Comparative analysis of the point clouds generated from UAV image data and terrestrial laser scanning for modeling information about historic buildings (hBIM)

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Key words: terrestrial laser scanning, point clouds, UAV

SUMMARY

Documentation of historic buildings by methods that do not require direct contact with the surface of the object is very common nowadays. The model in HBIM (Heritage Building Information Modeling) technology is particularly useful for conservation purposes, because a correctly made model contains comprehensive information about the object, such as geometric data, used building materials and painting decor, or data on the functionality of the object.

The aim of the article was to compare the data obtained from the unmanned aerial vehicle (UAV) and from the terrestrial laser scanning (TLS). Point clouds were generated on the basis of UAV image data and acquired with a Faro Focus scanner. UAV data were acquired at different flight altitudes and generated using different parameters. TLS point clouds were compared with UAV clouds for data completeness. The accuracy of the mapping of such elements as the basement of the building, the interior of the building or the upper parts of the building was checked. Then, analyzes were carried out in terms of geometric consistency of the object mapping on the TLS and UAV data. The following subjects were analyzed: the accuracy of georeferencing of point clouds obtained for a historic object, various measurement methods, as well as geometric consistency of the structure.

Georeferencing of image data from UAV was made on the basis of data from the GPS / INS module and a photogrammetric network of Ground Control Points, where GPS measurement accuracy was ± 2cm. This allowed to obtain a very precise georeferencing of point clouds, where the average RMSEXY point position error was ± 3cm for the cloud processed in Agisoft PhotoScan and in PIX4D. The RMSEZ position error for the point clouds from the flight over 40 meters was ± 2cm.

The paper gives a look at the problem of the accuracy and the quality of point clouds from modern photogrammetric systems.

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1. INTRODUCTION

Building Information Modeling (BIM) is a very broad term that describes the process of creating and managing digital information about an object throughout its lifecycle. The BIM concept, in addition to its wide application in the new construction sector, is increasingly used in relation to existing buildings, including historic buildings. The term hBIM is therefore related to the acquisition of data for the purposes of BIM for cultural heritage objects. Currently, the main source of data used for hBIM modeling of existing facilities is still laser scanning technology, therefore determining the minimum scanning resolution to ensure the appropriate level of detail and accuracy of the hBIM model is crucial. (Fryskowska and Stachelek, 2018).
Existing legal standards (eg. COBIM) describe every aspect of BIM modeling. In this model, the following data accuracy requirements were proposed: error in determining the point location <1cm and the resolution of the point cloud <0.5 cm. In hard-to-reach places, scanning can be supplemented with data from other post-military methods. (Owersko and Pęczek, 2016). Therefore, in a situation where certain parts of the building (roof, higher parts) are often impossible to obtain with this technology. Currently, unmanned aerial vehicles (UAVs) are becoming more and more popular in photogrammetry. The use of UAV significantly facilitated the acquisition of image data for photogrammetry, while reducing the cost of their acquisition. Photogrammetry from unmanned platforms fills the gap between photogrammetric or remote sensing ground, aerial and satellite measurements, complementing the existing measurement methods. (Wierzbicki et al., 2015; Karabin et al., 2021; Hejmanowska et al., 2018).
The aim of the article was to compare the data obtained from the unmanned aerial vehicle (UAV) and from the terrestrial laser scanning (TLS). Point clouds were generated on the basis of UAV image data and acquired with a Faro Focus scanner. UAV data were acquired at different flight altitudes and generated using different parameters. TLS point clouds were compared with UAV clouds for data completeness. The accuracy of the mapping of such elements as the basement of the building, the interior of the building or the upper parts of the building was checked. Then, analyzes were carried out in terms of geometric consistency of the object mapping on the TLS and UAV data. The following subjects were analyzed: the accuracy of georeferencing of point clouds obtained for a historic object, various measurement methods, as well as 3D consistency of the structure's geometry. The results of the research can be valuable information for planning to scan an object in order to develop a BIM model with the given accuracy and detail.

