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DIGITAL ARCHIVING OF HISTORICAL WATER UTILIZATION STRUCTURES USING AN INTERDISCIPLINARY METHOD

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ABSTRACT

Human efforts to regulate watercourses and the use of water energy in their favour goes back into the past. Although historical water management and utilization structures are the proof of that, only a small number of such structures have been preserved. The article deals with the applied research of the use of modern geodetic laser scanning stations in combination with photogrammetric digital technologies for creating technical documentation and digital visualization of historical structures and national cultural monuments. Specifically, in this case, we will focus on the water utilization buildings – the water mill and water sawmill in the National Open-Air Museum, Rožnov pod Radhoštěm, Czech Republic. Digital twins created using modern technologies may well serve not only for geo-tourism purposes but also as basis for potential future reconstruction or redevelopment projects.

Keywords: 3D visualization; Digital photogrammetry; Digital twin; Industrial monuments; Laser scanning.

1 INTRODUCTION

The history of water management and utilization structures has been closely connected with the beginning of establishing the first human settlements. This fact points to the importance of water as a basic resource for human life. Nowadays, the issue of efficient use of water resources and hydropower, given their quantity and quality, is one of the main topics not only for economists but also for spatial planning authorities. The issue has been gaining momentum, especially in recent years, as an increasing number of regions have faced problems with insufficient capacities of water reservoirs during recurring periods of prolonged periods of drought and due to a decrease in regular rainfall affected by climate change.

Small lakes, ponds, and artificially built local dams have long helped to affect the surrounding fauna and flora, but also significantly contributed to water management. They may have several functions from flood control measures, serving as water reservoirs for irrigation purposes, include gear mechanisms used to generate power, or may form spaces suitable for recreation. In the Czech Republic, the history of building ponds, mill construction and milling has had a long-standing tradition. During the peak of milling in the Czech Lands (late 19th century), a mill, either wind or water, made part of almost every village [1].

Unfortunately, only a small number of these technical monuments have been preserved to date. The main task of this research is to apply progressive geodetic technologies and to combine the results of measurement with innovative digital technologies in order not only to document the existing historical monuments but also to bring a new dimension to their presentation to the public through mobile applications, augmented and virtual reality. The essential part of the project is the creation of a digital twin, the virtual copy of its reality [2]. Changes and modifications created on the digital model can serve as a basis for the reconstruction or redevelopment of the building, thereby affecting the building in the real world [3].

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2 TEST SITE SELECTION

The area of Mlýnská dolina in the National Open-Air Museum located in Rožnov pod Radhoštěm, Zlín Region, Czech Republic, was chosen as a suitable location for experimental measurements. The Mlýnská dolina complex (Fig. 1) has functional technical water utilization monuments (fulling mill, mill, sawmill, hammer mill, and oil mill), which point to the coexistence of man with nature, his ingenuity and intelligence for the exploitation of natural forces (in this case the water energy). Industrial monuments have been carriers of architectural, historical, and technical values of the nation, and they also represent material evidence of the production and development of industry [4].

Figure 1. *Area description – selected technical monuments of Mlýnská dolina, Rožnov. DJI Mavic Pro, 3D model of the area generated by RealityCapture software using orthophotos*

Water utilization facilities are located on an artificially built canal leading from the Rožnovská Bečva River. In the upper part of the area is situated a small water reservoir which ensures a sufficiently strong flow of water for the operation of technical facilities even in the dry season.

3 GEODETIC SURVEYING PROCESS METHOD

The choice of the methodological procedure for creating the documentation of historical objects depends on the technical and software equipment, the requirements for detail and content of the final product and the historical and cultural significance of the documented object. The appropriate technique chosen for the creation of documentation should be most effective, least destructive, most efficient and most economical means to obtain the necessary information.

