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Original article

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VERIFICATION AND UPDATING OF THE DATABASE OF TOPOGRAPHIC OBJECTS WITH GEOMETRIC INFORMATION ABOUT BUILDINGS BY MEANS OF AIRBORNE LASER SCANNING DATA

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Abstract

Airborne laser scanning data (ALS) are used mainly for creation of precise digital elevation models. However, it appears that the informative potential stored in ALS data can be also used for updating spatial databases, including the Database of Topographic Objects (BDOT10k). Typically, geometric representations of buildings in the BDOT10k are equal to their entities in the Land and Property Register (EGiB). In this study ALS is considered as supporting data source.

The thresholding method of original ALS data with the use of the alpha shape algorithm, proposed in this paper, allows for extraction of points that represent horizontal cross section of building walls, leading to creation of vector, geometric models of buildings that can be then used for updating the BDOT10k. This method gives also the possibility of an easy verification of up-to-dateness of both the BDOT10k and the district EGiB databases within geometric information about buildings. For verification of the proposed methodology there have been used the classified ALS data acquired with a density of 4 points/m^2. The accuracy assessment of the identified building outlines has been carried out by their comparison to the corresponding EGiB objects. The RMSE values for 78 buildings are from a few to tens of centimeters and the average value is about 0,5 m. At the same time for several objects there have been revealed huge geometric discrepancies. Further analyses have shown that these discrepancies could be resulted from incorrect representations of buildings in the EGiB database.

Keywords: *airborne laser scanning, Database of Topographic Objects, alpha shape*

1. Introduction

Within the last several years there can be observed the growing awareness of using airborne laser scanning technology (ALS) for automatic identification of several different land cover elements, such as archeological objects (Poloprutský et al., 2016), landslides (Pawłuszek & Borkowski, 2016), trees (Hauglin & Næsset, 2016), roads (Zhao et al., 2011) and also buildings (Wei, 2014; Matikainen et al., 2010). Modelling of space's geometric elements using ALS data has become a reality. Thanks to characteristic attributes of laser scanning, in particular the ability of a laser beam to penetrate vegetation and register a few echoes of a single laser pulse, laser scanning must follow limitations of airborne, satellite as well as direct field measurements, giving the possibility to identify objects that are covered by vegetation and also effectively distinguish high anthropogenic objects from vegetation or ground.

A vast informative potential stored in ALS point cloud makes therefore that there are still new ideas for its effective use wherever there are important up-to-dateness, credibility and completeness, so certainly for modelling of buildings and keeping spatial datasets in a current state. The attention is also paid to the necessity of automating the process of spatial databases' up-to-dateness, keeping all accuracy requirements, according to the guidelines for databases functioning (Vosselman et al., 2004; Rottensteiner, 2008).

In recent years in Poland there have been realized many geospatial projects. One of them is the Georeference Database of Topographic Objects (GBDOT) with the National Management System, with its final product which is the reference database of topographic objects of accuracy appropriate for topographic maps at the scale of 1:10 000 (BDOT10k) together with its management system. Another project is the Information Technology System of the Country's Protection against extreme hazards (ISOK), which results in circa 289 000 km^2 area of Poland covered by ALS data. There is a question that comes to mind: is it possible to use the results of these projects in such a way that would be beneficial for both of them?

Geometric information about buildings is an extraordinarily significant issue of functioning the Polish, reference spatial databases, mainly the Land and Property Register (EGiB), BDOT10k and ISOK, which create the Polish Infrastructure for Spatial Information. This information has a wide spectrum of applications, and one of the most desirable nowadays is 3D building modelling (Jarząbek-Rychard & Borkowski, 2016; Orthuber & Avbelj, 2015).

However, it is worth remembering that information is only useful when it is current. Although there are noticeable many actions aiming at ensuring the best quality of information about buildings, such as modernisations of district EGiB databases, there is still not enough fast and effective solutions checking the up-to-dateness of buildings stored in databases by means of numerical height data. Such a similar situation can be observed also in other European and world's countries.

Admittedly, the dominant and basic method of updating databases with geometric information about buildings is field measurement, but there also is paid more and more attention to nonconventional data sources (e.g. Yuan, 2016).

