DIFFERENT DATA JOINING AS A BASIC MODEL FOR HBIM – A CASE PROJECT ST. PATALEIMON IN SKOPJE

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ABSTRACT:

H-BIM (Heritage Building Information Modelling) is principle and system of use of historic buildings that can be used for the management, reconstruction or renovation and restoration of monuments. It is a set of geometric and descriptive information about a building. In the last decade, several historical objects were documented using modern methods, mainly advanced photogrammetrical and laser technologies, for a wide range of users to get benefits from economically, safety, presentation, and life cycle management of historical buildings. The rapid development in geomatics is possible thanks to advanced technologies of data capturing, sufficient capacity of computer technology and transmission and information networks. The most used technologies are terrestrial laser scanning (TLS), personal laser scanning (PLS) or mobile mapping systems (MMS), terrestrial or aerial drone based close-range digital photogrammetry (using SfM – structure from motion technology and MVS – multi view stereo). Today's modern advanced technologies allow geometrical and textural data collection within a few centimetres' accuracy outside and inside infrastructure by various methods of PLS, photogrammetrical SfM and TLS. In terms of object visualisation, VR or AR (virtual or augmented reality) technology is proving to be suitable. The following text discusses the use of geomatics technologies for the creation of H-BIM on the example of a cultural monument in Skopje, North Macedonia, including visualization in virtual reality (VR).

1. INTRODUCTION

1.1 BIM and H-BIM

BIM is an abbreviation for "Building Information Modeling." It is a digital process that involves creating and managing information about a building or infrastructure project throughout its lifecycle. BIM allows architects, engineers, contractors, and other stakeholders to work collaboratively, share information, and make informed decisions throughout the design, construction, and operation phases of a project. BIM uses a 3D model as a shared information source, which contains information about the building's geometry, materials, performance, and other aspects of its design and construction. BIM models can also include information about the project's schedule, cost, and environmental impact. It is widely used in the architecture, engineering, and construction (AEC) industry, as well as in building operations and maintenance. It can improve collaboration, reduce errors, and rework or renovation, and help stakeholders make better-informed decisions. BIM has become increasingly important in recent years as sustainability and efficiency have become top priorities in the AEC industry. It can also be used in the conservation and management of cultural heritage sites, such as historic buildings, monuments, and archaeological sites. This process is known as "heritage BIM" (H-BIM). H-BIM involves creating a digital model of the cultural heritage site, which includes information about its geometry, materials, condition, and historical significance. The model can also include information about the site's surroundings, such as topography, vegetation, and other cultural features.

The H-BIM model can be used to facilitate collaboration among stakeholders, such as architects, conservators, archaeologists, and heritage managers. It can help them make informed decisions about conservation and management strategies, such as repairs, maintenance, and visitor access. H-BIM can also improve the efficiency and accuracy of documentation and record-keeping. For example, it can be used to track changes to the site over time, monitor its condition, and manage its conservation and maintenance. Overall, H-BIM has the potential to enhance the conservation and management of cultural heritage sites, by improving collaboration, decision-making, and documentation.

Generally, H-BIM is a set of geometric and descriptive information about a building. Many people think that BIM or H-BIM is the creation of a nice 3D model. This is a common misunderstanding. BIM and H-BIM is mainly a tool to maintain and manage a building throughout its lifetime. However, a geometrically accurate 3D model is always the basis of BIM; the questions are always the level of detail (LoD) and then the data maintenance technology. For the system to be truly beneficial and have economic advantages, it needs to be kept up-to-date, which costs some financial resources.

In the last decade, several historical objects were documented using modern methods, mainly advanced photogrammetric and laser technologies, for a wide range of users to get benefits from economically, safety, presentation, and life cycle management of historical buildings (HBIM, Heritage Building Information Modelling), (Poloprutský, 2019; Ewart and Zuecco, 2019).

1.2 Technology for documentation

Today's modern advanced technologies allow geometrical and textural data collection within a few centimeters' accuracy outside and inside infrastructure by various methods.
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networks. The most used technologies are terrestrial laser scanning (TLS), personal laser scanning (PLS) or mobile mapping systems (MMS), terrestrial or aerial drone based close-range digital photogrammetry (using SfM – structure from motion technology and MVS – multi view stereo), (Luhmann et al., 2006; Remondino, 2011).