3.1 Current state and possibilities of documentation of historical objects

Basic documentation can be made using a pencil and paper. The main part of this type of documentation consists usually of text describing important historical facts concerning the object. Hand sketches and drawings are used to capture the major geometric parameters of the object (floor plan, side view) and detailed drawings of characteristic elements (parts of sculptures, frescoes, architectural elements). This method is economically undemanding, it is used for initial surveys, expeditionary surveying and mapping. Drawing of hand sketches is based only on visual perception, the geometric dimensions are not precisely documented. The drawings are not technical, but they carry only informative characteristics.

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More technically advanced methods utilize geodetic equipment in surveying. With the help of a laser total station, the surveyor is able to define the dimensions of mapped objects or locations precisely, with an accuracy of centimetres. The graphic output represented by 2D sections (floor plan, side view) constructed by CAD software with metric defined dimensions. They represent a full-fledged technical basis for the needs of reconstruction, restoration and planning. In this case, the documentation is complemented by photographs capturing e. g. facade, interior and exterior details.

When measuring with a total station, we capture only the essential structural elements for the creation of sections (e. g. the floor plan of the load-bearing walls), which is given by the measurement speed, 5–10 points per minute. The measure speed of laser scan station ranges from hundreds of thousands to millions of recorded points per minute. This allows us to measure more parameters in less time. The captured point cloud represents a 3-dimensional copy of the scanned object, including the surrounding environment. The point cloud is a convenient input for the creation of 3-dimensional digital models.

The output of the photogrammetric survey can be transformed into point cloud or 3D mesh model. However, for the correct scaling of the 3D model dimensions, it is necessary to combine photogrammetry with other measuring methods (verification of control measures, determination of spatial position of reference points and measuring position of targets by total station or GNSS technology). A special case is the use of aerial photogrammetry. The compact drone allows quick mapping of difficult-to-access parts of buildings such as building roofs.

The aim of our experimental measurement is to demonstrate a combination of laser scanning and photogrammetry in order to achieve high time-, qualitative- and quantitative- efficiency in regard to the volume and content of measured data.

3.2 Combination of laser scanning with ground and aerial photogrammetry in surveying routine

The geometric parameters of the mill and sawmill objects were measured by non-contact methods (Fig. 2). The supporting structure of the project is a point cloud created by the terrestrial laser scanner Faro Focus3D X330 consisting of 25 scanning positions, altogether 195 million of measured points.

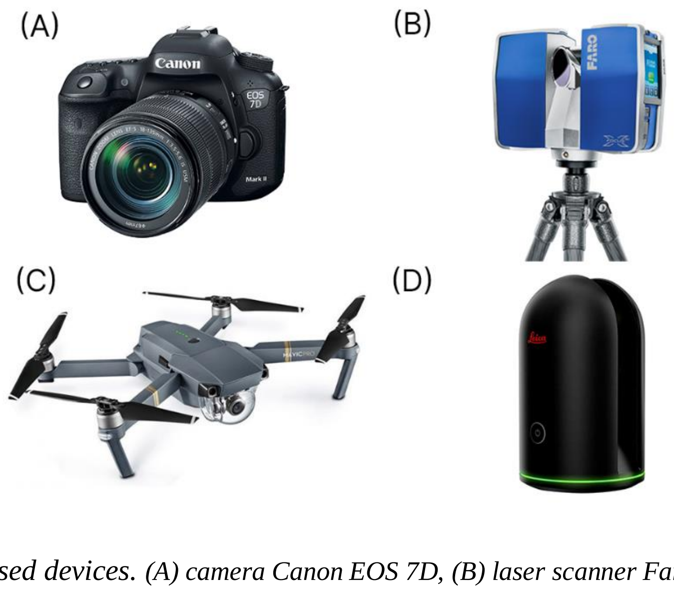

Figure 2. *Used devices. (A) camera Canon EOS 7D, (B) laser scanner Faro Focus3D X330, (C) drone DJI Mavic Pro, (D) laser scanner Leica BLK360*

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According to the external lighting conditions and the close distance to the observed subject, the scan quality was set to the medium recording density of the point cloud, panoramic images were created in HDR mode. Due to the rugged terrain, the problem areas were additionally captured by the Leica BLK 360 compact static scanner. Its low weight made it possible to scan even problematic parts around the wooden viaduct and the water wheel, where we could not situate the massive Faro Focus3D X330 scanner due to the waterlogged steep terrain (Fig. 3). The geodetic survey was quickened using reference spheres with a diameter of 15 cm. Through this, we were able to semi-automate the referencing of individual observation positions in the local coordinate system during the processing of point clouds in the Faro Scene software. Mean distance error of 1.1 millimetre was achieved by registration of laser scans. Therefore, the laser data were chosen as a reference by later adjustment of photogrammetric model.

