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TESTING OF CLOSE-RANGE PHOTOGRAMMETRY AND LASER SCANNING FOR EASY DOCUMENTATION OF HISTORICAL OBJECTS AND BUILDINGS PARTS

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ABSTRACT

In contemporary times, technology has dramatically simplified the process of documenting cultural heritage objects. This paper aims to illustrate modern methodologies for documenting historical monuments by applying advanced technologies, as these case studies show. Two technologies were used: laser scanning and digital photogrammetry. The first subject of our study was a historically significant 16th-century building located in Jachymov, situated in the North-West region of the Czech Republic. The object was documented by laser scanning (BLK360) and using a standard digital camera Canon Powershot SX230 HS. The laser scanning data were post-processed using Cyclone Register 360 Plus, while photogrammetric point clouds were generated with Agisoft Metashape. The second object was building and sculpture in the historical UNESCO city of Telč. For this object laser scanning instruments, digital photogrammetry and a new low-cost ViDoc documentation system was used. Our study is focused on analyzing sets of point clouds obtained from the data processing, conducted using CloudCompare to draw insights and conclusions. It turns out that the rapid development of techniques and technology makes it possible to use low-cost devices for sufficiently accurate and fast documentation; however, the mentioned ViDOC device can only be used for very close and small objects up to about 5 meters. For the documentation of sculptures, classic close-range photogrammetry is especially appropriate; for the documentation of buildings, laser scanners are suitable; the problem lies in hidden spaces and it is often necessary to use either a platform or a combination with photogrammetry using a drone, especially for upper parts of the object.

KEYWORDS

Photogrammetry, Laser scanning, Cultural heritage, Object documentation, ViDOC

INTRODUCTION

Half a century ago, construction documentation relied mainly on geodetic methods, limited to the tape measure. Data collection was minimal, with most existing data presented in paper format. Nowadays, the concept of the digital twin has become a global phenomenon, marked by remarkable advances [1, 2].

Over the past decade, laser scanning, and photogrammetry have been the primary tool for 3D data collection of complex heritage objects. The need of documenting cultural heritage objects is substantial and arises for various purposes. The need of accurate, fast and comprehensive documentation, especially of historic buildings, is demanded by today's world. Objects are often subject to destruction due to social neglect, wars, vandalism, natural phenomena, or rapid urban development. The documentation methods have evolved progressively through classical geodetic methods to today's laser scanning and automated methods of close-range photogrammetry in the form of structure from motion (SfM) and Multi View Stereo (MVS). Mobile laser scanning is developing very rapidly, especially in heritage care as mobile personal laser scanning [3-5].

The primary goal of these measurements is to accurately depict the object in a three-dimensional context. The resulting data performs several essential roles, initially focused on the object's representation, then expanding to encompass the assessment and detection of potential damage. Furthermore, those measurements prove valuable in the analysis and strategic planning of maintenance and preservation efforts for these culturally significant objects. In recent years, the use of mobile handheld laser scanners has become significant. Their advantage is fast and three-dimensional documentation of objects of interest. Similarly, drone imagery combined with terrestrial imagery has been used extensively in the last decade. Nowadays, the logical output of documentation of historic buildings is export to heritage building information modeling (HBIM), which enables a comprehensive description of the object and its management [6-9]. The following work aims to demonstrate the easy to use three-dimensional visualization of a historical cultural object through measurements from a laser scanner and a digital camera.

METHODS

Instruments

For measurements and point cloud generation, different instruments were chosen. In the first case study, a scanner Leica BLK360 and a common digital camera Canon PowerShot SX230HS were used [10, 11].

Fig. 1 – Laser scanner BLK360 (left) and Canon PowerShot SX230 HS (right)

The second case study used a BLK360 scanner, a Canon 450 camera and a new low-cost ViDoc device from Pix4D. The project was complemented by the analysis of older measurements of the same object with a Surphaser 25 HS laser scanner and a Pentax 645 camera.

Fig. 2 – ViDOC (left), Pentax 645 and laser scanner Surphaser 25 HS (right)

ViDoc is a simple device that includes ViDoc RTK rover device, phone case (for iPad Pro or iPhone 12 Pro and higher with lidar sensor) and GNSS antenna.

