

UAV-based verification and updating of the BDOT500 topographic database

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Summary

The study investigates the applicability of lowcost unmanned aerial vehicles (UAVs) for the verification and updating of the BDOT500 topographic database – one of the key components of the national spatial information infrastructure in Poland. The research focused on evaluating whether data acquired using lowaltitude photogrammetry can meet the accuracy requirements necessary for updating objects classified within the first group of terrain details. Photogrammetric imagery was collected using a DJI Mini 3 Pro UAV at three flight altitudes – 50 m, 75 m, and 100 m – and subsequently processed in Agisoft Metashape Professional to generate orthophotomosaics, dense point clouds, and digital terrain models (DTMs). Verification of BDOT500 content was performed in Bentley MicroStation V8i by comparing existing database objects with the orthophotomap and identifying discrepancies such as outdated, incorrectly located, or missing features. Additionally, elevation values from the BDOT500 were compared with DTMderived values to assess vertical accuracy. The results demonstrated that UAV data acquired from 50 m and 75 m meet the accuracy thresholds required for firstgroup terrain details, with the 75 m altitude providing the most favorable balance between precision, flight duration, and processing workload. The use of dense point clouds further enabled a precise vectorization of complex terrain features, improving the geometric representation of selected objects. The findings confirm that lowcost UAV platforms can effectively support the updating of BDOT500 by rapid acquisition of highresolution spatial data, reducing fieldwork requirements, and increasing the overall efficiency of topographic database maintenance.

Keywords

UAV photogrammetry • BDOT500 • digital terrain model (DTM) • orthophotomosaic • ground control points (GCP)

1. Introduction

The dynamic development of geospatial technologies, particularly evident in recent decades, has greatly expanded the use of digital spatial databases across a wide range of practical and scientific applications. Contemporary spatial information systems form the basis for the functioning of public administration, spatial planning, environmental management, and technical infrastructure. As one of the key components of spatial information infrastructure, topographic data enables the integration of information derived from various sources for comprehensive use in spatial analyses and thematic studies [Longley et al. 2015, Burrough et al. 2015].

In the national context, particular importance is given to the state geodetic and cartographic registers, which together form a coherent territorial information system. One of the system's core components is the Topographic Objects Database (BDOT500), operating alongside such registers as the Land and Buildings Register (EGiB) and the Geodetic Register of Utility Networks (GESUT) [Gaździcki 2003]. BDOT500 serves as a reference spatial dataset with a high level of detail, forming the basis for the preparation of the base map as well as for numerous analyses and specialized studies. Consequently, the quality of the data stored in this database directly affects the reliability of cartographic products and the decisions made on their basis. In accordance with ISO 19157-1:2023, geospatial data quality can be described using factors such as completeness, logical consistency, positional accuracy, thematic accuracy, temporal quality, and usability.

The BDOT500 database contains detailed information on topographic objects located on the Earth's surface, including their location, geometry, descriptive attributes, and spatial relationships. The thematic scope of the database includes, among others, transport networks, buildings, utility infrastructure elements, land cover, and terrain morphology [Olszewski 2009]. The structure and maintenance principles of BDOT500 are defined in the applicable legal acts, particularly in the Regulation of the Minister of Development, Labour and Technology of 23 July 2021, which introduced significant changes regarding object classification and data organization [Regulation 2021]. These changes aimed to improve system consistency and adapt it to the contemporary needs of spatial data users.

Despite legislative and organizational efforts, ensuring data timeliness remains one of the most significant problems associated with the functioning of BDOT500. Data are acquired and updated using various methods, such as field surveys, digitization of archival materials, or integration with other databases. In practice, this often leads to discrepancies between the actual state of land development and the database records, which may negatively affect the quality of spatial analyses and decision-making processes [Bielecka et al. 2014]. Therefore, the processes of verifying and updating topographic data are becoming increasingly important.

Verifying and updating spatial databases requires a systematic comparison of the data stored in the register with the actual state of land development, along with the addition of appropriate geometric and descriptive corrections [Konecny 2014]. The traditional approach to these processes is based on classical geodetic surveys and field inspections, which despite their high accuracy, are time-consuming and costly, especially for large areas [Ajayi and Oruma 2022]. These limitations mean that data updates do not always keep pace with the dynamic changes in geographical spaces.

In response to these challenges, modern remote sensing techniques that enable rapid and efficient acquisition of spatial data over large areas are becoming increasingly important. The most significant of these include aerial photogrammetry, laser scanning, and satellite imagery [Baltsavias 1999]. In recent years, particular attention has been paid to developing low-altitude photogrammetry performed using unmanned aerial vehicles (UAVs).

Unmanned aerial vehicles are currently one of the most rapidly developing tools for acquiring geospatial data. They can capture imagery with very high ground sampling resolution (GSD of several centimeters), while maintaining relatively low operational costs and short mission execution times [Colomina and Molina 2014, Nex and Remondino 2014]. Compared with conventional aerial photogrammetry, UAV systems demonstrate greater flexibility in flight planning and the capacity to conduct surveys over small areas, while reducing formal requirements [Eisenbeiss 2009]. Due to these characteristics, UAV systems are widely applied in engineering geodesy, cartography, environmental monitoring, archaeology, and crisis management [Pajares 2015].

In the context of topographic databases, the possibility of generating advanced photogrammetric products, such as orthophotomaps, digital terrain models (DTM), digital surface models (DSM), and three-dimensional point clouds gives the UAV technology an important advantage [Remondino et al. 2012]. These products may constitute a valuable source of information used both in verification and updating processes of spatial data.