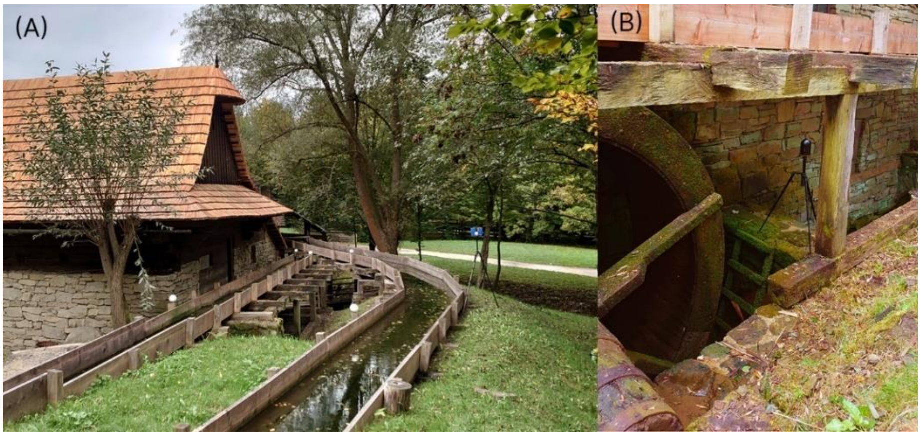

Figure 3. *Geodetic survey. (A) – Water mill documentation using a scanning station Faro Focus3D X330, (B) – Capturing difficult-to-access places with a compact scanner Leica BLK360*

The method of terrestrial and aerial photogrammetry was chosen as a complementary surveying method. Terrestrial photogrammetry provides a higher degree of mobility when capturing the object (Fig. 4). The position of the camera centre can be significantly varied, and in a short period we will capture the details of the object from several perspectives. Using two Canon EOS 7D cameras (Canon EF-S 18-135mm lens), 450 images were taken in UHD resolution. The geometric credibility of the final 3D model, when processed entirely by the photogrammetric method, does not only depend on the correctness of the methodological procedure during capturing the geometry of the object, but largely depends on the choice of software for automated image registration [5]. Despite the fact that photogrammetry is generally considered a low-cost measurement method, in combination with laser scanning, it is a very powerful and effective tool [6].

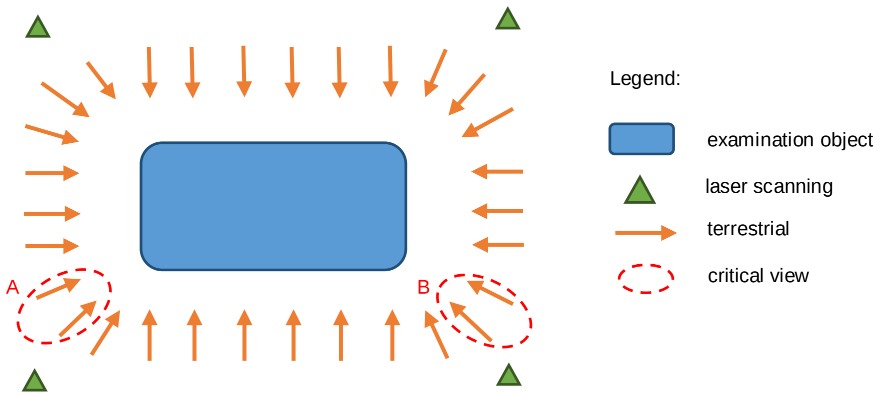

Figure 4. *Combination of static scanning and terrestrial photogrammetry scheme*

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The problematic part was the saddle roof, which we could not scan completely from the ground due to the low height of the scanner tripod. Aerial photogrammetry using a Mavic Pro drone has proven to be a suitable measurement method [7]. For the flight plan, we chose a low flight altitude (40 m), as a result of this we achieved a resolution of 1.4 cm per pixel. The region with an area of 90x50 m was captured with 100 images in UHD resolution (Fig. 5). The images from the drone also served as a basis for modelling the digital terrain model in the RealityCapture software.