Leica BLK360 is a compact laser scanner. It is small and light (around 1kg) easy to transport and use only for one person in site. The scanner is equipped with a camera for point cloud coloring and a thermal sensor; it accomplishes a comprehensive 360-degree panoramic image capture and finishes a full-dome scan in less than 30 seconds (with smallest resolution without images) till 6 minutes (full resolution with HDR images), where the vertical field of view is 300˚ and the horizontal field of view is 360˚ [10]. Based on testing and technical parameters, the accuracy of a measured spatial point is 4mm on 10m distance. The BLK360 includes an app called BLK Live, allowing us to control the laser scanner's images and quickly assess the on-site data for feedback, quality assurance, and quality control using a tablet. After measurements, the Leica Cyclone REGISTER 360 software helps with quickly setting up and organizing the collected data in the field. Canon PowerShot SX230 HS is a common low-cost compact digital camera that was used to capture photos of the buildings inside. It is equipped with a 12.1-megapixel CMOS sensor, 14x optical zoom lens (from 5mm to 70mm), allowing you to capture distant subjects with remarkable clarity and precision. Additionally, it incorporates built-in GPS functionality, enabling geotagging and location tracking for photos [11]. An older Surphaser 25 HS laser scanner was used to document the sculptures in 2018. It is one of the most accurate scanners with an accuracy of 0.6 mm at 10 meters, which is exceptional and very suitable especially for sculptures [12]. The scanner does not have a camera, but the declared accuracy is excellent; other laser scanners are not very suitable for documenting sculptures, as they have worse accuracy and the sculptures do not have proper detail. This is already lost at an accuracy of a few millimetres. Therefore, nowadays it is better to use photogrammetry, which gives an accuracy of up to 0.1 millimetres without any problems if done correctly, and the camera is several orders of magnitude cheaper than a laser scanner. In 2018, a professional 51Mpix Pentax 645 camera was used to document the sculpture for comparison with the laser scanner (Figures 1 and 2), [13].

Case study

In terms of simple methods of documentation of historical elements and objects, two case studies were carried out. Both of them show the easy and quick possibilities of 3D documentation especially for endangered heritage objects.

Documentation of historical parts inside the object

The first case study is the documentation of building element in historic house where it was not clear if it would be saved for the future. This house and its parts is located in the town of Jáchymov, northwest part of the Czech Republic near the Germany border; the town was founded in 1516 after the discovery of rich silver deposits. After silver and later tin were down mined in the area, the area rapidly declined, and the mines were no longer profitable. Marie-Curie Sklodowska discovered radium in the Jáchymov ore. This led to the reincarnation of the town with radon baths establishment. However, a major turning point came after the expulsion of the German population after 1945 following the end of World War II [14]. A population that had no relation to traditions and landscape slowly moved into the entire border area. Added to this was the decade-long exploitation of local uranium deposits by the former Soviet Union for strategic reasons and the labour camps for political prisoners following the communist takeover after 1948.

Fig.3 – Inside the house No.12, Jáchymov, year 2021. Gothic ribbed circular vault.

Many historic buildings have not been maintained for a long time. The landscape, population and employment opportunities have changed fundamentally, and these changes are still visible. The house no. 12 on the Republic Square in Jáchymov dates mostly from the turn of the Gothic and Renaissance periods. It was originally a noble house of a rich owner. The original parts of the structure from the time of the building's construction have been preserved (the cross vaults on the ground floor, the staircase to the first floor with a stone handrail and, in particular, the beautiful ribbed circular vault in the upper hall). Some details of the interior, the historic plasterwork on the first floor and the second-floor hall, and the exterior are also of considerable historical value. The entrance portal and the Renaissance lining of the window openings are original. The building was in a poor but habitable condition in the 1980s, but the rear wing and the support buildings behind the house were already in a state of desolation. Poorly executed anti-radon protection was also a factor, and the building degraded rapidly in the post-revolutionary period (after 1989). The great boom in property purchases during the Covid 19 pandemic caused a change of owner who decided to save the building. The pandemic and the high cost of construction work and materials in the post-Covid era delayed the work. Today, however, the building is in use again and has been well restored thanks to the efforts of the new owner (Figures 3 and 4).