The issues of building identification in remote sensing data are widely discussed in literature. Most frequently there are used integrated data - high resolution satellite photos and ALS point cloud (Wang et al., 2011; Cheng et al., 2008), as well as tri-stereoscopic satellite images (Bachofer & Hochschild, 2015) and oblique imaginery (Nex et al., 2013).

According to ALS data research pertain to mainly application of derivatives, such as Digital Terrain Models (DTM), Digital Surface Models (DSM) and also their product, which is normalized Digital Surface Model (nDSM). Although these approaches unable to identify buildings as a horizontal cross sections of roofs, so geometric representations of buildings, which are inappropriate for supplying and updating of spatial databases, but they still can be used for verification of databases' up-to-dateness, which has been presented in papers (Matikainen et al., 2010; Rottensteiner, 2008). Many authors pay also attention to the necessity of using raster ALS data of a resolution not worse than 1 m in order to obtain better results (Martin et al., 2014; Rottensteiner, 2008).

Concerning original ALS data there are many papers about building identification and modelling, also as database objects. One of the most interesting and innovative approach has been presented in the paper of Wei (2014). The author has proposed the algorithm based on vertical structures derived from ALS data. Firstly, there has been classified the point cloud. Secondly, the building walls and roofs have been identified and after that they have been attributed to the respective buildings by the 2D connected component algorithm, which can connect wall and roof points within a certain distance in 2D.

The achieved outcomes have been corrected by a size and angle as well as a size and structure filtering and also the 3D connected component algorithm. One of the last stages of identification of the horizontal cross sections of building walls is to use the 3D Hough transform, assuming that there are dominant directions for each building. To complete the gaps in delineating wall lines there has been used information about the identified building roof outlines. The accuracy assessment of the identified building footprint outlines has been conducted by the parameters of completeness (97%), correctness (98%) and quality (95%).

Another interesting conception has been presented by Zhang et al. (2006). First of all, the authors have separated ground points from non-ground points using the progressive morphological filter. Second of all, there has been used the region growing algorithm based on the plane-fitting technique to identify points reflected from buildings and other objects. Next, to remove noise in a building footprint there have been used the Douglas-Peucker algorithm, the algorithm for estimating the dominant direction of a building and the innovative method for regularization of building shapes, based on weighted line segment lengths. The building footprint outlines have been identified with a total error of 12%, caused mainly by a lower point cloud density in a certain parts of the outlines. However the building identification problem presented in the paper of Martin et. al. (2014) has turned out to be possible to eliminate.

It is worth mentioning that the accuracies of methods based exclusively on ALS point cloud allow to achieve comparable identification accuracies of building footprint outlines to the methods integrating different data sources (Tomljenovic et al., 2015).

The goal of this research is to propose a simply methodology that can be used for 2D building modeling based on ALS data. Moreover this research should answer the question if ALS data and proposed approach can be used for verification and updating of buildings in topographic databases.

In this paper, we use simple approach for identification of building footprint outlines, using the alpha shape algorithm and thresholding of the original ALS point cloud acquired within the ISOK project. We assume that the building footprint outlines can be identified only from ALS data, without using additional information. The accuracy and correctness assessment have been carried out by a comparison of the final building models to their geometric representations in the EGiB database.

2. Methodology

2.1. The alpha shape algorithm

The alpha shape algorithm has been first introduced in the paper (Edelsbrunner et al., 1983) as a way of shape's description for the unstructured dataset on a plane R^2, which border is an alpha hull (α-shape).

Definition: In a finite set of points $S \in R^2$ there is identified such *a* point $p \in S$, which lies on a rotating circle of a 1/α radius. If any other point lies on a given circle, then *a* point is an extreme point in a sense of *α*. Two extreme points $a, b \in S$, which lie on the same circle are neighbouring points in a sense of *α*. The alternating rectilinear links between neighbouring points in a sense of *α* create an alpha hull (Fig. 1.).