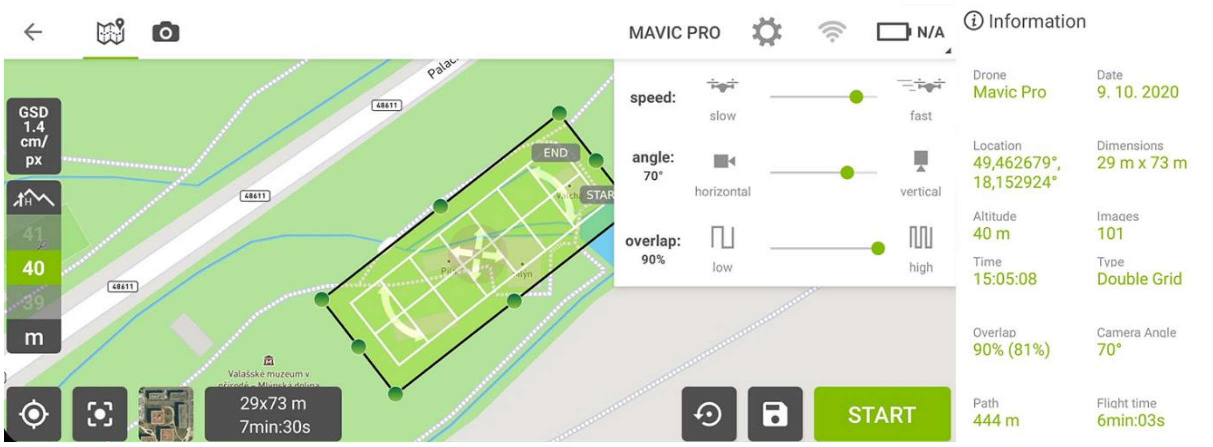

Figure 5. *Drone flight planning – Pix4D Capture*

4 CREATION OF THE DIGITAL TWIN

Traditional surveying methods designed for documentation purposes cannot completely capture every detail of the observed object or locality. At each step in the documentation process, a certain degree of generalization occurs (Fig. 6), which is specified by methodological procedures and visualizing technologies. By this point, traditional methods reach their limits.

Considering the combination of laser scanning and photogrammetry, the resulting model represents a full-fledged, comprehensive digital replica of physical object in real world.

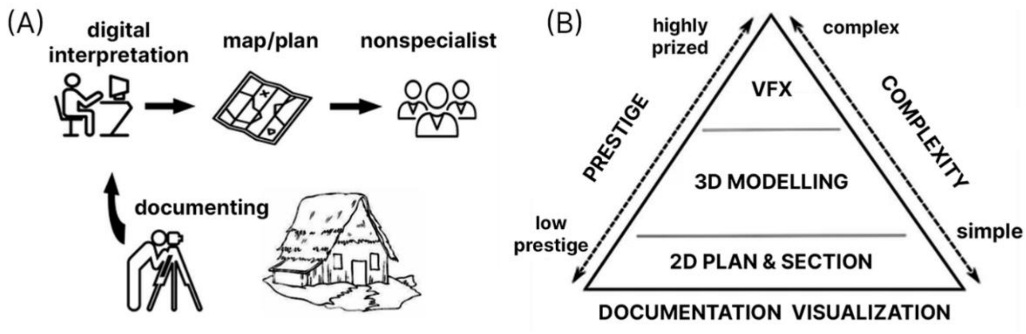

Figure 6. *Object documentation processing practice scheme. (A) – Data generalization in the process of information transfer, (B) – Different approaches to visualization. Upgrading basic technical 2D drawings into the 3D models of objects and their animation in VFX software ("Visual Effects") for immersive visualization (adapted from [8])*

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Applying a variety of devices required us to use a broad spectrum of software tools. Unification of heterogeneous data into a single homogeneous system is the key part of project implementation. Success was ensured thanks to the RealityCapture software, the unique feature of which is the combination of laser scans and photogrammetric data into a complete mesh, based on the principle of cloud to cloud solution. Figure 7 captures the methodological process from geodetic surveying to the final visualization of digital models.

