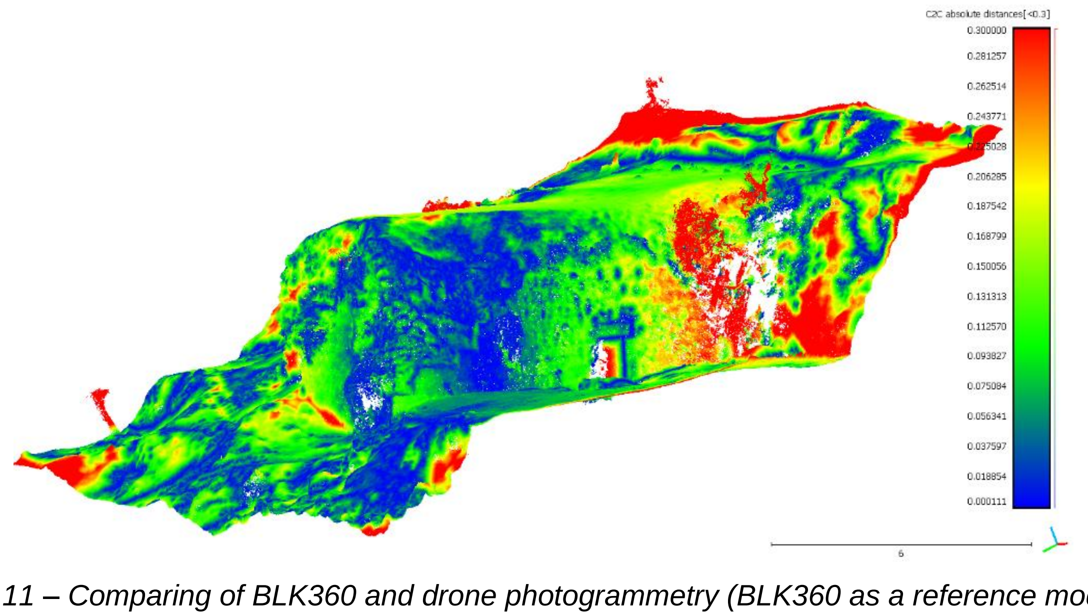


Fig.11 – Comparing of BLK360 and drone photogrammetry (BLK360 as a reference model)

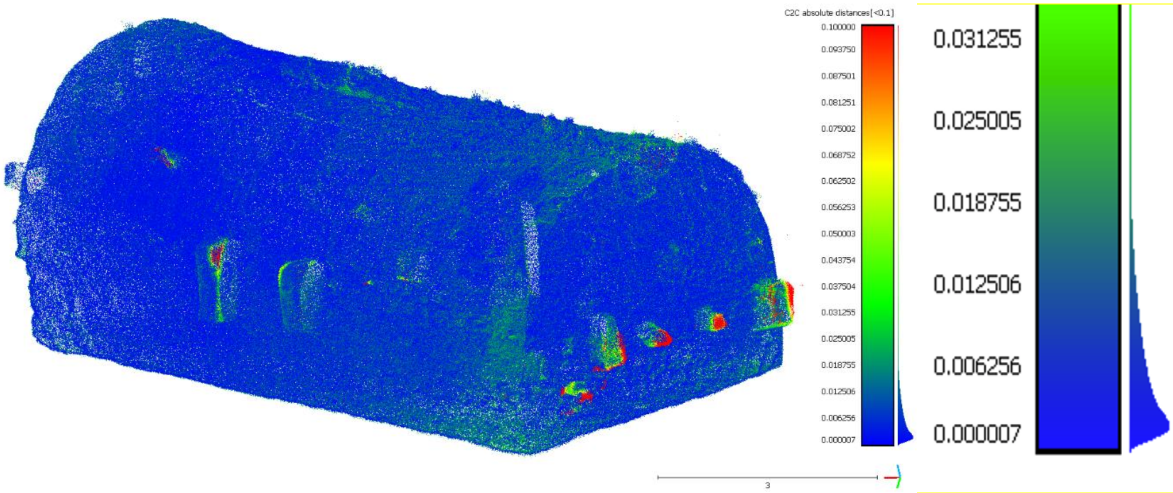


Fig.12 – Inside parts were documented very precise.