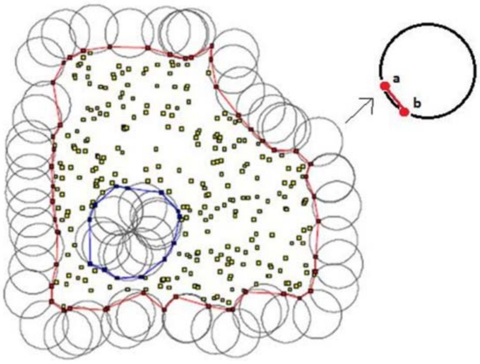


Fig. 1. The alpha shape algorithm extracting principle (based on Fayed & Mouftah, 2009)

The hull's level of detail is determined by the value of *α* parameter – the higher the parameter is, the smaller is the level of generalization of object's shape. In figure 2 there have been presented exemplary borders of datasets representing alpha hulls, depending on the value of *α* parameter.

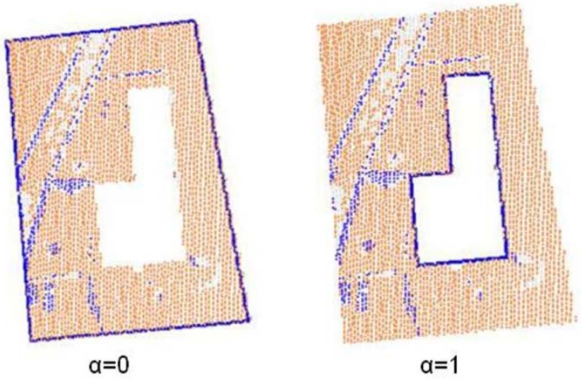


Fig. 2. The identification of building's shape by the alpha shape algorithm, for various values of α parameter (α=0 on the left, α=1 on the right)

Building footprint outline, identified by the alpha shape algorithm, is composed of a zigzag shape (Fig. 3.).

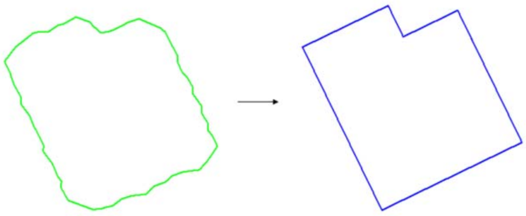


Fig. 3. Building footprint outline identified by the alpha shape algorithm (on the left) and after a regularization of its shape (on the right)

For that reason it is necessary to apply generalization and regularization of its shape. Different approaches can be utilized to perform that.

Wei (2008) has proposed the Improved Pipe Algorithm, which allows for removal of intermediate points and identification of building's inflexion points by judging the direction changes of a line in a given pipe with a diameter *d*, which is a threshold value of this algorithm. A boundary regularization can be carried out in a rather simple way by using the Circumcircle Regularization Algorithm (Wei, 2008) or Clustering and Adjustment Algorithm (Wei, 2008).

Another method has been presented in a paper (Albers et al., 2016). It enables to regularize a building footprint outline, identified by the alpha shape algorithm, using the Hough transform and an energy minimization approach, which is evaluated with the Viterbi algorithm (Viterbi, 1967).

In this paper, for building vector, geometric models of buildings, appropriate for the BDOT10k, there has been used a modified implementation of the alpha shape algorithm in the Matlab environment (Mathworks, 2013), which realizes the alpha shape algorithm using the Delaunay triangulation.

2.2. Automatic identification of buildings and verification

According to the conception presented in this paper (Fig. 4.), the building footprint outlines have been identified by the thresholding method of classified, original ALS data in regard to relative heights of points. The threshold value has been determined based on the normalized digital surface model (nDSM), generated from ALS data. Such an approach has been proposed by Martin et al. (2014) and Wang et al. (2011). The dataset after thresholding consists of no points of a height less than the mean height of buildings. In our study the threshold value is set at 2 m. (Fig. 5.). Thanks to this fact, the echoes from objects situated near ground, but not belonging to the building footprint outline, such as constructional element of building roofs (eaves, ledges, dormers, cornices), are eliminated. At the same time there has been noticed that the same results can be achieved by thresholding of last pulses (Fig. 4.), but because of the fact that it is needed to previously separate these points, this solution is regarded as less efficient.