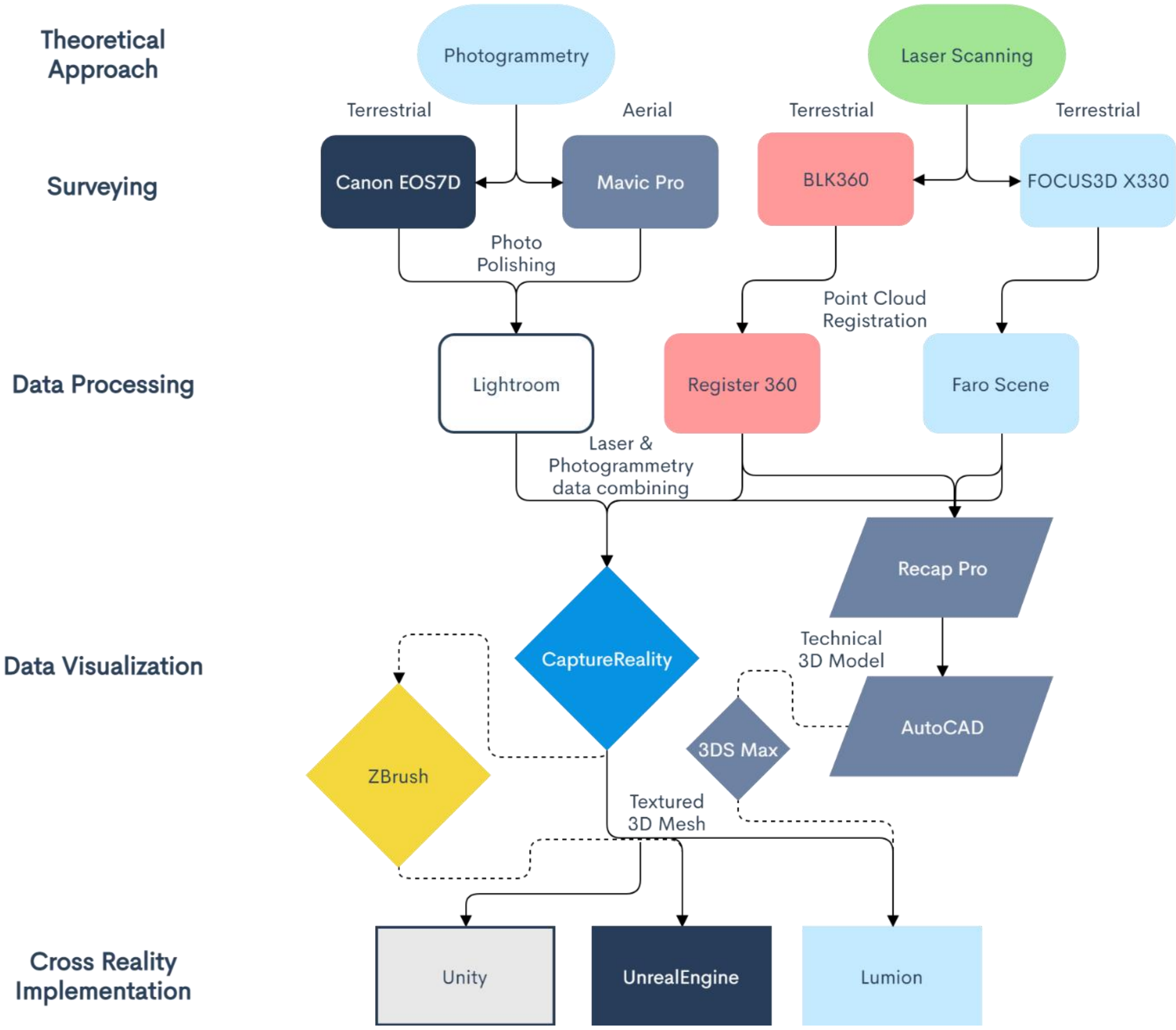

Figure 7. *Hierarchic structure of the project solution*

4.1 Processing 3D models

The data of the individual methods were processed separately in the first step and were compared with each other (Fig. 8). A point cloud from laser scanning was used as a reference unit [9]. Deviations of the model made from Mavic Pro drone imaging reached values up to 15 cm. These inaccuracies arose mainly in the areas of vegetation cover, where the signal of the laser scanner was able to penetrate to the Earth's surface. When using an optical sensor placed on a drone, the limit was the upper part of the vegetation cover. When comparing the model generated from terrestrial photogrammetry images with laser scanning data, the deviations reached values of up to 90 cm. The value of the