A key issue related to the application of UAV data in geodesy, however, is meeting the accuracy requirements specified in applicable regulations and technical guidelines. The accuracy of photogrammetric products is influenced by many factors, including camera parameters, flight altitude, image overlap, the quality of photogrammetric control networks (GCPs), image orientation methods, and the data processing algorithms [James and Robson 2014]. Research results suggest that proper flight planning and a right distribution of control points can achieve accuracy comparable to classical surveying methods [Siebert and Teizer 2014, Deliry and Avdan 2021]. At the same time, the necessity of evaluating the quality of acquired data and their suitability for specific applications is emphasized in each case [Nex and Remondino 2014].

Contemporary directions in the development of geodesy and cartography indicate the growing importance of automating spatial database updating processes, integrating multi-source data, and utilizing three-dimensional technologies [Biljecki et al. 2015]. Solutions that enable the rapid detection of land development changes and the semi-automatic updating of the geometry and attributes of topographic objects are becoming

crucial [Ajayi and Oruma 2022]. In this context, data acquired from unmanned aerial vehicles complement traditional methods, increasing the frequency of data updates and improving their quality, while optimizing costs and work execution time [Božek et al. 2023, Dorož et al. 2024].

Therefore, using low-altitude photogrammetry to verify and update BDOT500 is consistent with the concept of a modern spatial information system. The key aspects of such a system are timely data, high spatial resolution, and the ability to reuse data for various analyses and thematic studies.

2. Research objectives and workflow

The aim of this study was to analyze the potential for using a low-cost unmanned aerial vehicle (UAV) to verify and update the BDOT500 Topographic Objects Database. Particular attention was paid to assessing of the usefulness of data acquired using low-altitude photogrammetry for identifying inconsistencies in the existing database and for introducing geometric changes to topographic objects.

The research included a thorough process of acquisition, processing, and analysis of geospatial data. In the first stage, photogrammetric flights were carried out using an unmanned aerial vehicle to acquire a set of high-resolution digital images. The data were then processed in the Agisoft Metashape Professional software for image orientation, point cloud generation, and the development of an orthophotomap and a digital terrain model.

The next stage of the research involved a verification of the BDOT500 database content by comparing it with the developed orthophotomap. This was performed in the Bentley MicroStation V8i environment, where discrepancies concerning the presence, absence, location, and geometric representation of selected BDOT500 objects were identified by comparing the database vectors with the orthophotomap. On this basis, the geometry of selected objects was corrected, missing objects identifiable in the imagery were added, and objects that were no longer present in the field were removed from the working vector dataset.

Another element of the analysis focused on assessing the vertical accuracy of the data by comparing elevation values obtained from the BDOT500 database with those derived from the digital terrain model generated from UAV data. This analysis was conducted in the QGIS environment, enabling the quantitative evaluation of elevation differences and the determination of the suitability of the photogrammetric data for geodetic applications.

The adopted research workflow was designed to evaluate the potential use of a low-cost UAV platform for verifying and updating the BDOT500 data geometrically, with particular emphasis on the applicable positional accuracy requirements.

3. Changes in the structure and content of the BDOT500 database

The new regulations concerning the scope and methods of collecting data on spatial objects were introduced in Polish legislation through the Regulation of the Minister of Development, Labour and Technology of 23 July 2021 on the topographic objects database and the base map. These changes had a significant impact on the structure and content of databases used within the national geodetic and cartographic resource.

One of the key modifications involved the transfer of certain objects that were previously included in the Land and Buildings Register (EGiB) to the BDOT500 Topographic Objects Database. As a consequence, the BDOT500 object catalogue was extended with a new layer of 'buildings not included in the land and buildings register and their associated structures.' This group includes, among others, buildings, above-ground and underground blocks, terraces, verandas, vestibules, stairs, ramps, underground entrances, and access ramps for people with disabilities.

According to the applicable regulations, objects that are not subject to geodetic as-built inventory surveys are not included in the land and buildings register. This applies, among others, to certain structures constructed on the basis of notification procedures. However, the changes introduced to the BDOT500 regulations indicate an attempt to limit this option by explicitly defining the scope of objects subject to registration.

Despite extending the thematic scope to include new object classes, the overall number of elements in the BDOT500 catalogue has been significantly reduced – from 113 to 73 items. At the same time, the objects were reorganized and new code designations were introduced in order to improve the structure, transparency, and functionality of the database.

As a result of these changes, several objects were removed from the catalogue, including tennis courts, cinder and bobsleigh tracks, ski jumps, port facilities (e.g., fenders, mooring dolphins, bollards), cranes, conveyor belts, stages, advertisements and information boards, fords, ferry crossings, drained areas, waterfalls, springs, marshes, wetlands, and reeds. Additionally, certain object classes were generalized by merging – for example, three types of technical reservoirs were combined into a single object category, similarly to various types of railway tracks.

These modifications reflect a tendency toward simplification and standardization of spatial databases, while increasing their consistency and adapting them to the contemporary needs of users of geographic information.

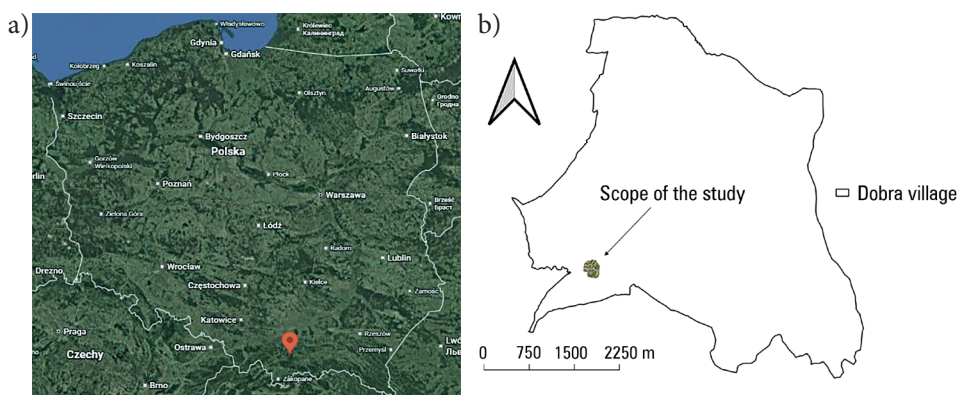
4. Study area

The research area this study was a 2.5 ha fragment of the village of Dobra, located in the south-western part of the Dobra cadastral district. The village of Dobra is situated in southern Poland, in the Małopolskie voivodeship, within Limanowa county, in the municipality of Dobra.