2. MATERIALS AND METHODS

The facility where the research was conducted is located in Warsaw in the Warsaw-Wilanów district. The area in which the facility is located is located between Lake Wilanowskie, the Wilanówka River and the Sobieski Canal. This area is part of the Morysin nature reserve. The building is the remains of a neo-gothic gate from the 19th century. The gate was built in 1846 on the initiative of August Potocki. The design of the gate and the adjoining watchman's apartment was made by Henryk Marconi (Fijałkowski, 1975). The gate, like most historic buildings in Warsaw, did not survive the war in 1944 and has not been rebuilt to this day.

Figure 1. Neo-Gothic gate, state from before 1939 on the left (Fijałkowski, 1975) and the present state (UAV image)

The facility is difficult to access and in very poor condition. In order to protect it from further destruction, a steel structure was used to keep the elements in place. The purpose of the measurements is the digital reconstruction of the object, which can be the basis for creating a *scan-to-BIM* 3d model for the needs of hBIM.

Clouds of points from photos were generated in Agisoft Photoscan and Pix4D. In both cases, the Semi-Global Matching (SGM) algorithm was used, which generates tie points based on the comparison of individual pixels of the photos. Thanks to this algorithm, it is possible to obtain a point cloud of high quality and resolution (Hischmuller, 2011).

2.1. UAV-image data

A semi-professional UAV produced by the DJI company was used to perform the flight. The Phantom 4 pro model, which is equipped with a 20 megapixel camera with a 1 ”CMOS sensor. The focal length of the lens in this model is 24 mm. The camera was mounted on a 3-axis gimbal with a precision of ± 0.03°, which compensates for the tilt and vibrations caused by the UAV movement. (net1)

2.1.1 Design of the photogrammetric flight time and photogrammetric control network

The DroneDeploy application was used to plan the photogrammetric flight. Image data was obtained from three heights of 40, 60 and 90 meters to check whether the flight height will affect the quality of the generated point cloud. As a result of the change in altitude, also such flight parameters as: time, number of photos taken and terrain pixel size (GSD) have changed. The parameters of all scheduled flights are presented in the table 1. UAV flights were made at three heights: 40 m; 60 m and 90 m.

Table 1. Parameters of different flights.

PARAMETER	FLIGHT I	FLIGHT II	FLIGHT III
No of pixels	4864 x 3648	4864 x 3648	4864 x 3648
Focal lenght [mm]	24	24	24
GSD [cm]	1.2	1.8	2.7
Flying height [m]	40	60	90
Flight time [mm:ss]	9:49	7:11	5:49
No pf images	176	103	67
Side overlap [%]	90	90	90
Frontal overlap [%]	90	90	90

Fluorescent paint was used to mark the ground control points (GCP) around the object, and dots were painted on the flat ground, cleared of plants. It was assumed that the photo points had the shape of a cross with dimensions of 50x50 cm and a thickness of about 2 cm (Figure 2).

Figure 2. Ground control points network

The designed matrix was measured with the GPS device - Leica GS15 VIVA, measuring 30 epochs on each of the points. In order to obtain a better accuracy of the determination of the measurement network points, a second GPS measurement was performed. The coordinates of the points were measured with an accuracy of 2-5 cm. The detailed arrangement of photo points is shown in Figure 2.

2.2 Terrestrial Laser Scanning data

The object was measured using a Faro Focus terrestrial scanner. Over 7 million points were obtained with an average resolution of about 1.5 cm (6x quality). The orientation of the scans from 12 positions was made with an accuracy of 1 cm, for a maximum error of ± 2 cm. The next stage of compiling the data from the TLS was assigning a frame of reference to the generated cloud of points.

Figure 3. TLS point cloud

In order to geo-reference the cloud of points obtained with the TLS method, the measurement of the characteristic elements of the object was performed. A Leica TS09 plus 2 ”R500 total station was used for the measurement. The tie points were measured with the GPR1 mirror, while the elements of the object were measured using the reflectorless method. The indirect orientation process was performed in the CloudCompare software on the basis of data obtained as a result of a tachymetric measurement made in the system 2000 zone 7 (code EPSG 2178). As a result of the indirect orientation process, the orientation process accuracy expressed in RMSE was obtained, which in this case is ± 6 cm.