achieved accuracy at the control points within the photogrammetric model during data processing did not exceed the limit value of 2 pixels. As demonstrated in Fig. 8, there was a distortion on the right side of the model.

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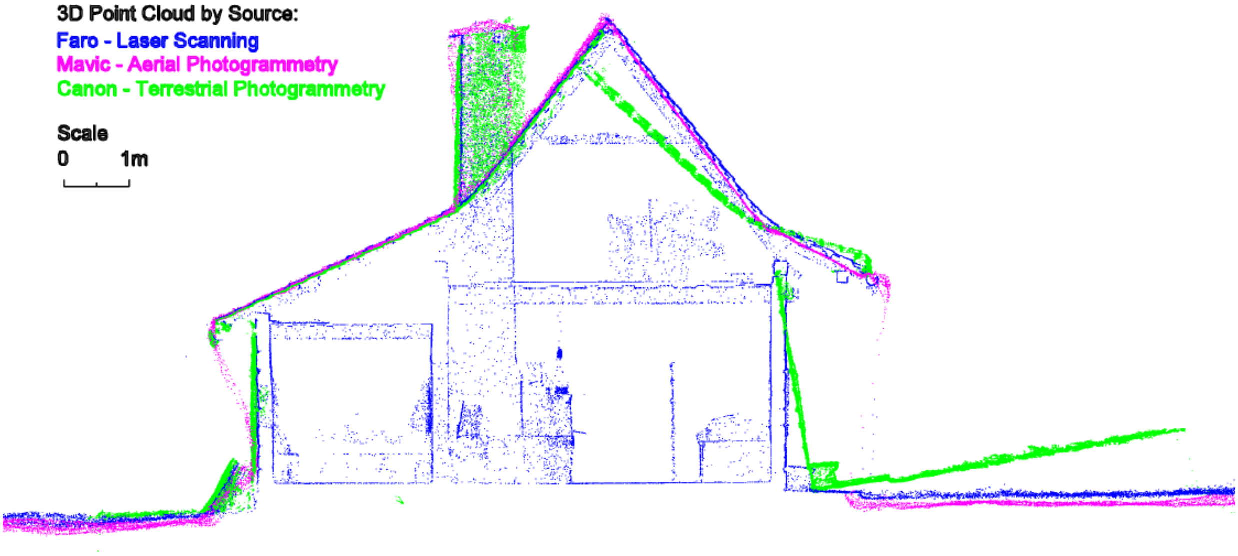

Figure 8. *Deviations of 3D models according to the type of applied surveying method. Analysis before cross-referencing models*

This deviation in the geometry of the compared models was caused by the lack of data outgoing from critical positions A and B (Fig. 4), where it was not possible to scan the object at an ideal angle due to obstacles and thus ensure the homogeneity of the photogrammetric data. This limitation was eliminated by dividing the model into 2 parts, which were processed separately.