The study area is located in the north-western part of Limanowa county, in the central region of the Island Beskids mountain range. The village is situated in the valley

of the Łososina river and its tributary, the Porąbka stream. The spatial arrangement of buildings and agricultural land sees development extending along the wide valley floor and the lower parts of the surrounding slopes. In the immediate vicinity, there are characteristic peaks of the Beskid Wyspowy range, such as Łopień (951 m a.s.l.), Ćwilin (1072 m a.s.l.), and Śnieżnica (1006 m a.s.l.), which significantly influence the terrain morphology and local topographic conditions.

The national road No. 28 passes through the study area, and a part of this road was included in the research. Additionally, the defunct railway line No. 104, connecting Chabówka and Nowy Sącz, as well as a network of local roads, runs through the village of Dobra. As a result, the analyzed area exhibits diverse land use and the presence of various transportation infrastructure elements. The location and spatial extent of the study area are presented in Figure 1.



Source: Authors' own study

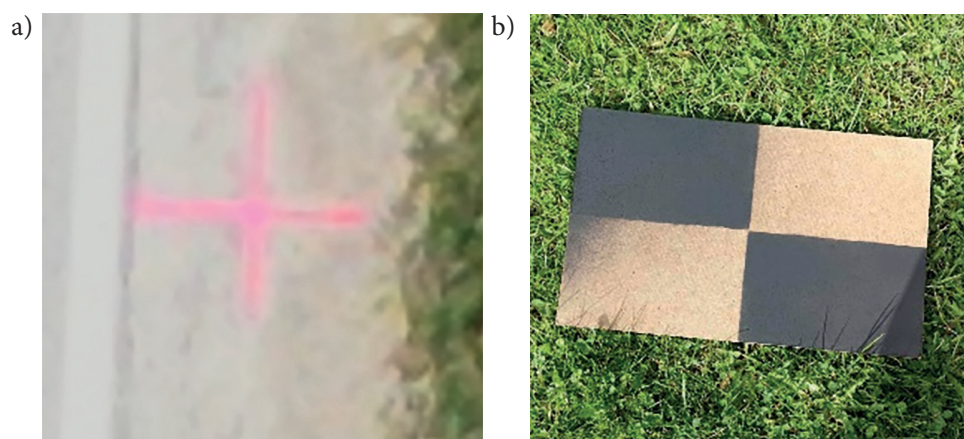
Fig. 1. Research site: a) Dobra village against the map of Poland, b) scope of the study against the map of Dobra village

5. Materials and methods

The study was based on low-altitude UAV photogrammetry performed using a low-cost DJI Mini 3 Pro platform. The input data consisted of high-resolution digital imagery acquired during automated photogrammetric flights. The measurement equipment used in the study also included a DJI RC N1 controller and a Trimble R2 GNSS receiver.

The first stage of the fieldwork involved measuring ground control points (GCPs), which had been previously marked in the field. In the roadway area, cross-shaped markings were applied, whereas in the remaining area, additional fibreboards fixed to the ground were used to ensure the stability and immutability of their position. Subsequently, control points were measured to assess the accuracy of the photogrammetric products during the office processing stage. The two types of field markers used as ground control points are presented in Figure 2.

The measurement of ground control points and control points was carried out using a GNSS receiver operating in RTK (Real Time Kinematic) technology. According to the manufacturer's specifications of the applied receiver, the nominal positioning accuracy was $10 \text{ mm} + 0.5 \text{ ppm}$ (RMS) for horizontal coordinates and $20 \text{ mm} + 0.5 \text{ ppm}$ (RMS) for the vertical coordinate. A session-specific RTK quality report containing actual measurement accuracy indicators, such as m_x , m_y , m_h or DOP values, was not archived. Therefore, the reported values should be interpreted as the manufacturer's nominal specifications rather than as the accuracy values empirically confirmed during the field survey. The accuracy of the photogrammetric control network measurements was a key factor in determining the quality of subsequent photogrammetric products.



Source: Authors' own study

Fig. 2. Types of ground control point (GCP) marking: a) marker, b) target

In the next stage of the study, automated photogrammetric flights were carried out using an unmanned aerial vehicle at three different altitudes: 50 m, 75 m, and 100 m. Flight mission planning was performed using the atomicMapper v.0.2 application to generate *.csv files containing detailed flight path parameters for each altitude. The flight plans developed for the three flight altitudes are presented in Figure 3.

The flights were conducted with the technical parameters of the UAV platform and the camera equipped with a 1/1.3" CMOS sensor. The most important system parameters included a real focal length of 6.72 mm, sensor width of 9.6 mm, and sensor height of 7.2 mm. The acquired images had dimensions of 4032×3024 pixels. The image capture interval was set to 3 seconds, with the UAV flight speed equal to 3.5 m/s. The camera was positioned in nadir orientation (gimbal tilt angle of -90°). Both longitudinal and transverse image overlap were established at 80%.