Fig.4 – The house No. 12 in Jáchymov before (left) and after reconstruction (right) in 2023.

Documentation of a sculpture and facade of a historical building

The second part of the work was focused on the possibilities of low-cost documentation of monuments in the town of Telč. This historical town center has been a UNESCO World Heritage Site since 1992 [15]. The aim of the research was to compare data from the BLK360 laser scanner and the new low-cost ViDoc device. The first part was focused on the comparison of scanning time and accuracy in terms of the smaller historical house documentation on the square in Telč. The house No. 61 on Zachariáš of Hradec Square was selected; it is a single-story house with an archway. The originally late Gothic house was preserved during the Renaissance renovation. Further changes took place before the mid-16th century (under the ownership of the baker Michael). The reconstruction is dated on the sgraffito of the facade L.P. 1555. The imposing Renaissance façade with a Venetian-type gable with pilasters and cornices dominates the square. The façade is decorated with sgraffito with vegetative motifs[1].

Fig.5 – Two selected historical objects on Zachariáš of Hradec Square in Telč city

[1] https://pamatkovykatalog.cz/mestansky-dum-700198

Possibilities of sculpture documenting was also part of the research. There are several suitable objects in the Telč square, a fountain and the Baroque Marian Column, a plague column built in 1716-1720. In the past, we have already performed measurements (2015) with very high precision Surphaser 25HS scanner and photogrammetrically with a professional Pentax 645D 51MPix camera. The measurements are highly accurate but time consuming, including the data processing.

MEASUREMENTS AND PROCESSING

Gothic ribbed circular vault inside the house No.12, Jáchymov

The first measurements were done by laser scanner. 7 scans of the building interior buildings were done (Figure 6). After that, the measurement data can be transferred with Wi-Fi and open in software Leica Cyclone REGISTER 360.

The next step after data import was the registration. This step involves aligning and merging multiple scan positions to create a unified point cloud dataset. This can be done automatically, where the program will match points in different scans, where the user can edit one by one. Following this, quality control can be performed, checking for alignment errors, outliers, and other issues to ensure the data's accuracy. After removing any unnecessary parts from the point cloud, we can visualize the 3D scan using various software tools. Through these processing steps, we achieved a successful result: 16 lines with a 50% overlap and an overall Bundle Error of 0.004 meters. The measurement takes 40 minutes, the semi-automatic data processing takes 30 minutes on a common HP workstation (processor I-7, 32 GB RAM) to a colored joined point cloud. Together 30 million spatial object points were saved.

Fig. 6 – View of all merging scans in SiteMap

The second measurement was done by a digital camera Canon PowerShot SX230 HS. 238 images were taken with shortest focal length 5mm, Shuter 1/300, F-stop F/3.1 and resolution 4000x3000. Agisoft Metashape software was used based on Structure-from-Motion (SfM) and MVS (Muti View Stereo) technology. This software is used in many different fields of application [8-11]. The following processing images workflow was used (Figure 7):