In the last ten years, the use of drones has become quite common in the documentation of objects. Usually, it is a combination of terrestrial photogrammetry and drone imagery, especially from the upper parts of objects that are inaccessible from the surface. This is a big improvement in comparison to the past (Haala and Alshawabkeh, 2006; Colomina and Molina, 2014; Gagliolo et al., 2017).

Another milestone (2018) is the combination of photogrammetric technology and laser scanning. This improvement was brought about by the companies producing the most widely used software for automatic photogrammetry using SfM and MVS. These products are Agisoft Metashape and Reality Capture.

The development of TLS is progressing rapidly, especially in data processing. In the beginning, using scan and go technology individual scans had to be joined manually, later special targets were used, and nowadays the trend is to join scans automatically using correlation. Laser scanners are now equipped with GNSS equipment and cameras to simplify orientation.

The most advanced technology is mobile laser scanning (PLS personal laser scanning). Here too, there is a great progress due to miniaturization of components and merging of devices and technologies such as GNSS, IMU (inertial measurement unit), SLAM (Simultaneous Localization and Mapping) technology, cameras (Thomson, 2013; Matoušková et al., 2021; Jaakkola et al., 2008).

Most PLS use SLAM technology. is a technology that allows devices to create a map of an environment and simultaneously determine their location within that map. SLAM technology is commonly used in robotics and autonomous vehicles, where it helps them navigate through unknown environments. This technology combines data from sensors such as cameras, scanning devices (LIDAR), and IMU to build a map of the environment and estimate the device's location. One of the main benefits of SLAM technology is its ability to operate in real-time, which allows for quick decision-making in dynamic environments; it has a wide range of applications, from indoor navigation to surveying and mapping, to augmented and virtual reality.

Recently, there have been produced systems using smartphones that, in addition to a high-quality camera, also have, a Lidar sensor (iPhone Pro 11-14) and RTK GNSS device. For short distances (approx. till 4-5 m) and smaller objects, the system can produce very easy a relatively good 3D textured model (Pix4d viDoc). Another system uses only a common smartphone and additional a RTK GNSS device (3D Survey + smartphone RTK). It can be a new type of low-cost 3D documentation device soon.

In general, it is always necessary to use the technology that is suitable for the object and the required output. PLS systems are fast, but the data contain more noise and are usually not accurate enough for certain applications. However, for basic building mapping and e.g., for creating the geometric basis for BIM they are ideal, likewise for documenting underground spaces.

In terms of object visualization, VR or AR (virtual or augmented reality) technology is proving to be suitable. Although the origins of these technologies are tens of years old, they have only recently become widespread due to relatively expensive hardware. The basis is 3D glasses, whose development in recent years has turned them into wireless technologies. Certainly, the expansion of VR and AR was enhanced by the Covid-19 pandemic, where several museums created different types of virtual tours. But a cheaper technology is AR, where a smartphone, tablet or regular laptop can be used to view objects. Placing QR codes in various places and then enabling visualization of what no longer exists is now common (Pavelka jr. and Raeva, 2019; Boboc et al., 2022).

2. CASE PROJECT

2.1 Documented object

This contribution presents the usage and integration of modern geomatics technologies to capture and process data into complex textured 3D model of the church of St. Panteleimon, located near Skopje, North Macedonia from the Byzantine period (12th century BC), was used as a case project (Dimitrova, 2015, Kuzmanov, 2023). The church of St. Panteleimon at Nerezi is one of the major surviving monuments of twelfth-century Byzantium (Figure 1). Although it is located on the Byzantine periphery, this church stands as an important testimony to twelfth-century Constantinopolitan artistic and architectural trends because of its five domes that emulate the famous buildings of the Byzantine capital, Constantinople (Dimitrova, 2015). According to the painted inscription in the church, it was built in 1164 by Alexios Komnenos, a member of the famous Komnenian dynasty that ruled Byzantium during the eleventh and twelfth centuries. The St. Panteleimon church is one of a very few surviving five-domed buildings and so it highlights this important, but rarely preserved architectural type. It was built by a group of talented unknown master-builders, using ordinary blocks of stone and bricks with great artistry that merged into multi-coloured surface (Kuzmanov, 2023). The project is devoted to preparing extended digital documentation in the form of two and three-dimensional outputs that can be used to facilitate further recording management of the building. The main 3D outputs are a model generated from photogrammetric terrestrial and aerial data, and laser scanned data from personal mobile mapping system. The final product is model, which can be used for future HBIM, and model transfer process into a virtual reality (VR) environment.