The adopted overlap values were determined by the terrain and atmospheric conditions. In particular, significant terrain elevation differences and variable weather

conditions required increased overlap to ensure adequate quality of the photogrammetric products.

The flights were performed using the Litchi Pilot application, into which the previously prepared *.csv files were imported. During the mission preparation stage, the parameters of the individual flights were verified and controlled to ensure consistency between the planned assumptions and the actual execution of the flights.

The main parameters of the three photogrammetric missions are summarized in Table 1.

Table 1. Flight plan parameters

UAV flight altitude [m]	Calculated Ground Sample Distance (GSD) [cm]	Flight distance [km]	Flight time [min]	Number of images acquired
50	1,70	2,3	16	160
75	2,62	2,0	14	127
100	3,61	1,5	11	77

Source: Authors' own study

The photogrammetric flights were carried out on 30 March 2024 under cloudless sky conditions, with an air temperature of approximately 17°C and strong wind conditions. The missions were performed during midday hours, which minimized the impact of long shadows on the quality of the acquired imagery.

The measurement data were processed in the form of digital images using specialized Agisoft Metashape Professional software. Within this environment, orthophotomaps were developed for the three flight altitudes: 50 m, 75 m, and 100 m. The data processing workflow included several stages characteristic of photogrammetric processing.

Initially, the image dataset was imported into the project and preliminary image alignment was performed. Then, ground control points (GCPs) were identified and measured on individual images to enable proper georeferencing of the data. In the next stage, a sparse point cloud was generated, followed by a dense point cloud, forming the basis for the development of spatial models. After each stage of generating a point cloud, erroneous and isolated points were removed by visual inspection and filtering. The cleaned dense point cloud was then classified in order to separate ground points from above-ground objects before generating the DTM.

Based on the obtained data, digital terrain models (DTMs) were generated for further processing. Each generated DTM had a spatial resolution of 0.10 m, corresponding to a grid cell size of 0.10 × 0.10 m. The next step was to develop orthophotomosaics for each flight altitude. The final stage of the work in the Agisoft Metashape environment involved quality control of the photogrammetric products by analysing the mapping accuracy based on control points. The geometric accuracy of the photogrammetric products was assessed using ground control points and independent checkpoints. The



Source: Authors' own study

Fig. 3. Flight mission plans developed in the Litchi Pilot application for flight altitudes of: a) 50 m - planned route length of 2.3 km and estimated flight time of 16 min; b) 75 m - 2.0 km and 14 min; and c) 100 m - 1.5 km and 11 min.

checkpoints were excluded from the photogrammetric adjustment and were instead used for an independent assessment of the accuracy of the resulting products. For each flight altitude, the root mean square errors in the east, north, and vertical directions, the total three-dimensional error, and the reprojection error were determined. The combined horizontal RMSE was calculated using the following formula:

$$RMSE_{XY} = \sqrt{RMSE_E^2 + RMSE_N^2} \quad (1)$$

where $RMSE_E$ and $RMSE_N$ - the root mean square errors in the east and north directions, respectively.

An example of the generated dense point cloud and the spatial distribution of the ground control points and independent check points are shown in Figure 4.



Source: Authors' own study

Fig. 4. Photogrammetric data processing results: a) dense point cloud and b) spatial distribution of ground control points (circles) and independent checkpoints (triangles) within the study boundary

6. Results and discussion

The results of the assessment of geometric accuracy obtained for the three flight altitudes are presented in Table 2. The results include errors calculated for both the ground control points used in the photogrammetric adjustment and the independent checkpoints used for accuracy verification.

At the independent checkpoints, the horizontal RMSE values were 0.026 m, 0.035 m, and 0.027 m for flight altitudes of 50 m, 75 m, and 100 m, respectively. The corresponding vertical RMSE values were 0.034 m, 0.040 m, and 0.035 m, while the total three-dimensional errors were 0.043 m, 0.053 m, and 0.044 m, respectively. In all three flight variants, the RMSE values of the east and north coordinate components were below 0.05 m, and the vertical RMSE values were below 0.07 m. Therefore, the coordinate accuracy requirements adopted in the study were satisfied for all three variants.

The maximum absolute deviations observed at the independent checkpoints were also compared with the adopted limits for a single point. For the flight variants conducted at altitudes of 50 m, 75 m, and 100 m, the maximum absolute east deviations were 0.019 m, 0.036 m, and 0.019 m, respectively. The corresponding maximum absolute north deviations were 0.032 m, 0.042 m, and 0.047 m, while the maximum absolute vertical deviations were 0.056 m, 0.058 m, and 0.077 m. All values were lower than the adopted

Table 2. Geometric accuracy of photogrammetric products obtained for individual flight altitudes

Flight altitude [m]	Point type	East RMSE [m]	North RMSE [m]	Horizontal RMSE [m]	Vertical RMSE [m]	Total 3D error [m]	Reprojection error [pix]
50	Control points	0.025	0.028	0.038	0.029	0.048	0.661
50	Check points	0.015	0.021	0.026	0.034	0.043	0.752
75	Control points	0.022	0.024	0.032	0.009	0.034	0.632
75	Check points	0.021	0.027	0.035	0.040	0.053	0.867
100	Control points	0.025	0.017	0.030	0.044	0.054	0.631
100	Check points	0.014	0.023	0.027	0.035	0.044	0.637

Source: Authors' own study

limits of 0.10 m for the horizontal coordinate components and 0.14 m for the vertical component. Considering the GSD values presented in Table 1, the variants conducted at altitudes of 50 m and 75 m also met the adopted GSD limit of 3 cm, whereas the 100 m variant, with a GSD of 3.61 cm, did not meet this criterion. Therefore, only the 50 m and 75 m variants fulfilled all the adopted positional accuracy and GSD requirements.