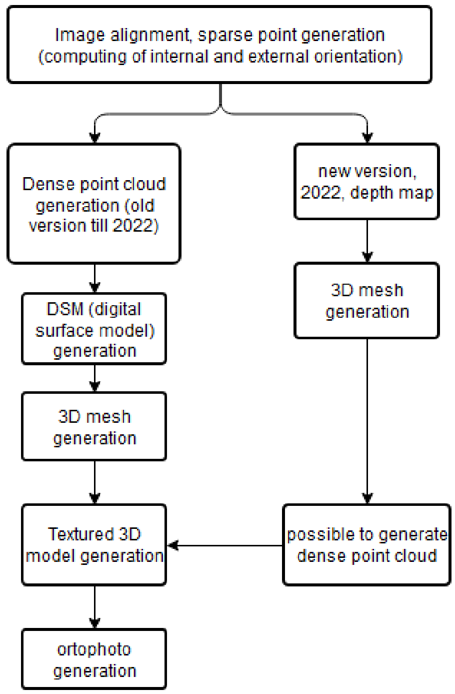

Fig. 7 – Agisoft Metashape flow-chart

The relative orientation was done by the "Align Photo" function in Agisoft Metashape software, where 283 from 238 images were co-registered. In this process, the program finds corresponding tie points between images. Using these points, it figures out how the images are positioned and rotated in relation to each other (internal and external parameters were calculated). The root-mean-square (RMS) reprojection error of relative orientation tie points was 1.37 pixels. Optimize Cameras function to refine relative orientation was used. After these steps, the software calculated the camera's internal settings through a self-calibration process. After that, the Dense Point Cloud was generated with High Quality parameter. After this, the triangle network known as the Mesh was calculated (Figure 8).

Fig. 8 – Point Cloud (left) and Mesh (Right)

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At the end the Tiled Model or Textured 3D was generated with high quality. Build Texture allows adding the photos taken to the shape of the pre-created 3D Mesh object (Figure 9).

Fig. 9 – Textured 3D model of the object

Comparison of two-point clouds

The purpose of this step is to compare two measurement methods with different techniques. To do this, we took the point cloud data from Leica BLK360 as our reference point and compared it to the point cloud data derived from the digital camera. CloudCompare software was used to make this side-by-side comparison.

To initiate the process, we acquire two sets of point clouds, each originating from different data capture instruments. Following this data acquisition, the critical step of aligning these two-point clouds ensues. It's essential to note that the laser scanner data consistently serves as the reference dataset, while the data from the camera is adjusted to align with this reference. Once reference points in both datasets are identified, the orientation process can continue. Subsequently, a comprehensive analysis between these two datasets is undertaken, employing the "Cloud-to-Cloud" method. This method enables a detailed comparison of point clouds. As a result of this analysis, the outcome is comparison image generation, which provides insights and visual representation of the alignment and comparison between these two sets of data (Figure 10).

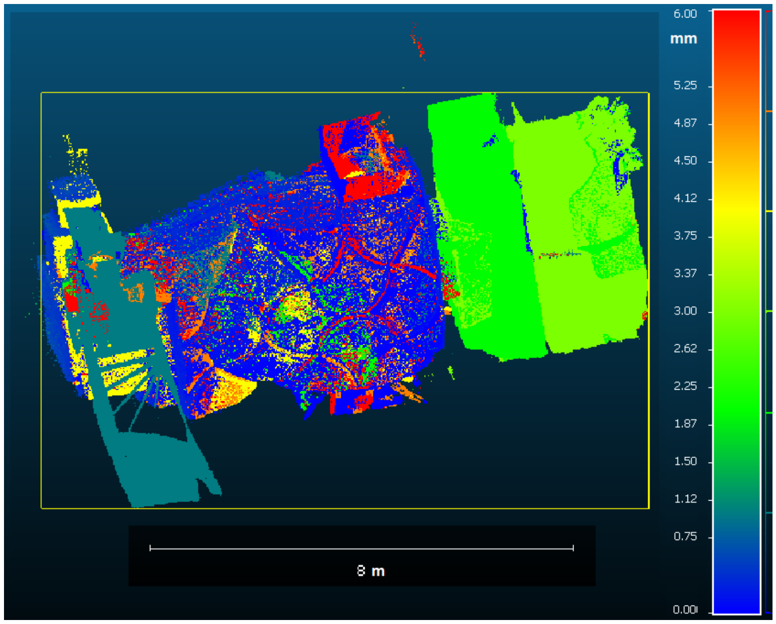

Fig. 10 – Comparison of point cloud from digital camera Canon PowerShot SX230 HS and Leica BLK360 laser scan

The default way to compute distances between two-point cloud is the 'nearest neighbor distance' for each point of the compared cloud, CloudCompare searches the nearest point in the reference cloud and computes their (Euclidean) distance. If the reference point cloud is dense enough, approximating the distance from the compared cloud to the underlying surface represented by the reference cloud is acceptable [16].