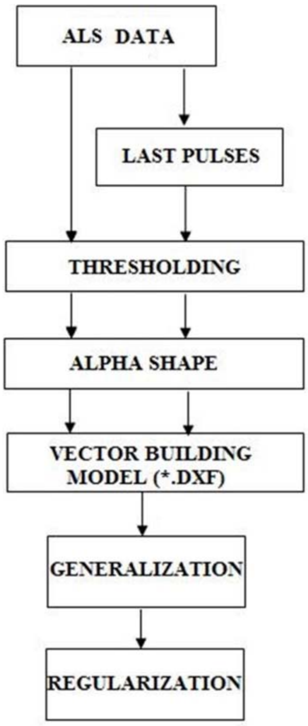


Fig. 4. Schema of building identification

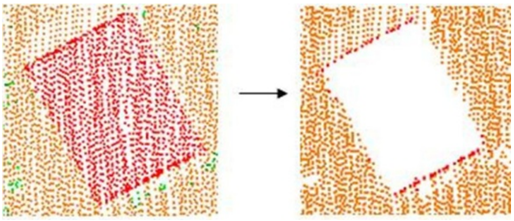


Fig. 5. The ALS point cloud before (on the left) and after thresholding (on the right) for one of the test object

The research conducted by (Burdeos et al., 2015; Rottensteiner & Briese, 2002) confirm a high effectiveness of methods based on the thresholding of ALS height data for identification of buildings. After thresholding the alpha shape algorithm has been implemented. The boundary between the area without and with points is an alpha hull. Generalization of the shape of building models has been conducted by the Simplify Building tool, which implements a generalization operator available in ArcGIS software and for their regularization there has been created the python script, implementing the algorithm that is in the ArcGIS tool - Regularize Building Footprint.

The accuracy assessment of the identified buildings has been carried out by their comparison to the corresponding EGiB objects. As the points for measurement of deviations (reference points) for each building there have been chosen corners and one point on each building wall. The deviations, which are distances between models, have been determined by a projection of the reference outline points, which come from the EGiB database, into the outline identified from ALS data. The lengths of deviations have been calculated for points on building walls alongside a normal line given in a reference point and for corners by determining a distance from the point of the first model to its corresponding point of the second model. The value of allowable deviation of object identification has been set according to the Polish technical standards of carrying out geodetic situational surveying. The layout of reference points and measurement of deviations for a part of one of the test objects have been presented in figure 6.

The quantitative assessment of building identification correctness has been carried out by determining the following parameters:

1. the mean value of linear deviations [m],
2. the root mean squared error (RMSE) [m], determined according to (1):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} d_i^{\,2}}{n}} \tag{1}$$

where d_i – the measured linear deviations, n- the number of deviations.

3. the effectiveness of object identification, calculated as a relation of the number of measured deviations of values not higher than the allowable value to the total number of measured deviations for each building [%].

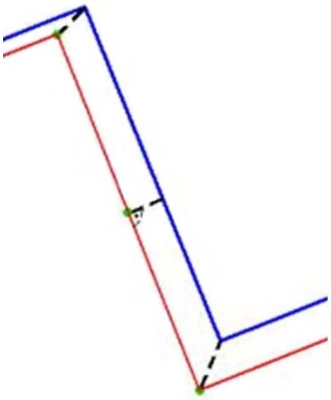


Fig. 6. The layout of reference points and measurement of deviations for the part of one of the test objects

Apart from parameters of the quantitative assessment of building identification correctness there have been also calculated the completeness (2) and correctness (3) of building detection.

These parameters together with the RMSE error are mostly used for accuracy assessment of the achieved outcomes (Poloprutský et al., 2016; Grigillo & Kanjiir, 2012):

$$K = \frac{TP}{TP + FN} \tag{2}$$

$$P = \frac{TP}{TP + FP} \tag{3}$$

where: K - completeness, P - correctness, TP - the number of buildings in the reference (EGiB) and the test dataset, FP - the number of objects that are not buildings in the reference dataset and that are buildings in the test dataset, FN - the number of buildings in the reference dataset that are not buildings in the test dataset.

3. Study area and dataset

In this paper, for experimental research there have been used only airborne laser scanning data acquired within the ISOK project (http://www.isok.gov.pl), for non-urban areas, without using additional procedures aiming at raising the quality or improving the classification results of the original ALS data.