The horizontal and vertical RMSE values obtained in this study at the independent checkpoints (0.026–0.035 m and 0.034–0.040 m, respectively) are consistent with the level of accuracy reported for other UAV surveys employing dense and well-distributed ground control networks, where results comparable to classical surveying methods were achieved [Deliry and Avdan 2021]. This accuracy is notably higher than that reported by [Siebert and Teizer 2014] for UAV-based mapping of a large-scale earthwork site, where the horizontal accuracy achieved using UAV photogrammetry was found to be markedly lower than that of a reference total station survey. The vertical accuracy of the two methods was comparable. This difference may be attributed to the considerably smaller study area, denser and more evenly distributed ground control points, and RTK-supported control point measurements applied in the present study, in contrast to the extensive earthwork site examined in that study.

The comparison of the BDOT500 vector data with the UAV-derived orthophotomaps and point clouds enabled the identification of selected geometric discrepancies within the study area.

The study was not designed to perform a complete quantitative inventory of all changes occurring in the BDOT500 database within the study area. The analysis focused on selected objects representing different types of geometry and spatial characteristics. Therefore, a complete assessment of the number of added, removed, and modified objects, as well as a comprehensive analysis of displacements in the X and Y

directions, was not conducted. Such a quantitative assessment should be the subject of further research covering a larger area and a greater number of objects.

Verification of the BDOT500 data and editing of the geometry of selected objects were performed in the Bentley MicroStation V8i environment. The study did not involve direct editing of the complete GML database structure or all descriptive attributes. Instead, the BDOT500 vector layers were compared with the UAV-derived orthophotomap, and selected object geometries were corrected in the working dataset. The developed orthophotomap was overlaid with data layers derived from the BDOT500 database, which enabled direct comparison between the database content and the actual land development represented in the photogrammetric imagery.

Based on the conducted analysis, discrepancies were identified between the database records and the current land development conditions. Elements, whose geometry could be unambiguously determined from the orthophotomap, were updated by adjusting their geometry to the current terrain conditions. Objects whose location was inconsistent with reality or which no longer existed in the field were removed from the database. Examples of the geometric correction and updating of selected BDOT500 objects are presented in Figure 5.

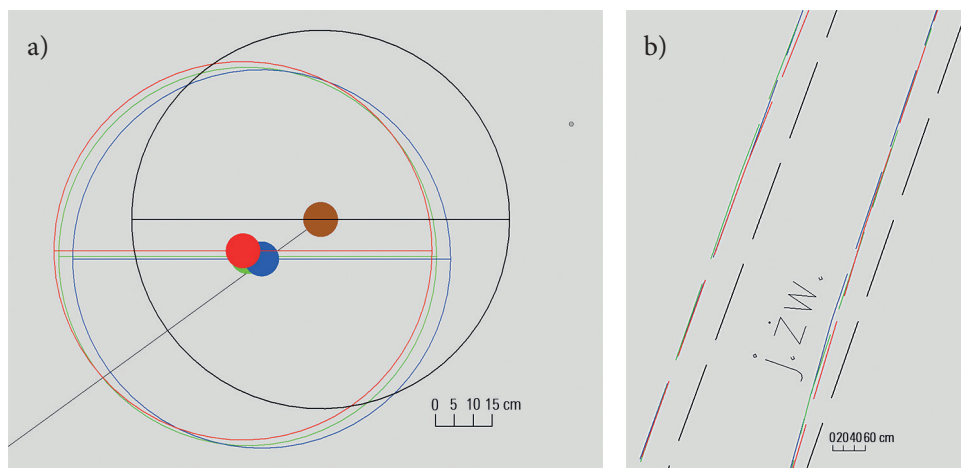
The conducted updating process improved the consistency between the BDOT500 database and the actual land development conditions in the analyzed area, confirming the usefulness of photogrammetric data in this type of study.



Source: Authors' own study

Fig. 5. Examples of updates to the BDOT500 database: a) paved surface, b) fence, c) carriageway surface

In order to assess the influence of flight altitude on the geometric interpretation of selected BDOT500 objects, the same features were digitized independently using orthomosaics generated from flights conducted at altitudes of 50 m, 75 m, and 100 m. The resulting geometries were then overlaid and compared with the existing BDOT500 geometry. The comparison included a circular feature and a selected linear road feature, as presented in Figure 6.



Source: Authors' own study

Fig. 6. Comparison of geometries digitized from orthomosaics generated for flight altitudes of 50 m (green), 75 m (red), and 100 m (blue) with the existing BDOT500 geometry (black): a) circular feature and b) road feature

The visual comparison showed that the general course and shape of the analyzed objects could be identified in all three orthomosaics. However, small differences were observed between the digitized geometries, particularly in the position of the object boundaries and the center of the circular feature. These differences stemmed from the varying spatial resolution and visual detail of the orthomosaics generated at different flight altitudes. The comparison also demonstrated that the existing BDOT500 geometry did not fully correspond to the geometries interpreted from the current UAV-derived imagery.

The BDOT500 database was also updated in the Bentley MicroStation V8i environment using a dense point cloud generated in Agisoft Metashape software. Based on the analysis of three-dimensional data, vectorization of selected terrain features was performed, particularly the course of the scarp, enabling a more precise representation of its geometry. The scarp geometry digitized using the orthomosaic is presented in Figure 7, whereas Figure 8 shows the same object against the dense point cloud.