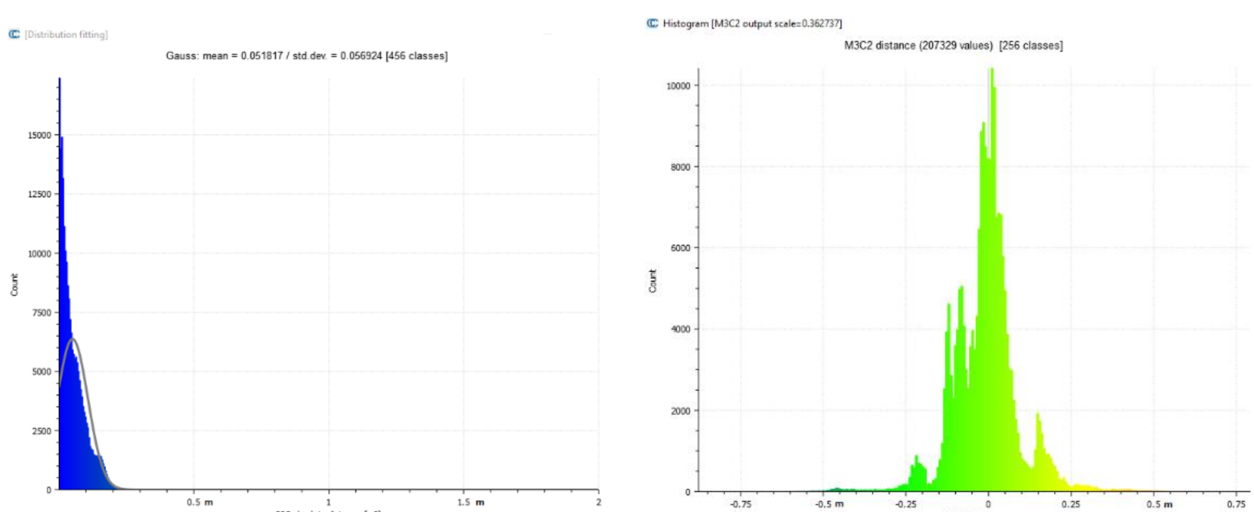

Fig. 11 – C2C absolute distance

To increase the accuracy of the product, it would be useful to have a control point and measurement with geodetic instruments. Unfortunately, this was not done in this project. For this reason, we relied on CloudCompare for the comparative analysis of metrics between two sets of point clouds. It is essential to note that measurements obtained through the BLK360 laser scanner proved significantly more accurate compared to those obtained with the Canon digital camera, therefore we used like the reference the point cloud of the laser scanner (Figure 10-11).

Tab. 1 – Measurement analysis

Instrument	Measurement time (minutes, hours)	Processing time (hours)	Price (kEuro)	Precision (mm)	Range (m)
Canon PowerShot SX230 HS	30 minutes	1	0.5	3	10
BLK360	60 minutes	1	30	4	30

For smaller and indoor objects, the time and accuracy are comparable in terms of laser scanning or photogrammetry. From a photogrammetric point of view, the lighting plays a role and must be of good quality to obtain images; however, it is also possible to take pictures with a flash. In terms of price, a laser scanner is logically several orders of magnitude more expensive (Table 1).

Objects on the historical Telč square

Fig. 12 – The 3D model created from ViDOC (left) and using the BLK360 laser scanner (right)

The differences in documentation of historic house occured due to range of devices. The BLK360 laser scanner has a range of 30 meters, and the photogrammetric measurement has a practically similar range. The difference is mainly in the use of ViDOC equipment, which has a realistic range of just over 5 meters and is not well suited for buildings. However, low objects and sculptures can be documented very easily, quickly, and accurately with ViDOC (Figures 12 to 14).