The vector, 2D geometric building models have been generated from the classified ALS data of a mean density of 5 points/m^2, (Fig. 7.). The point cloud classification has been performed in the framework of the ISOK project and we have used the data as they are. The data have been classified into eight classes according to the LAS 1.2 standard. In compliance with the ISOK requirements (http://codgik.gov.pl/index.php/zasob/numeryczne-dane-wysokosciowe.html), the classification correctness should be not less than 95%.

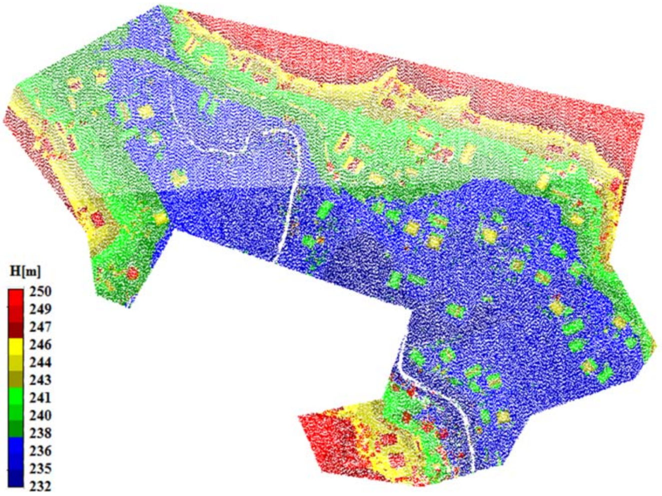


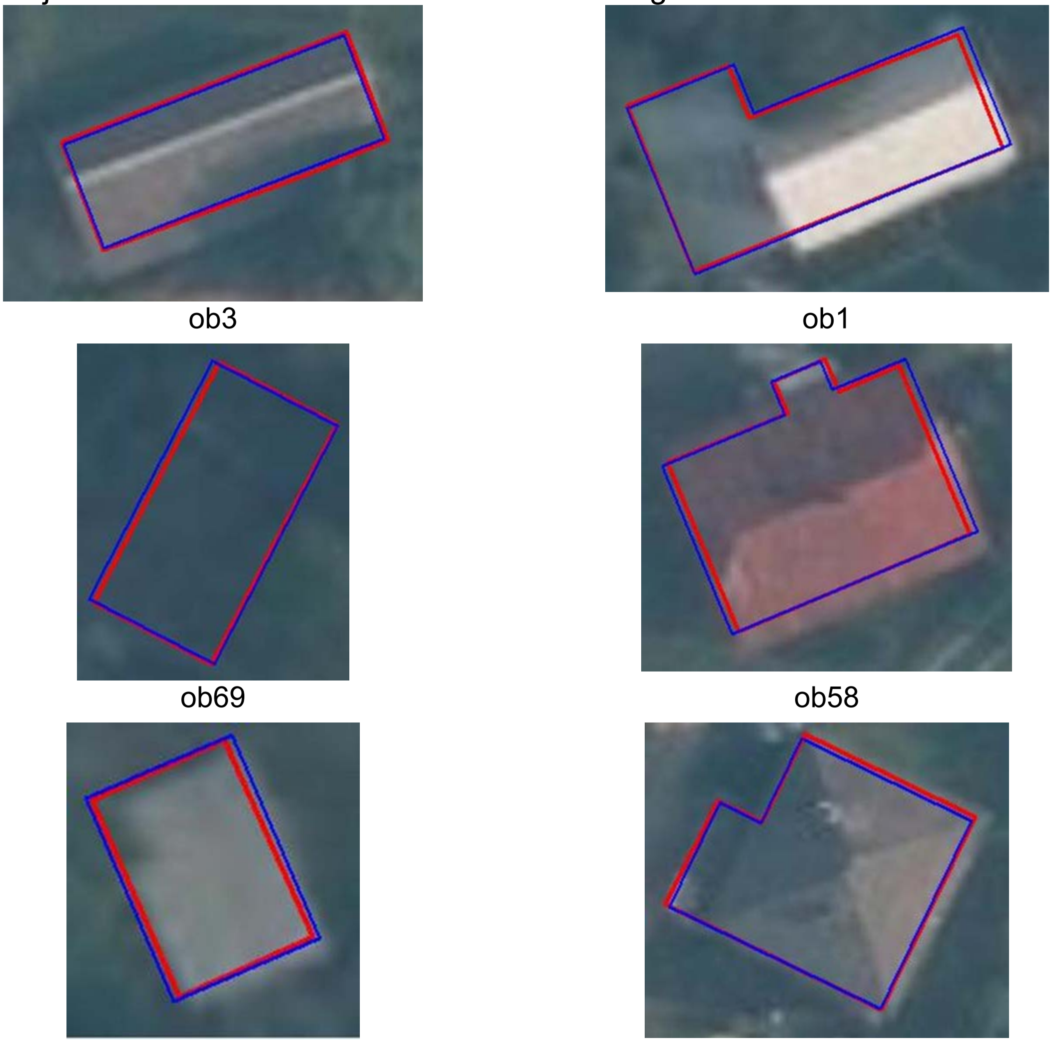
Fig. 7. The study datasets presented in regard to absolute heights of points