When comparing the interior of the synagogue, it was found that for the interior spaces the variations are significantly smaller, which is also due to the basic use of both scanners. Here most of the points were almost identical, with maximum deviations found in the hard-to-reach window areas, which were overgrown with vegetation; however, this can in no way be considered a measurement error. Most of the points were within 1 to 2 cm of the maximum deviation (Fig ure12).

(a) *(b)*

Fig. 13 – Reality and visualization (a,b)

The final visualisation is shown in Figure 13 in comparison with the actual state after the reconstruction, completed in 2023 based on the metric documentation (Figure 14) described in this article.

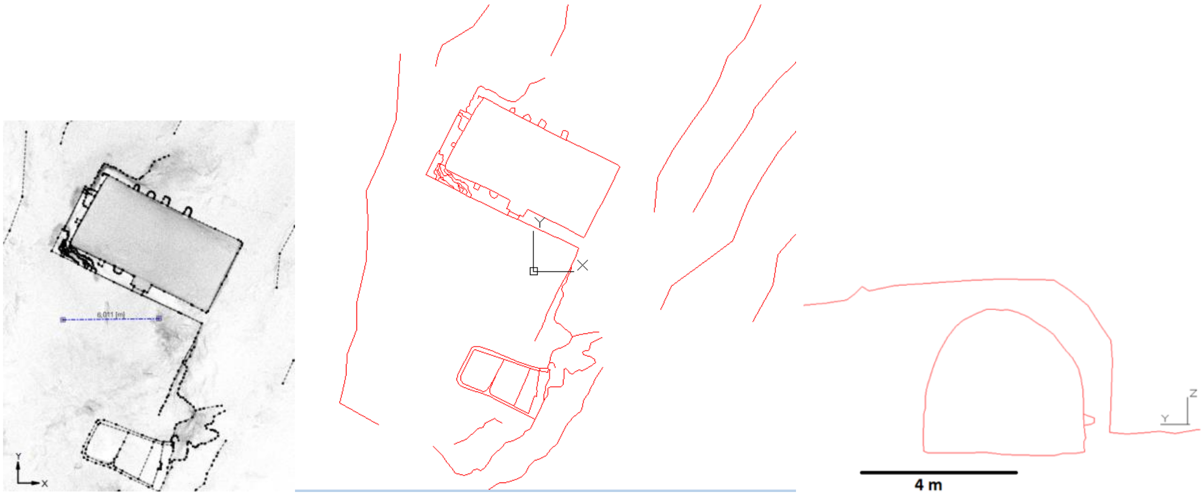


Fig. 14 – Output prom PLS ZEB-REVO - vectorisation of the point cloud (left) and cross-section are very easily done in several minutes (middle and right transfer to ACAD).

CONCLUSION

Within the project, data was acquired by two laser scanners (TLS and PLS) and drone images were taken for photogrammetric processing. The result of the measurements was a visualization created in the UE game engine, which served as a basis for the restorers to plan the work, also point clouds were taken and calculated, which served as a basis for measurements in 3D space and for cross-checking the data. As part of the study, a comparison of the models and technologies used was also carried out. As expected, the most accurate model was the one from BLK360. The main output was to be the previously mentioned visualization and plans, photogrammetric processing was also needed, which resulted in a model including high quality texture. The inaccuracies in the surrounding area were not entirely significant, the result was a model of the surroundings with sufficient resolution for the restorers, plans and sections for the construction activity. The virtually completed model was pre-approved by the investor, so here visualization and virtual reality helped significantly, which is now becoming a desirable tool and output for planning and visualization.

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