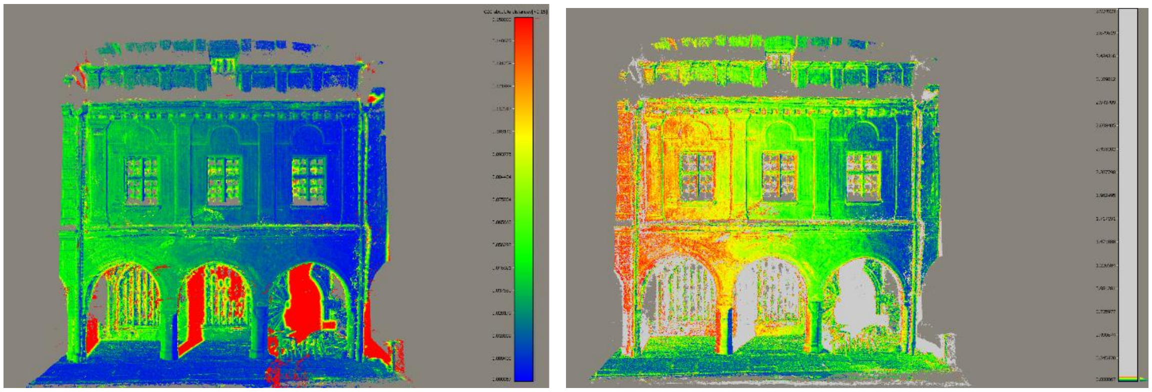

Fig.13 – The comparison of the BLK360 data with the ViDOC data. The BLK360 data was selected as a reference. In the picture differences especially in the hidden areas are shown (left, red color). The BLK360 scanner is static and measurements were taken from only one station, so there are several hidden areas. ViDOC is a mobile device and the model is more complex, it is possible to see a slight systematic deformation of the model, given by the oblique measurement with the BLK360 scanner, when its accuracy decreases with greater distance. On the left side a complex analysis is shown with hidden spaces, which were only on laser scanned data set (red color), better analysis is shown on the right figure; there are discrepancies no more than 5 centimetres.

Fig.14 – View of the object and position of the moving device, plan view and side view created by projection of the point cloud from the ViDOC device.

Fig.14 – View of the object and position of the moving device, plan view and side view created by projection of the point cloud from the ViDOC device.

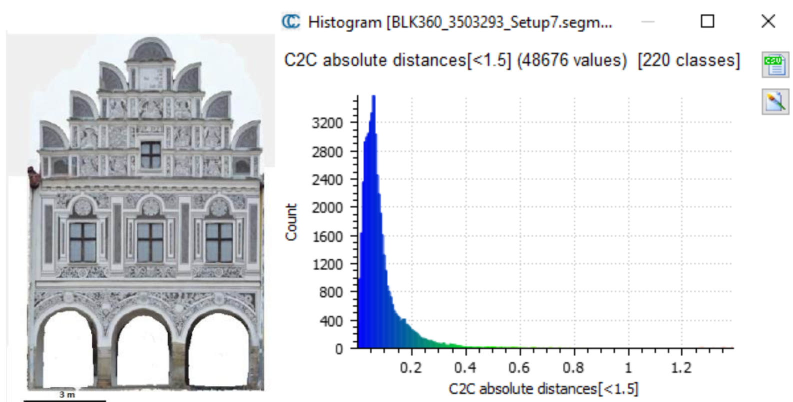

Fig.15 –Created orthophoto from Agisoft Metashape software (left) and comparison of BLK360 data with digital close-range photogrammetry (right); BLK360 data was used as reference data set. Most deviations are in the range of 1-2 centimeters, but at shorter distances up to 10 meters.

Using Agisoft Metashape software, a house 3D model, its orthophoto and a dense point cloud were created from the digital camera images (Figure 15). Twenty-two images and 3 geodeticaly measured control points with RMS of 4 mm were used, the calculated point cloud contains 4,798,102 points and the triangular mesh consists of 959,608 triangles. The generated point cloud was further compared with the output of the laser scanner BLK360 in CloudCompare software. After several adjustments iterations, a satisfactory result was obtained comparing the two point clouds. Most deviations between the point clouds are in the units of cm, however, especially in the window and ground floor area the inaccuracies are larger. The orthophoto was created with a pixel size of 3 mm.