3. COMPARATIVE ANALYSIS AND RESULTS

The point clouds from the photos were developed in Agisoft Photoscan and Pix4D. The program uses the Semi-Global Matching (SGM) algorithm, which generates binding points based on the comparison of individual pixels of photos. Thanks to this algorithm, it is possible to obtain a point cloud of high quality and resolution (Hischmuller, 2011; Osińska-Skotak et al., 2019).

Table 2 shows the obtained accuracies in determining the coordinates of the points for both studies.

Table 2. Accuracy of points for both methods

	Flight height [m]	**RMSE XY [m]**	**RMSE Z [m]**
	Agisoft Photoscan		
1	40	0.03	0.02
2	60	0.06	0.19
3	90	0.08	0.15
	Pix4D		
1	40	0.03	0.02
2	60	0.06	0.19
3	90	0.08	0.15

Figure 4 shows a summary of the generated point clouds for the flights from different heights. This resulted in point clouds of varying accuracy and completeness.

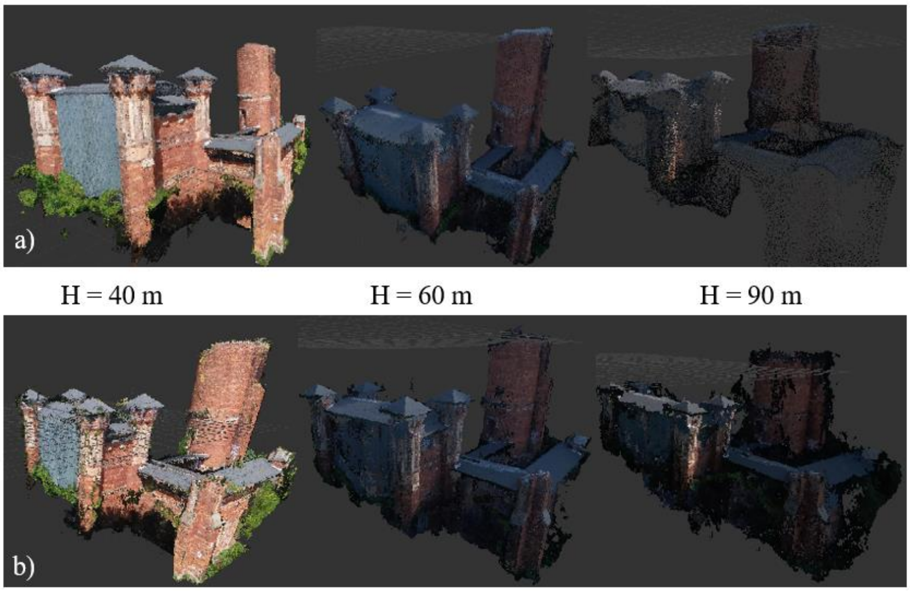

Figure 4. Imagery-based point clouds from different heights: a) for Agisoft b) for Pix4D

The following analyzes and results concerned the determination of the completeness of the generated products and comparison with the information content presented by TLS.

4. RESULTS

The comparative analysis was first performed for point clouds generated in various software. It was observed that the generated point clouds by Agisoft and PIX4D software differently represent points on linear elements. The edges generated in the PIX4D software are very noisy which can be observed, among others, at the edges of the chimney (Fig. 5).

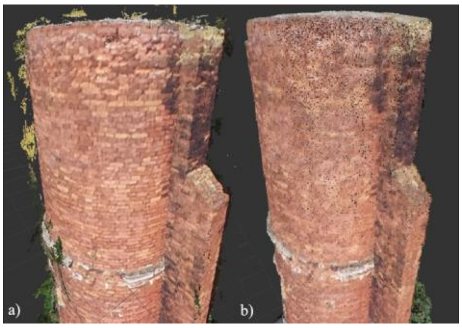

Figure 5. A fragment of a point cloud showing a fragment of a chimney (a) PIX4D (b) Agisoft Photoscan.