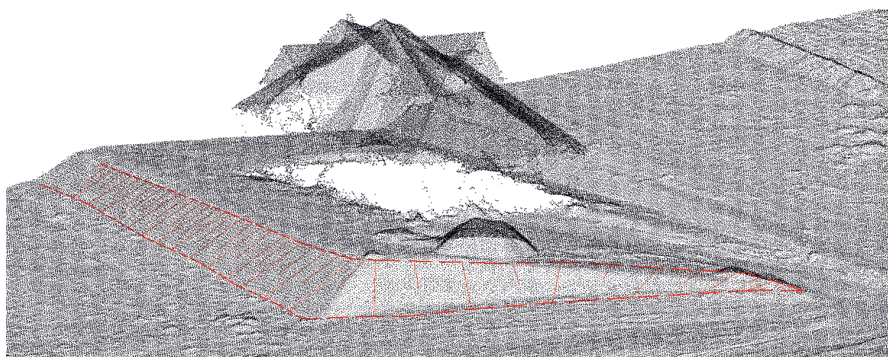
The conducted updating process improved the consistency between the working BDOT500 dataset and the actual land development conditions in the analyzed area, indicating a potential usefulness of photogrammetric data in this type of study.

The use of three-dimensional data, such as a dense point cloud, can facilitate the representation of complex terrain forms and extend the scope of possible analyses. Therefore, 3D data may constitute a useful supplementary source of information in the verification and geometric updating of topographic databases such as BDOT500.



Source: Authors' own study

Fig. 7. Digitized scarp against the orthomosaic background



Source: Authors' own study

Fig. 8. Digitized scarp against the dense point cloud

It was also demonstrated that the generated digital terrain model (DTM) can be used to obtain point elevation values. Differences between the DTM and BDOT500 data were compared.

In order to quantitatively assess the consistency of the elevation data, an analysis was performed to determine the difference between the elevation values derived from

the BDOT500 database and the data obtained from the DTMs generated for the individual flight altitudes. The elevation difference for each analyzed point was calculated using the following formula:

$$\Delta H_i = H_{\text{DTM},i} - H_{\text{BDOT500},i}$$

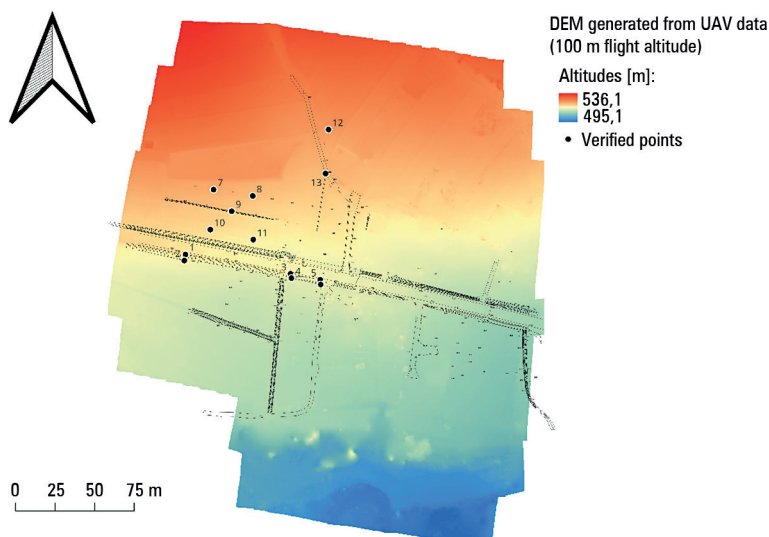
where:

- ΔH_i – the elevation difference for the i -th point,
- $H_{\text{DTM},i}$ – the elevation derived from the digital terrain model,
- $H_{\text{BDOT500},i}$ – the corresponding elevation recorded in the BDOT500 database.

Positive values indicate that the DTM elevation was higher than the BDOT500 elevation, whereas negative values indicate that the DTM elevation was lower.

The elevation comparison was based on 13 points distributed across the approximately 2.5 ha study area. Given the limited spatial extent of the case-study site and the comparative objective of the analysis, which was primarily to assess elevation differences between DTMs generated for three different flight altitudes, the adopted number of points was considered sufficient for an initial evaluation of vertical consistency within the analyzed area. Nevertheless, the limited sample size restricts the statistical representativeness and generalizability of the results. Further studies should therefore include a larger number of points covering both natural and artificial terrain features, as well as more extensive and spatially heterogeneous study areas.

The spatial distribution of the BDOT500 elevation points used in the comparison is shown in Figure 9.



Source: Authors' own study

Fig. 9. Location of analyzed BDOT500 points with DTM elevations

The elevation differences obtained for the DTMs generated from flights conducted at 100 m, 75 m, and 50 m are presented in Figures 10–12, respectively.

The stepwise character of the obtained elevation differences is due to the precision, with which the natural spot elevations were stored in the BDOT500 database (recorded to 0.1 m). Consequently, the calculated differences occur mainly in increments of 0.1 m. This reflects the precision of the source BDOT500 data and should not be interpreted as the vertical accuracy of the UAV-derived DTM.