Sculptures documentation

Sculpture documentation is problematic. It depends on its size and especially the spatial complexity of the sculptures, on the material, on the devices used and its accuracy, and mobility in terms of covered and small spaces. Various devices were used here, mobile ViDOC, an expensive and high-quality digital camera Pentax 645, a very accurate laser scanner Surphaser 25 HS, and data from the camera of the iPhone 11 smartphone (Figure 16 to 17).

Fig.16 – The textured 3D mesh from iPhone 11 (left) and a detail from this model (from about 3 meters). Right – 3D model from the ViDOC instrument. Based on the lidar sensor and RTK GNSS, the model is scaled, and it is possible to measure real distances on the model.

The difference in both models was mainly in the area of the head of the statue (it was not possible and allowed to scan) and reached a maximum of 2cm. Typically around 0.5-1 cm.

Tab. 2 – Measurements analysis (sculpture)

Instrument	Measurement time (minutes, hours)	Processing time (hours)	Price (kEuro)	Precision on ideal distance (mm)	Range (ideal, max) (m)	Georeference
iPhone	5 minutes	0.5	1	5	3 ; 20	Yes, low precision
Pentax 645D	30 minutes	2	10	0.1	3; 30	No, GCP´s necessary
ViDOC	10 minutes	0.5	6	5	3; 10	Yes, precise
Surphaser 25HS	1 hour	3	40	0.6	10; 40	No, GCP´s necessary

Sculpture documentation varies considerably in terms of time of data acquisition, processing, and cost of equipment. See Table 2.

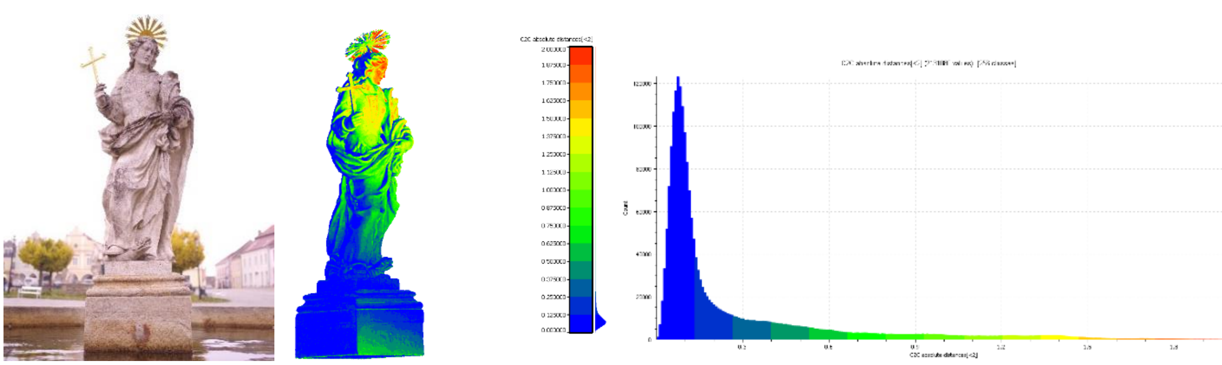

Fig.17 – Data processing (Surphaser 25HS and Pentax 645D), the between both models.

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CONCLUSION

This paper describes the need of photogrammetry and laser scanner for the historical objects reconstruction. Instrument description used for the measurements was explained at the begining. Throughout this paper, we used two technologies for measurements: one involving a laser scanner and the other was photogrammetry. The first building was documented by laser scanner BLK360 and using a standard digital camera Canon Powershot SX230 HS. Other objects were a building and a sculpture in the city of Telč, for documentation here a BLK360 scanner, a Canon 450 camera, a new low-cost ViDoc device from Pix4D, an expensive and high-quality digital camera Pentax 645, Surphaser 25 HS laser scanner, and data from the camera of the iPhone 11 smartphone was used. This paper demonstrates how these measurements were done, processed and the accuracy achieved. Working with the laser scanner was relatively simple for creating a 3D model, and the processing was not overly complex. However, working with the digital camera and iPhone was slower due to manual photo-taking, and the overlapping in each photo varied. To execute the processing and analysis of our acquired data, various softwares were used. Following data processing, our study advances to the crucial phase of comparing the generated point clouds by CloudCompare software. For documenting sculptures, classic close-range photogrammetry works particularly well, while laser scanners work for documenting buildings. The challenge lies in hidden spaces or in upper parts of objects. Therefore, it may be necessary to incorporate two or more technologies in some cases.