As can be seen in Figure 5a, the point cloud obtained with Pix4D, even though I also use the SGM algorithm, creates a lot of undesirable points, in the form of noise, at the edges of the linear elements. The point cloud from the PIX4D software requires additional manual filtration, because the use of automatic filtration methods may result in excessive removal of points that correctly represent the object. In the case of the Agisoft Photoscan cloud (Figure 5b), no erroneously generated points at linear elements were found.

Then, the point clouds of imaging origin were compared against the s = terrestrial laser scanning data. The main difference between the TLS point cloud and the UAV is the mapping of the roofs. The ground scanning maps the visible lower layers of the roof, while the image data obtained from the height map the top layer of the roofing. The differences in the generated cloud of the roof fragment can be seen in Figure 6.

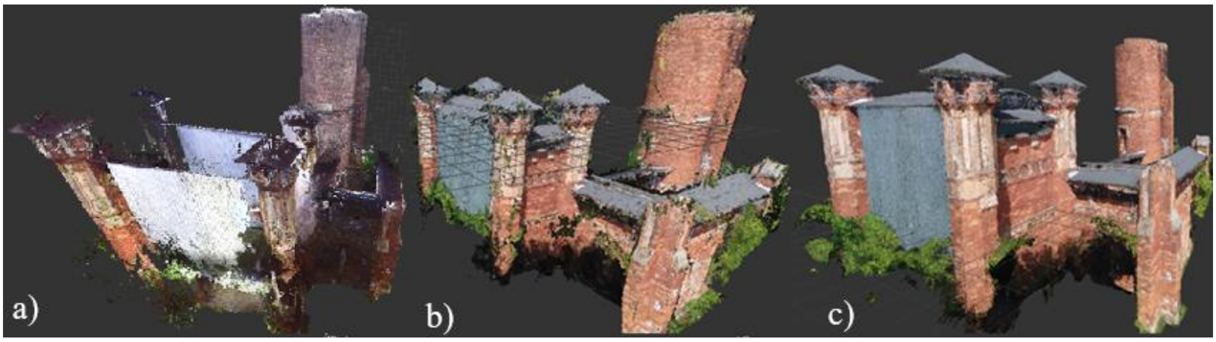

Figure 6. General view of point clouds obtained using: a) TLS b) image data obtained from UAV developed in PIX4D, c) image data obtained from UAV developed in Agisoft.

In addition, the difference of point clouds obtained from TLS and UAV was obtained by generating a difference model in the CloudCompare software. The results of the differential models are shown in Figure 7.

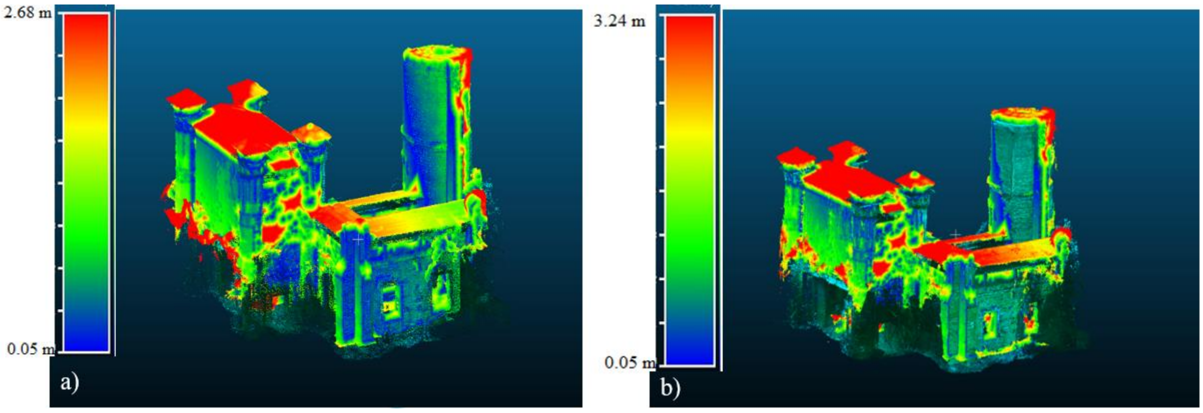

Figure 7. Differential models of point clouds: a) TLS and UAV Agisoft) TLS and UAV PIX4D