Figure 1. The church of St. Panteleimon at Nerezi.

Both doctoral and master's students worked on the documentation of the building (Šartner, 2020).

3. USED MESUREMENT OVERVIEW

Of course, due to the location, it was necessary to use equipment suitable for air transport as hand luggage. Miniaturized measuring devices may have inferior technical parameters in terms of measurement accuracy, but the goal was to acquire a basic 3D model for H-BIM where the expected accuracy was sufficient. Three easy-to-use methods were used for this project. The idea was to try to compare the 3D models processed by different technologies and methods, and to point out the potential of combining close-range photogrammetry and laser scanning for recording and documenting in the field of cultural heritage. Shortly are presented the used methods:
- terrestrial close-range photogrammetry,
- aerial / drone photogrammetry,
- terrestrial/mobile laser scanning.

3.1 Terrestrial close-range photogrammetry

Close-range photogrammetry usually applies to objects ranging from a few decimetres up to 200 meters in size and 300 meters in distance. Close-range photogrammetry has the benefits of being relatively cheap and mobile. Also, it does not require special permits and usually is allowed in many places. On the other hand, operator’s expertise is required, certain mandatory requirements on the taking photos etc. Digital SLR cameras are mostly used in close-range. In this project we used Nikon DSLR calibrated camera D3200 with 25 MPix resolution (Figure 2).

3.2 Drones

RPAS (remote piloted aerial system) is one of most cited technology for non-contact documentation in last years. RPAS, however, for the wide society it is commonly known as drone, UAV (unmanned aerial vehicle), or UAS (unmanned aerial system). In general, RPAS is a system of flying vehicle, ground-based controller and a system of communications between the two, equipped with a camera and brought together to fulfil a specific task (Colomina and Molina, 2014; Gagliolo et al., 2017). Multicopters DJI Mavic Pro was used for documentation of hard-to-reach parts. The advantage was taking images of upper parts of the building that are not accessible from the surface (the roof, the upper part of the church tower, etc.). In the principle, a photogrammetric model is scale-less when aren’t GCP´s used. Drones comprise generally a GNSS device and IMU which both add to all images necessary information about elements of exterior orientation; based on the GNSS, the generated model can be georeferenced. The precision of georeferencing depends on both above mentioned devices. For smaller drones that do not have RTK GNSS, direct referencing cannot be relied on too much; the scale of the model is not usually accurate, and it is necessary to use either control points (GCS´s) or merging with laser scanner data. In this case, totally, more than 450 images were taken (Figure 3).

3.3 TLS

The BLK360 laser scanner was used. It is easy to transport and simple to use. The stop-and-go technology was used. Unfortunately, only several scans were made, because of instrument failure. The precision occurs 4 millimetres on ten metres.

3.4 PLS

The ZEB – REVO personal mobile laser scanner (PLS) was used. Based on older project, we have had a very good experience with this facility. It is very well applicable especially for interiors of historical buildings. The accuracy of spatial points is usually 1-3 cm depending on the type of material, which is usually sufficient.

This device is primarily intended for creating basic object documentation. For buildings, these are 2D plans and cross-sections that can be used for BIM creation or as classic construction drawings. However, the basic version of the ZEB-REVO device does not have a camera, so the cloud taken in this way was not coloured. Only a relatively sparse cloud can be obtained, which cannot be used for more precise work (Matoušková et al., 2021), (Figure 4-5).

3.5 Data processing

First, models were created from photogrammetric surveying. Terrestrial photogrammetry and a drone were used. The images show the distribution of images and the advantage of using a drone for the upper part of the building, which is invisible from the surface (Figure 2). Here the advantage of combining both types of data is clearly shown. Using a drone eliminates the need for a platform or scaffolding; taking photos with a drone is cheap and fast (took about 30 minutes and two flights due to battery reasons, Figure 6.)