Numerical experiments have been conducted for 98 buildings, situated in the north-west part of Dubiecko commune, in the przemyski district.

4. Results

The exemplary outcomes of building identification, which have been achieved according to the methodology presented in the chapter 2.2, have been shown on a digital orthophoto in the background, in figure 8. Apart from that, the figure 9 presents all buildings, which belong to the apartment blocks, used in the performed experimental works. Based on these figures (Fig. 8., Fig. 9.), for 78 objects there can be observed a high conformity of the building outlines generated from ALS data with the outlines from the EGiB database, but for the rest of several objects there are noticeable higher geometric discrepancies, resulting from their incorrect representations in the EGiB. The graphical illustration of this problem for a few test objects has been shown in figure 11.

All vector building models, presented in this chapter, have been generalized and regularized (Fig.5). It has been assumed, for the regularization, that the building outline segments are either parallel or orthogonal. The simplification tolerance parameter for the Simplify Building tool in ArcGIS software has been set up on 1,5 m for all objects. This value has been determined using trial and error method.



ob3

ob1

ob69

ob58

ob74

ob36

Fig. 8. The vector, geometric models of buildings (ob1, ob3, ob36, ob58, ob69, ob74, vide Tab.1) identified by the α-shape algorithm (blue) with the EGiB data (red) and a digital orthophoto in the background

The results of the quantitative assessment of building identification correctness have been presented in Table 1. The values of the root mean squared error for 78 buildings are from a few to tens of centimeters and the average value is 0,49 m. All buildings have been recognized with 100% effectiveness. The higher values of the mean linear deviations result from both the lower ALS point cloud density in a given part of an outline and errors of building shape regularization.

It is also worth to mention that the achieved outcomes pertain to buildings that are completely covered by ALS data. Buildings, which walls are not completely covered by ALS data and modelled according to the conception presented in this paper, will be adequate for the horizontal cross section of their roofs.

Such models are not geometric representations of buildings appropriate for updating the BDOT10k as well as the EGiB database. The problem of missing laser pulses in the area of building footprint outlines has been discussed by Wei (2014).

The completeness and correctness of building detection are accordingly 100% and 81%.