The red color on the models of differential point clouds of TLS and UAVs are marked points that are more than 2 meters apart between the clouds. (Figure 7a and Figure 7b), As can be seen in Figure 7, the red color corresponds to the points that were not mapped to the TLS (roofs and chimney).

Another difference is the incompleteness of the point cloud with the TLS resulting from the too close proximity of the scanning station to the object. An example of the incompleteness of the TLS cloud on the example of a selected object element and its mapping on the UAV cloud is shown in Figure 8. TLS, it also has a problem with mapping tall elements such as a chimney as shown in Figure 9.

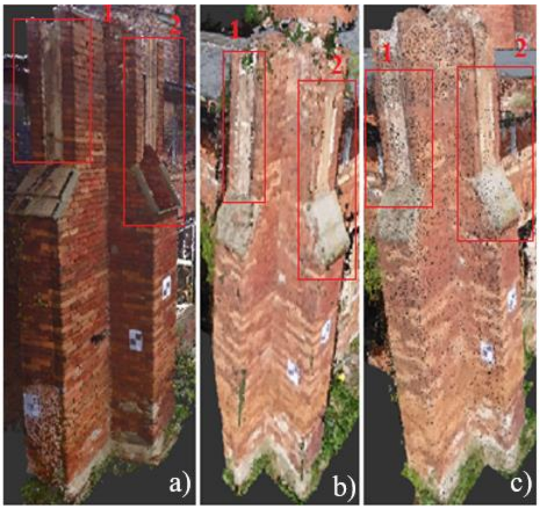

Figure 8. Mapping a building element on the cloud a) TLS b) PIX4D c) Agisoft

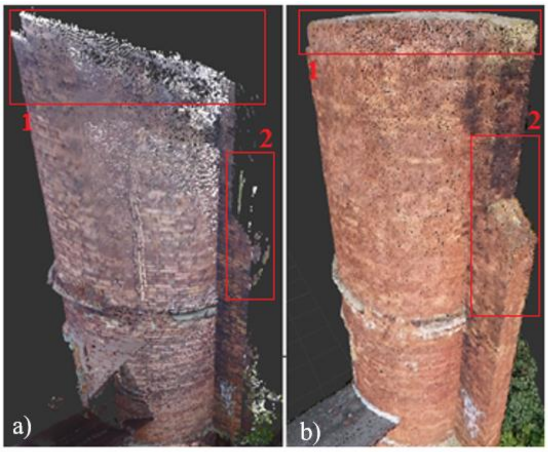

Figure 9. Incomplete representation of a tall object on the example of a chimney a) TLS b) Agisoft

4.1 Measurements of the characteristic elements of building

After preliminary visual analyzes of point clouds, aimed at selecting the best generated data for later analyzes, the measurement of the length of the characteristic elements of the object was started. Among other things, the length of the roofs, the cornice and the window opening were measured. Selected elements for measurements are shown in the figure 10.

Figure 10. Measurement of the characteristic linear elements of the object on the example of the TLS cloud

The results of measurements of the length of linear elements are summarized in Table 3. As can be seen, the highest value of the difference in lengths was obtained for the highest roofs. This is due to the fact that the TLS did not accurately reproduce very high elements such as the roof.