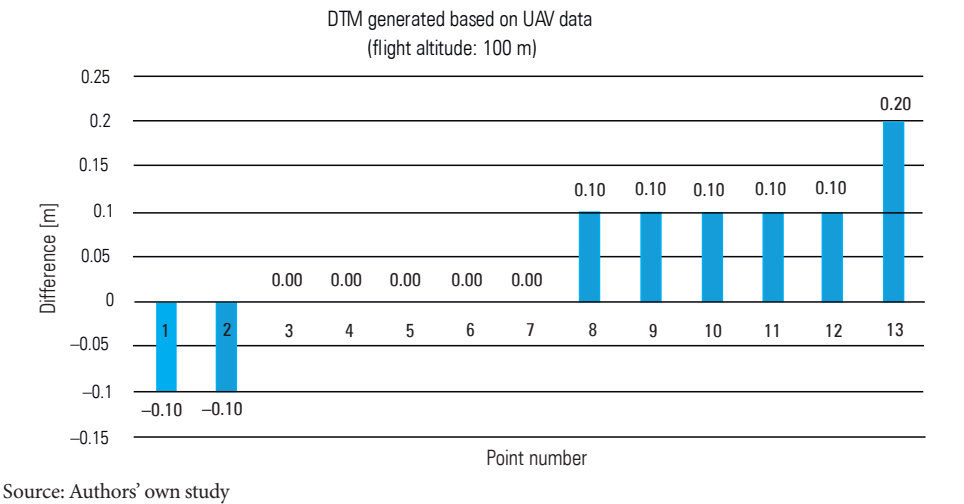


Fig. 10. Comparison of BDOT500 and DTM elevation data

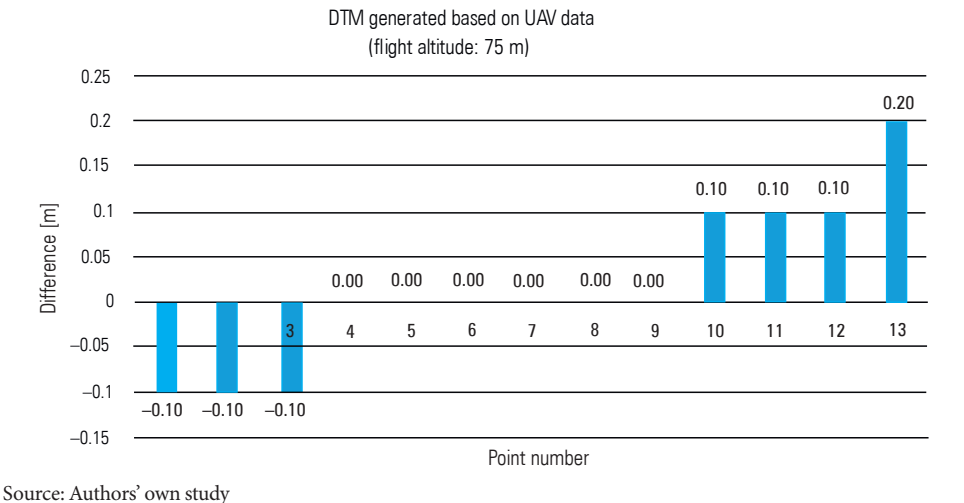
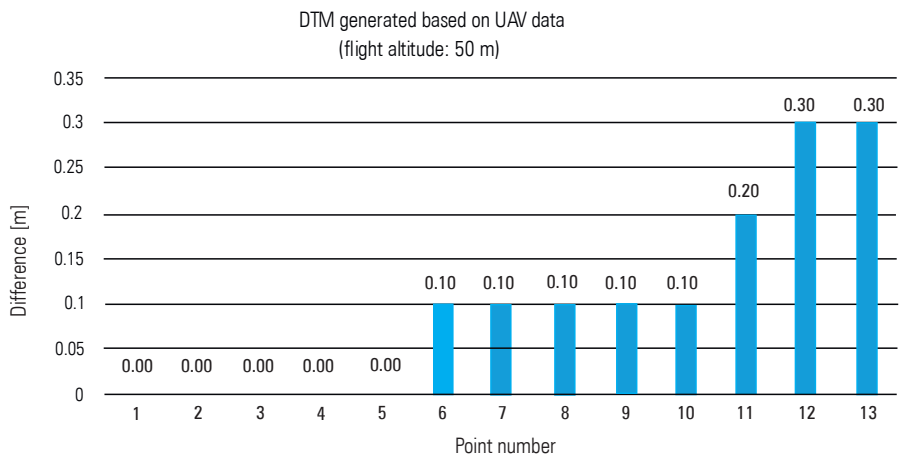


Fig. 11. Comparison of BDOT500 and DTM elevation data



Source: Authors' own study

Fig. 12. Comparison of BDOT500 and DTM elevation data

From an operational perspective, direct GNSS RTK/RTN surveying may be more efficient for small study areas where coordinates are required only for a limited number of objects, as it provides measurement results directly in the field without the need for subsequent photogrammetric processing. In contrast, the UAV-based workflow requires additional post-processing, including image alignment, point cloud generation, classification, and the development of an orthomosaic and a terrain model. However, this approach provides comprehensive and reusable spatial documentation covering the entire study area. Therefore, the relative efficiency of UAV photogrammetry and GNSS RTK/RTN surveying depends on the size and characteristics of the study area, the number and type of objects to be surveyed, and the range of required final products.

7. Conclusions

The research concluded that data acquired using a low-cost unmanned aerial vehicle can effectively complement the verification and geometric updating of the BDOT500 database. The developed photogrammetric products, particularly the orthophotomaps and terrain models, enable inconsistencies within the database to be identified, such as incorrect object locations, outdated objects, or missing elements in the register. At the same time, they allow the database to be supplemented with new, clearly identifiable elements and enable the correction of the geometry of existing objects.

The use of UAV-acquired data in geodetic studies, particularly with regard to objects classified within the first group of terrain details, requires compliance with the accuracy requirements specified in the applicable technical guidelines. According to these requirements, the ground sample distance (GSD) value should not exceed 3 cm,

while the root mean square errors of X and Y coordinates at control points should not exceed 0.05 m, and 0.07 m for the vertical coordinate Z. Additionally, the maximum absolute deviations for a single control point should not exceed the following values: $dx = 0.10$ m, $dy = 0.10$ m, and $dh = 0.14$ m.

Analysis of the results obtained using the DJI Mini 3 Pro platform demonstrated that all three flight variants met the adopted coordinate accuracy requirements. At the independent checkpoints, the horizontal RMSE ranged from 0.026 m to 0.035 m, while the vertical RMSE ranged from 0.034 m to 0.040 m. However, taking into account the ground sample distance requirement of no more than 3 cm, only the products obtained from flight altitudes of 50 m and 75 m fully met all the adopted criteria.