Table 1 presents a comparison of the achieved accuracy of the methods for data registration using the cloud to cloud method and the subsequent increase in the accuracy of 3D models after the implementation of reference points. It is remarkable to notice within cloud-to-cloud registration, how the results from the Mavic Pro drone provided further more accurate data, compared to terrestrial photogrammetry, even though the Mavic Pro drone sensor (13.2x8.8mm CMOS sensor, 12 Mpix) has inferior specifications in comparison to the Canon EOS 7D (22.3x14.9mm CMOS sensor, 18 Mpix). This points to the importance of a geometric model of observational positions. The flight plan was automated using the Pix4D Capture application, which in combination with suitable lighting conditions helped to achieve such a quality result.

Maximal deviations of photogrammetry models are compared to reference model (laser scan data). With Referenced Model we achieved improved accuracy of pure photogrammetry models (aerial and terrestrial) by implementation of control points across all three models (laser scanning, aerial and terrestrial photogrammetry). After correcting the models with reference points, the maximum deviations were minimized. Due to that, all three models could be merged into a single homogeneous project.

Table 1. *Numeric comparison of models*

Surveying Method	**Terrain Model** Max. Deviation [m]	**Structure Model** Max. Deviation [m]	**Referenced Model** Max. Deviation [m]
	None model cross-reference implemented		
Laser Scanning	Reference model	Reference model	Reference model
Aerial Photogrammetry	0.15	0.07	0.06
Terrestrial Photogrammetry	0.90	0.30	0.03

4.2 3D model final cut

Using the RealityCapture software, a polygon mesh was created from a homogeneous point cloud. Laser scanning played an important role in the geometric accuracy of the mesh. Photogrammetry, in turn, showed its strength in colouring and texturing.

Due to the size of the area, models of individual buildings and terrain were exported separately. The terrain model consists of 14.9 mil. triangles, the sawmill model is made up of 18.1 mil triangles. The model of the water mill with captured interior and exterior is pretty detailed, consisting of 158.5 million triangles. Afterwards, the models have been optimized in the ZBrush software (reduction of the number of triangles, contour smoothing). The modified model represents an ideal basis for creating visual experiences in a virtual environment using Lumion, UnrealEngine or Unity applications.