Table 3. Measured lengths of the rope elements of the building with differences between individual point clouds

	TLS [m]	**AGISOFT [m]**	**PIX4D [m]**	**TLS - AGISOFT [m]**	**TLS - PIX4D [m]**	**AGISOFT- PIX4D [m]**
1	1.73	1.61	1.62	0.12	0.11	-0.01
2	1.43	1.65	1.69	-0.22	-0.26	-0.04
3	3.63	3.56	3.56	0.07	0.06	0.00
4	0.63	0.60	0.60	0.03	0.03	0.00
5	6.23	6.25	6.25	-0.02	-0.02	0.00
6	2.27	2.18	2.18	0.09	0.09	0.00

In addition, the lengths of characteristic elements calculated on the basis of total station measurement data were compared with their equivalents on the TLS and UAV point clouds. The results of the obtained analysis are presented in Table 4.

Table 4. Analysis of the length of linear elements measured by total station and on TLS and UAV point clouds

	Linear element (D)				**ΔD**		
	Total station (TACH) [m]	**AGISOFT [m]**	**PIX4D [m]**	**TLS [m]**	**TACH - AGISOFT [m]**	**TACH- PIX4D [m]**	**TACH - TLS [m]**
1	0.47	0.47	0.47	0.48	0.00	0.00	-0.01
2	0.46	0.45	0.46	0.47	0.01	0.00	-0.01
3	0.39	0.38	0.38	0.40	0.02	0.01	-0.01
4	0.37	0.35	-	0.39	0.03	-	-0.02
5	0.48	0.47	0.48	0.48	0.01	0.00	0.00
6	0.47	0.49	0.47	0.48	-0.02	0.00	-0.01
7	0.43	0.42	0.45	-	0.01	-0.02	-
8	0.51	0.50	0.49	-	0.01	0.03	-
9	0.78	0.78	0.78	0.79	0.00	0.00	-0.01
10	0.77	0.78	0.77	0.76	-0.01	0.00	0.01
11	0.59	0.60	0.60	0.63	-0.01	-0.01	-0.04
12	2.19	2.19	2.16	2.18	0.00	0.03	0.01

Then, the accuracy of the geometric representation of the object was determined, which was defined by the mean square error of measurement of linear elements. The following formula is used to determine this parameter:

$$RMSE_D = \sqrt{\frac{[\Delta D^2]}{n}} \quad (1)$$

where $RMSE_{D,}$ - mean square error of linear measurments of the construction, $[\Delta D^2]$ – the sum of squared deviations of the measured lengths of the object's elements and n- the number of measured elements. The accuracy of the geometric consistency of the generated point clouds was determined. The parameter values for the TLS and UAV clouds are presented in Table 5.

Table 5. Accuracy of the geometric consistency of the object on point clouds (TLS and UAV)

Parametr	**UAV**		**TLS**
	Agisoft	**PIX4d**	
Accuracy of geometric consistency	0.01 m	0.01 m	0.02 m

Satisfactory accuracy was obtained for each of the clouds. The obtained values prove that the tested object was correctly mapped on the TLS and UAV clouds. The difference between the parameters for UAV and TLS clouds of ± 1 cm is due to an observer's error when measuring one of the lengths.

4.2 . Georeferencing - quality

The next stage of the analysis was to perform a comparative analysis of the coordinates of the characteristic points of the object. For this purpose, 20 points were selected on the object. Based on the coordinates of the selected points, the RMSE XY and Z calculations were performed. The obtained mean square errors and the data necessary for their calculation are presented in Table 6.

Table 6. RMSE of comparison for point clouds obtained from TLS and UAV image data

	TLS-AGISOFT			**TLS-PIX4D**			**AGISOFT-PIX4D**		
	ΔX [m]	**ΔY [m]**	**ΔZ [m]**	**ΔX [m]**	**ΔY [m]**	**ΔZ [m]**	**ΔX [m]**	**ΔY [m]**	**ΔZ [m]**
RMSE	0.08	0.08	0.86	0.05	0.15	1.07	0.04	0.05	0.34
RMSE XY	0.11			0.15			0.06		

As can be seen from the data in Table 6, the comparison of the coordinates of the characteristic points between TLS and UAV clouds is subject to a large error. The coordinates of the horizontal position are determined with an accuracy of ± 0.11 m and the height coordinates of ± 0.95 m. Comparing the georeference between UAV clouds, very small values of the average error of the horizontal and vertical position were obtained. The average error of the horizontal position between the points of two UAV clouds is ± 0.06m and the vertical position error is ± 0.34m. In conclusion, the accuracy and geometric coherence of point clouds is very high, and errors in georeferencing result from the accuracy and selection of reference points for the transformation.