Of the variants that satisfied both the coordinate accuracy and GSD requirements, the flight altitude of 75 m provided the optimal balance between geometric accuracy and operational efficiency. Although the 50 m variant produced a lower total three-dimensional error at the independent checkpoints, amounting to 0.043 m compared with 0.053 m for the 75 m variant, the 75 m flight reduced the flight time from 16 to 14 minutes and the number of images acquired from 160 to 127.

The photogrammetric product obtained from the flight altitude of 100 m also met the adopted coordinate error limits, with a horizontal RMSE of 0.027 m and a vertical RMSE of 0.035 m at the independent check points. However, its calculated GSD of 3.61 cm exceeded the adopted limit of 3 cm. Therefore, this variant did not fully satisfy all the requirements assumed for updating objects belonging to the first group of terrain details.

In summary, low-cost UAV platforms can complement traditional surveying methods in the verification and geometric updating of topographic databases, as they provide comprehensive spatial documentation, including orthomosaics, point clouds, and terrain models. Their usefulness and operational efficiency depend on the size and characteristics of the study area, the required accuracy, the number and type of objects to be surveyed, the adopted flight parameters, and the time required for both field data acquisition and office processing.

References

- Ajayi O.G., Oruma E. 2022. On the applicability of integrated UAV photogrammetry and automatic feature extraction for cadastral mapping. *Advances in Geodesy and Geoinformation*, e19.
- Baltsavias E.P. 1999. Airborne laser scanning: Basic relations and formulas. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2–3), 199–214.
- Bielecka E., Leszczyńska M., Halls P.J. 2014. User perspective on geospatial data quality: Case study of the Polish Topographic Database. In: *Proceedings of the International Conference on Environmental Engineering (ICEE)*, vol. 9. Vilnius Gediminas Technical University.
- Biljecki F., Stoter J., Ledoux H., Zlatanova S., Çöltekin A. 2015. Applications of 3D city models: State of the art review. *ISPRS International Journal of Geo-Information*, 4(4), 2842–2889.
- Bożek P., Świątek Ł., Doroż A., Taszakowski J. 2023. Wykorzystanie danych z bezzałogowych statków powietrznych do aktualizacji i modernizacji geodezyjnych baz danych. *Przegląd Geodezyjny*, 95.

- Burrough P.A., McDonnell R.A., Lloyd C.D. 2015. Principles of Geographical Information Systems. Oxford University Press.
- Colomina I., Molina P. 2014. Unmanned aerial systems for photogrammetry and remote sensing: A review. *ISPRS Journal of Photogrammetry and Remote Sensing*, 92, 79–97.
- Deliry S.I., Avdan U. 2021. Accuracy of unmanned aerial systems photogrammetry and structure from motion in surveying and mapping: A review. *Journal of the Indian Society of Remote Sensing*, 49(8), 1997–2017.
- Doroż A., Bożek P., Taszakowski J., Janus J. 2024. Use of UAV imagery for land consolidation: analysis of the accuracy of the resulting orthophotomosaic in relation to the GNSS RTK measurement. *Applied Geomatics*, 16, 561–573.
- Eisenbeiß H. 2009. UAV Photogrammetry (doctoral dissertation), ETH Zurich.
- Gaździcki J. 2003. Systemy informacji przestrzennej. Wydawnictwo Naukowe PWN, Warszawa.
- Geoforum.pl. 2021. Zmiany w przepisach ws. BDOT500 i mapy zasadniczej. <https://geoforum.pl/news/30922/sporo-zmian-w-przepisach-ws-bdot500-i-mapy-zasadniczej>
- Goodchild M.F., Longley P.A., Maguire D.J., Rhind D.W. 2005. Geographic Information Systems and Science. Wiley, West Sussex.
- Główny Urząd Geodezji i Kartografii (GUGiK). 2025. Wytyczne techniczne w zakresie geodezyjnych pomiarów sytuacyjnych realizowanych z wykorzystaniem fotogrametrycznych platform bezzałogowych, w szczególności na potrzeby modernizacji ewidencji gruntów i budynków. Warszawa.
- James M.R., Robson S. 2014. Mitigating systematic error in topographic models derived from UAV and ground-based image networks. *Earth Surface Processes and Landforms*, 39(10), 1413–1420.
- Konecny G. 2014. Geoinformation: Remote Sensing, Photogrammetry and Geographic Information Systems. CRC Press.
- Nex F., Remondino F. 2014. UAV for 3D mapping applications: A review. *Applied Geomatics*, 6(1), 1–15.
- Olszewski R. 2009. Bazy danych przestrzennych jako element infrastruktury geoinformacyjnej w Polsce.
- Pajares G. 2015. Overview and current status of remote sensing applications based on unmanned aerial vehicles (UAVs). *Photogrammetric Engineering and Remote Sensing*, 81(4), 281–330.
- Remondino F., Del Pizzo S., Kersten T.P., Troisi S. 2012. Low-cost and open-source solutions for automated image orientation – A critical overview. In: *Euro-Mediterranean Conference*. Springer, Berlin, Heidelberg, 40–54.
- Rozporządzenie Ministra Rozwoju, Pracy i Technologii z dnia 23 lipca 2021 r. w sprawie bazy danych obiektów topograficznych oraz mapy zasadniczej (Dz.U. 2021, poz. 1385).
- Siebert S., Teizer J. 2014. Mobile 3D mapping for surveying earthwork projects using an unmanned aerial vehicle (UAV) system. *Automation in Construction*, 41, 1–14.