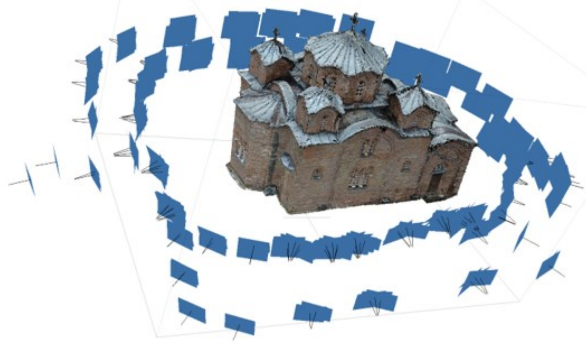

Figure 2. Terrestrial photogrammetry and the upper part of the church model.

Figure 3. Drone photogrammetry and the upper part of the church model.

Data from PLS can be used as a point cloud, but the system is more focused on creating of plans and cross-sections. Together 9 million points were collected in 30 minutes (two measurements, approximately 300MB). The measurement was made outside and inside the object, but logically the upper part outside is missing. A sure option would be to place the ZEB REVO on a drone; but a large professional drone would have to be used for that.

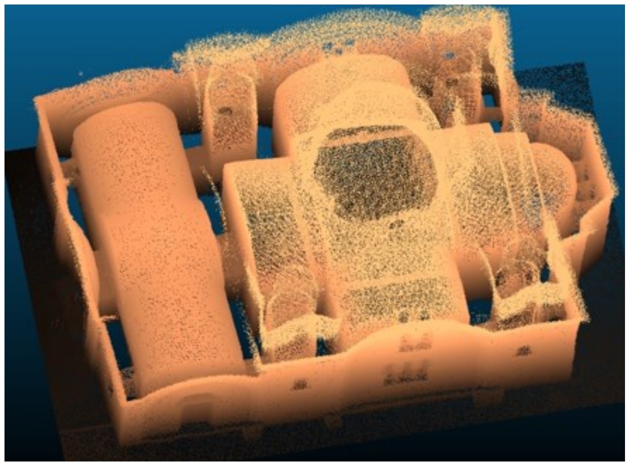

Figure 4. Point cloud from PLS ZEB REVO.

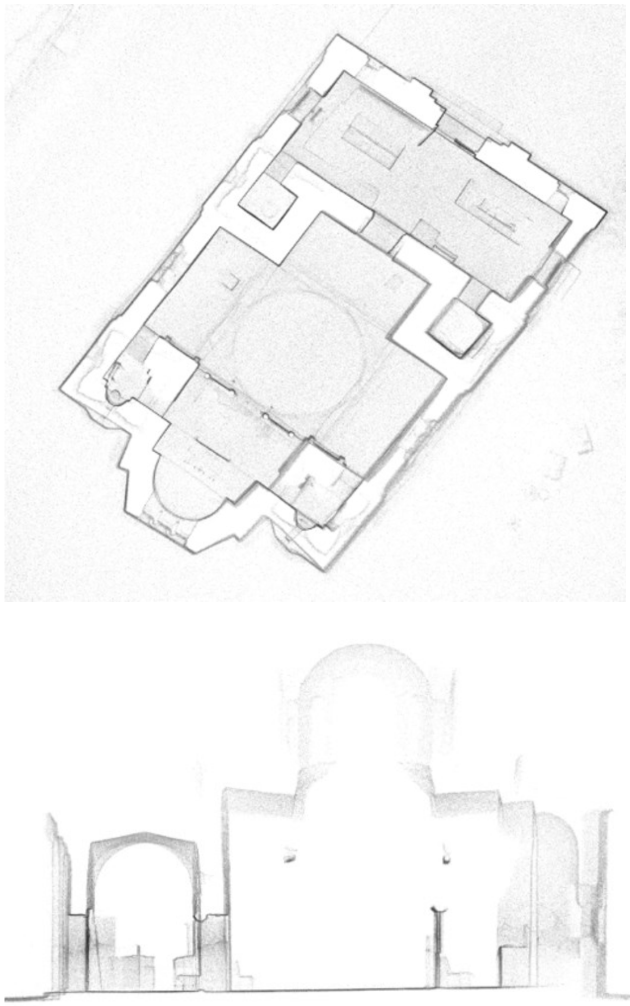

Figure 5. Projected point cloud and cross-section from PLS ZEB REVO.