5. CONCLUSIONS

On the basis of the conducted experiments, it was found that modern UAV platform can deliver geometric information about histpric structures. Of course with limited accuracy.
The geometric consisteny of point clouds geberated on the basis of low-cost UAV imagery is very high, nevertheless accuracy of georeferencing is still a challenge for post processing stage. Georeference of image data from UAV was made on the basis of data from the GPS/INS module and a photogrammetric matrix set up in the vicinity of the facility, where GPS measurement was not difficult and the measurement accuracy was ± 2 cm. It allowed to obtain a very precise georeferencing of point clouds, where the average RMSEXY point position error was ± 3 cm for the cloud developed in Agisoft PhotoScan and in PIX4D. The RMSEZ position error for the point clouds from the flight over 40 meters was ± 2 cm.
The method of obtaining information on georeferencing for objects that are difficult to access using UAV, despite the lack of detail in the internal parts of the object, is a much more accurate method and requires less work.

REFERENCES

Fijałkowski W., 1975, *Wilanów*, RSW Prasa-Książka-Ruch, Warszawa

Fryskowska, A.; Stachelek, J., 2018,A no-reference method of geometric content quality analysis of 3D models generated from laser scanning point clouds for hBIM. J. Cult. Herit. 2018, 34, 95–108

Hejmanowska B., Mikrut S., Głowienka E., Struś A., Michałowska K., 2018, 4D Models in World Wide Web. Baltic Geodetic Congress (BGC Geomatics). DOI: 10.1109/BGC-Geomatics.2018.00007

Hischmuller h., 2011, *Semi-Global Matching – Motivation Developments and Applications*, Conference: Photogrammetric Week, Berlin

Karabin M., Bakuła K., Łuczyński R., 2021, Verification of the Geometrical Representation of Buildings in Cadastre Using UAV Photogrammetry, Geomatics And Environmental Engineering, Vol. 15, Number 4, https://doi.org/10.7494/geom.2021.15.4.81

Osińska-Skotak Katarzyna, Jełowicki Łukasz, Bakuła Krzysztof, Michalska-Hejduk D., Wylazłowska J., Kopeć D., 2019, Analysis of Using Dense Image Matching Techniques to Study the Process of Secondary Succession in Non-Forest Natura 2000 Habitats , Remote Sensing, vol. 11, no. 8, pp. 1-28, DOI:10.3390/rs11080893

Owerko T., Pęczek W., 2016m Geometics for BIM, Gliwice

Wierzbicki, D.; Kedzierski, M.; Fryskowska, A., 2015, Assesment of the influence of UAV image quality on the orthophoto production. In Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Toronto, Canada, 30 August–2 September 2015.

Netography:

(net1) https://knowledge.faro.com/Hardware/3D_Scanners/Focus/Checkerboard_Registration_Targets_Download_for_the_Laser_Scanner_or_Hand-Held_Scanner

BIOGRAPHICAL NOTES

Anna Fryśkowska-Skibniewska – Graduate from the Military University of Technology in Warsaw, Poland. She received the PhD degree in geodesy and cartography in 2013 and Habilitation degree in 2019. Her work is centered around developing and integrating innovative methods and approaches to acquiring and processing pohotogrammetric geodata. Broadly, her methodological research focuses on application of modern photogrammetic systems in mapping, environmental and cultural heritage fields. Dr. Fryskowska works on photogrammetric products accuracy, comparative effectiveness research, and image data processing. She co-leads the science labs, study programmers where she coordinates educational process.

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