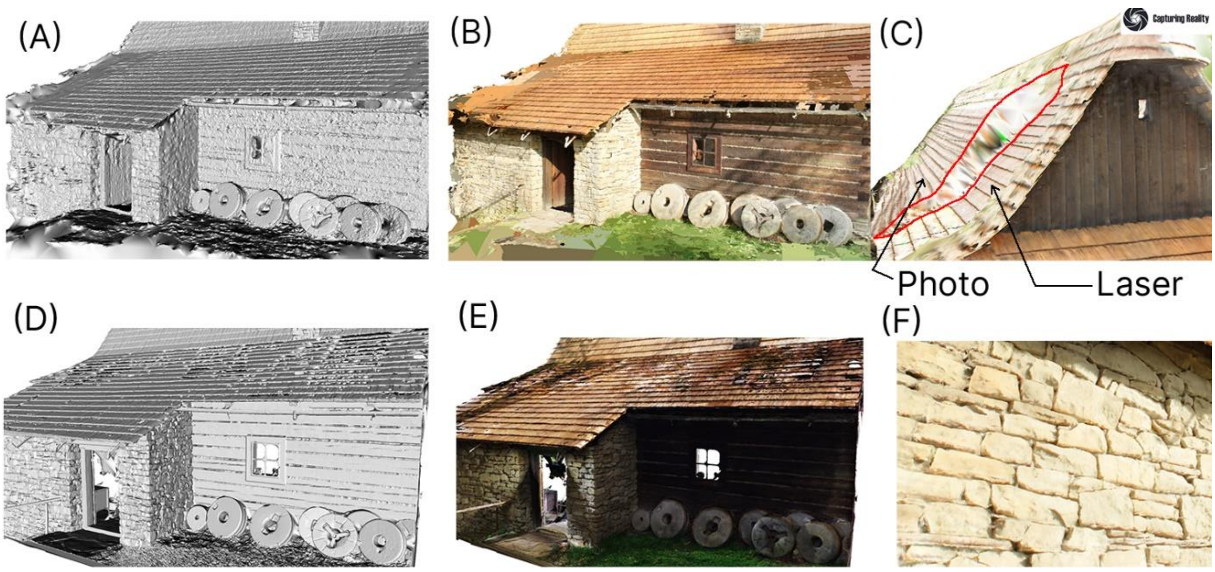

Figure 9. *Visualization of digital models in RealityCapture. (A) Terrestrial photogrammetry – grayscale mesh, (B) Terrestrial photogrammetry – textured model, (C) Geometry error comparison, before model merging, (D) Laser scanning – grayscale mesh, (E) Laser scanning – textured model, (F) Finalized texture on stone wall (combination of laser scan geometry and photo texture)*

5 DISCUSSION

The development of the methodology required interdisciplinary cooperation [10]. It was necessary to combine the knowledge of geodesy and photogrammetry to ensure the correct surveying procedure and the selection of appropriate measuring equipment. The principles of physical optics were a condition for adequate adjustment of the measuring devices in consideration to the current weather conditions during the surveying. Data processing was performed applying information technologies designed for the geodetic, technical, artistic, graphic and game segments. With the assistance of advanced technology, surveying is now time-saving. The 4-member team mapped the area and relevant objects in 4 hours. Replacing the static terrestrial laser scanner with SLAM ("Simultaneous localization and mapping") system can cut the surveying time requirement up to 1/5 of the time demands of classic surveying executed by total station [11]. Although the enormous time-saving using SLAM solutions (e.g. Leica BLK2GO or GeoSLAM ZEB Revo) comes with the cost of decrease in precision and accuracy by calculation of absolute spatial position. Due to the quantity of measured data, office work required considerably more time. However, this fact depends on the extent of documentation required by the client (2D plans, 3D models, application development). The implementation of the created 3D models into information applications is the source for creating an interactive platform documenting and representing real-world objects in a virtual interface. The

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emerging information technologies bring extensive possibilities of usage and presentation of data, which will find their application not even among tourists and visitors of cultural monuments as demonstrated on the 360° Panoramic Viewer of Imperial Cathedral in Königslutter (Germany) [12].

Physical reconstruction of damaged or destroyed historical monuments is an extensive and high-priced process. Historians, architects, renovators or artists can find solutions by applying digital technologies. A good example is the restoration of Agr-e Bam (Iran). Whole complex of adobe buildings was destroyed by an earthquake. At first, the complex was reconstructed only digitally because of financial reasons. Later, the real reconstruction began and the digital model of the town served as an important tool by the management of building program [13]. When objects can no longer be saved, but their historical significance for future generations is indisputable, these can be reconstructed in digital form by documenting their existing condition. As mentioned in Kennedy et al. [14] on the digital reconstruction of St. Andrews Cathedral (Scotland), the building was destroyed in the 16th century, but based on historical paintings, the object has been recently reconstructed in virtual reality [14]. Real reconstruction of the cathedral ruins was no longer desired because of changes in ideology. The space for digital model presentation to the public opens up in the environment of mobile applications, cross-reality and in the online world [15, 16].

6 CONCLUSION

The results of the measurement indicate the direction in which the technical documentation of the objects will take in the coming years. Laser scanning in collaboration with photogrammetry represents an ideal combination of surveying methods for documenting the geometric and visual parameters of an object of interest. However, it is necessary to be aware of the pros and cons of individual technologies. Laser scanning provides more detailed and more precise information about object geometry while it is missing the quality of colours and textures photogrammetry can achieve. To ensure the accuracy in geometry of the photogrammetric model, support of other surveying technique (in this case - of laser scanning) is required. Texture reprojection from the aligned photogrammetric model on the laser scan model will result in a high detailed 3D model with photorealistic textures. Properly configured scheme of the methodological procedure from survey preparation to visualization of the 3D model is a key element of the process of digitization of real objects. Current digital data visualization tools allow creating 3D models in a relatively simple and smart way, which are an accurate image of their original in the real world.

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