Figure 6. Final photogrammetric model combined with laser scanned data for getting of correct scale of the model (Agisoft Metashape and RealityCapture).

3.6 Data analysis

A photogrammetric model was created, as well as a model from PLS and partly from TLS. The CloudCompare software was used for comparing of all three captured types of church model parts. As a reference model (a part only because of instrument failure) the model created from BLK 360 was used, but for complex models the combinate photogrammetrical model was used as reference (based on the fact, that ZEB REVO has worse accuracy). Here it must be said that the object is irregular, without smooth plaster, and it was not the aim to create a model with millimetre accuracy. It was confirmed that all three models were significantly identical, and the deviations were at most around 5 cm - especially in the hard-to-reach places, which is due to the poorer quality of the model in these locations (Figure 7, Table 1).

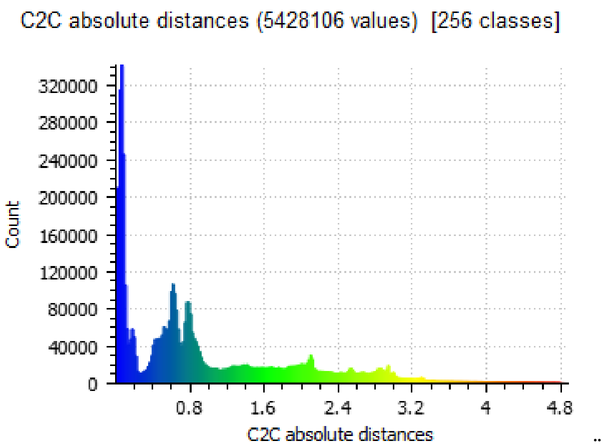

Figure 7. Differences between point cloud from combined terrestrial and aerial photogrammetry.

Device	Accuracy [mm] on 10 m	Range [m]	Acquiring points/sec	Data size [MB]	Time [minutes]
Nikon D3200	5-20	10	~30 photos/minute	~10/photo	~30 photos/minute
DJI Mavic Pro	5-30	30	~20 photos/minute	~4/photo	~20 photos/minute
ZEB-REVO	10-30	30	43000	100/min	slow walking
BLK360	4	30	360000	600/scan	6/scan

Table 1. Measurement time and data volumes.

3.7 Creating of VR model

A simplified 3D model was created from the measured data. SketchUp and Revit software were used. Models need to be modified for transfer to VR. In our flowchart, we use the Unreal Engine for VR. A low-poly model must be created for proper display. This is produced by decimation of the data; a low-poly model has only a few percent of the polygons of the original model, the 3D vision is created with a suitable texture that takes over the spatial representation (Figure 8-15).

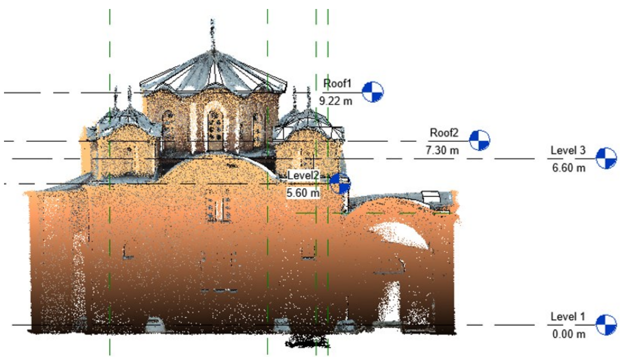

Figure 8. Defining of levels for creating of simplified model.