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REFERENCES

[1] Pavelka, K., Raeva, P., Pavelka jr., K., Kýhos, M., and Veselý, Z. 2022. Analysis of Data Joining from Different Instruments for Object Modelling, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLIII-B2-2022, 853–860, https://doi.org/10.5194/isprs-archives-XLIII-B2-2022-853-2022

[2] Petrovič, D., Grigillo, D., Kosmatin Fras, M., Urbančič, T., Kozmus Trajkovski, K. 2021 Geodetic Methods for Documenting and Modelling Cultural Heritage Objects, International Journal of Architectural Heritage, 15:6, 885-896, https://doi.org/10.1080/15583058.2019.1683779

[3] Luhmann, T., Chizhova, M., Gorkovchuk, D., Hastedt, H., Chachava, N., Lekveishvili, N. 2019. Combination of Terrestrial Laserscanning, UAV and Close-Range Photogrammetry for 3D Reconstruction of Complex Churches in Georgia, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W11, 753–761, https://doi.org/10.5194/isprs-archives-XLII-2-W11-753-2019

[4] Pavelka jr., K.. 2022. Photogrammetry, Laser Scanning and HBIM for Construction Diagnostic, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLVI-5/W1-2022, 171–176, https://doi.org/10.5194/isprs-archives-XLVI-5-W1-2022-171-2022

[5] Dlesk, A., Vach, K., Holubec, P. 2019. Analysis of Possibilities of Low-Cost Photogrammetry for Interior Mapping, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-5/W3, 27–31, https://doi.org/10.5194/isprs-archives-XLII-5-W3-27-2019

[6] Vileikis, O. 2023. A Strategy Using Heritage Documentation for Managing Change of the Historic Centre of Bukhara. ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume X-M-1-2023, 29th CIPA Symposium “Documenting, Understanding, Preserving Cultural Heritage: Humanities and Digital Technologies for Shaping the Future”, Florence, Italy

[7] Tobiasz, A.; Markiewicz, J.; Łapiński, S.; Nikel, J.; Kot, P.; Muradov, M. 2019. Review of Methods for Documentation, Management, and Sustainability of Cultural Heritage. Case Study: Museum of King Jan III's Palace at Wilanów. Sustainability, 11, *7046.* https://doi.org/10.3390/su11247046

[8] Patias, P., Grussenmeyer, P., Hanke, K. 2008. Advances in Photogrammetry, Remote Sensing and Spatial Information Sciences: 2008 ISPRS Congress Book
Imprint CRC Press, pp. 22, ISBN 9780429207327

[9] Bouček, T.; Stará, L.; Pavelka, K.; Pavelka, K. 2023. Monitoring of the Rehabilitation of the Historic World War II US Air Force Base in Greenland Remote Sensing. 2023(15), ISSN 2072-4292. https://doi.org/10.3390/rs15174323

[10] Leica Geosystems. Leica BLK360 User Manual. Version 2.0 English. https://shop.leica-geosystems.com/leica_blk360_manual (accessed on 30 Sept. 2023).

[11] PowerShot SX230 HS Camera User Guide. https://pssx230hs (accessed on 30 Sept. 2023).

[12] Surphaser, laser scanner, https://surphaser.com/, (accessed on 30 Nov. 2023)

[13] Foto Škoda, https://www.fotoskoda.cz/pentax-645z-55-2-8-d-fa-sdm-aw/, (accessed on 30 Nov. 2023)

[14] Bohdalek, P., 2012. Jáchymov - famous mining town in Bohemian Erzgebirge, online https://doi.org/10.13140/RG.2.1.2735.5924

[15] Telč, https://whc.unesco.org/en/list/621/, (accessed on 30 Nov. 2023)

[16] CloudCompare. User Manual. Version 2.6.1. Available online: https://www.cloudcompare/manual.pdf (accessed on 30 Sept. 2023).