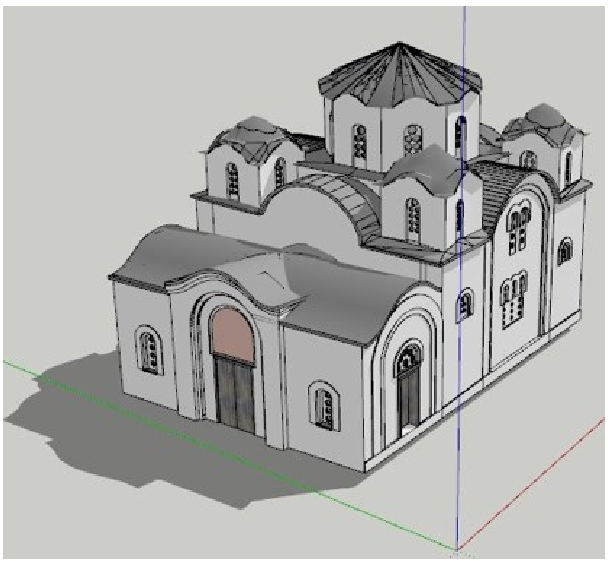

Figure 9. Model from SketchUp.

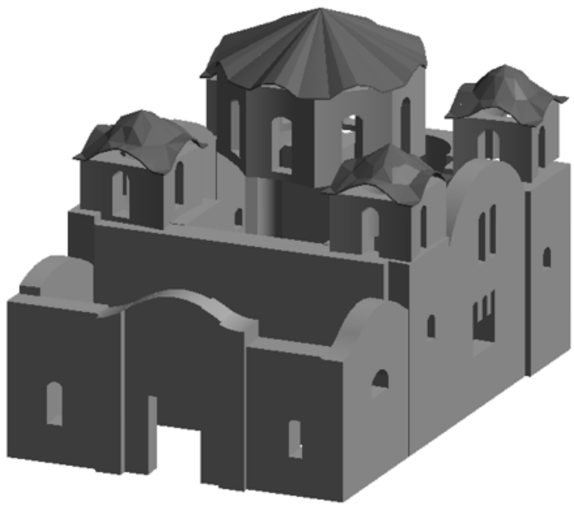

Figure 10. Model from Revit.

Figure 11. Low-poly model (110 thousand polygons from original 4.5 million polygons based on photogrammetric model.

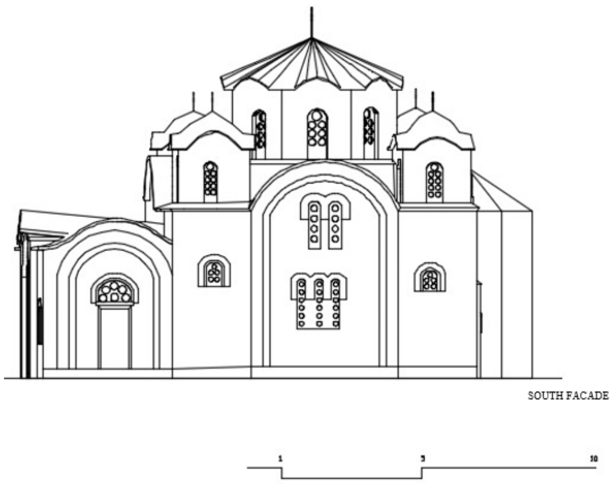

Figure 12. Generated views from simplified models (SketchUp).

Figure 13. Generated VR model with texture (UnrealEngine).

Figure 14. VR model rendered in Lumion.

Figure 15. Comparison of both 3D models: BIM geometrical basic model (grey), photogrammetrical model (blue).

4. CONCLUSION

A high-quality 3D model of the exterior of the building was created from ground and aerial data in Agisoft Metashape software. Unfortunately, we did not have permission to photograph the painted interior, so the interior is created without texture from ZEB REVO data only. In the process of creating the outputs, different types of software were used to process the set of 3D models and documenting the monitored historical building. The final 3D processing and visualizations were made in Revit software, (BIM), for the transfer to VR, Unreal Engine was used. Finally, a 3D rendering software Lumion was used to bring the 3D model 'to life' with surroundings like trees, grass, bricks etc. Low-cost and easy-to-use photogrammetric methods like close-range aerial/terrestrial photogrammetry and mobile laser scanners are technologies that reach high satisfactory results for the needs of documenting these historical sites. The integration of these different photogrammetric approaches has proved its indisputable potential as the best way to the cultural heritage documentation and monitoring. The full paper will describe the accuracy analysis, advantages and disadvantages of each data type, a detailed comparison of the models and a series of image outputs. A case study of this type is of particular interest for monuments in both North Macedonia and Kosovo, as their condition and existing documentation is often not commensurate with their significance, making digital rapid and inexpensive documentation very important.

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