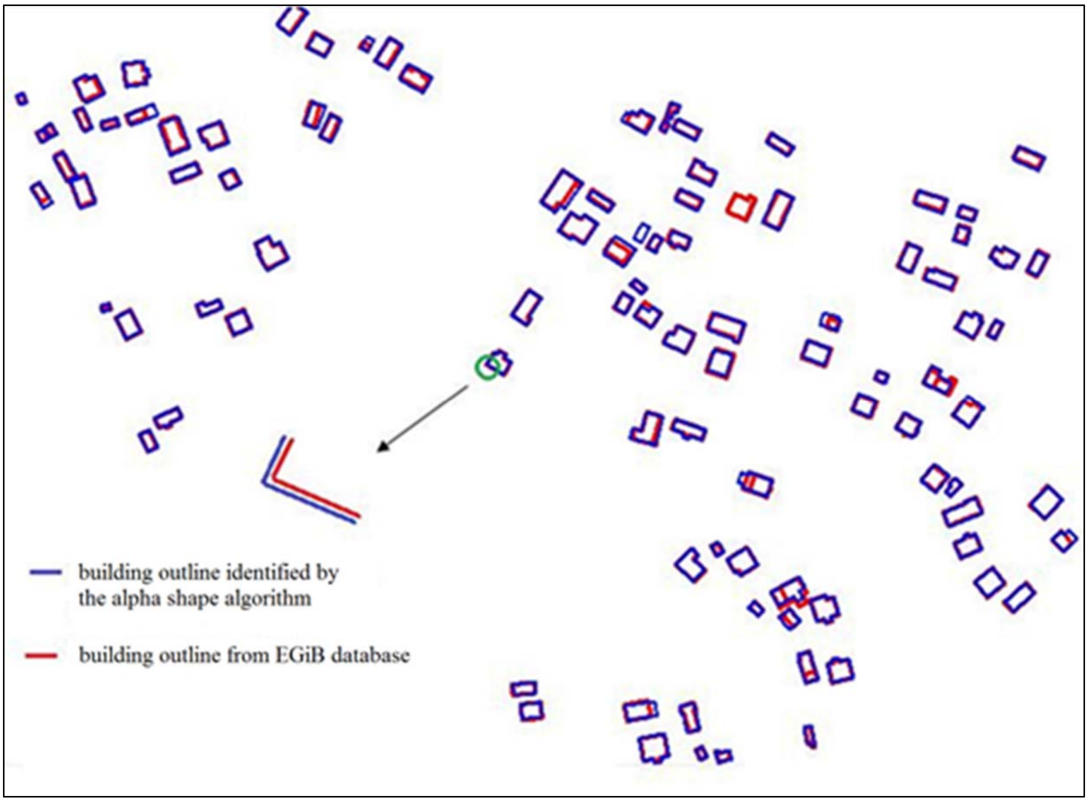


Fig. 9. The vector, geometric models of buildings, which belong to the apartment blocks, identified by the α-shape algorithm with the EGiB data in the background

Tab. 1. The effectiveness of building identification by the α-shape algorithm

the number of the object	the mean value of deviations [m]	the mean error (RMSE) [m]	the number of the object	the mean value of deviations [m]	the mean error (RMSE) [m]
ob1	0,17	0,19	ob29	0,29	0,31
ob2	0,42	0,49	ob30	0,65	0,73
ob3	0,14	0,15	ob31	0,39	0,44
ob4	0,60	0,68	ob32	0,47	0,51
ob5	0,45	0,50	ob33	0,51	0,58
ob6	0,36	0,38	ob34	0,56	0,61
ob7	0,38	0,42	ob35	0,86	0,91
ob8	0,24	0,27	ob36	0,13	0,17
ob9	0,36	0,47	ob37	0,27	0,32
ob10	0,77	0,79	ob38	0,36	0,42
ob11	0,68	0,70	ob39	0,35	0,45
ob12	0,67	0,73	ob40	0,24	0,27
ob13	0,63	0,77	ob41	0,63	0,70
ob14	0,25	0,26	ob42	0,34	0,39
ob15	0,36	0,40	ob43	0,34	0,42

ob16	0,63	0,66	ob44	0,36	0,41
ob17	0,75	0,79	ob45	0,26	0,29
ob18	0,42	0,50	ob46	0,46	0,51
ob19	0,48	0,54	ob47	0,47	0,49
ob20	0,35	0,38	ob48	0,32	0,35
ob21	0,57	0,62	ob49	0,38	0,45
ob22	0,46	0,49	ob50	0,61	0,68
ob23	0,51	0,55	ob51	0,32	0,40
ob24	0,91	0,99	ob52	0,34	0,36
ob25	0,43	0,47	ob53	0,54	0,63
ob26	0,57	0,60	ob54	0,46	0,48
ob27	0,56	0,60	ob55	0,77	0,82
ob28	0,55	0,77	ob56	0,57	0,62
ob57	0,68	0,74	ob68	0,25	0,32
ob58	0,21	0,25	ob69	0,11	0,13
ob59	0,42	0,48	ob70	0,30	0,35
ob60	0,28	0,33	ob71	0,26	0,28
ob61	0,48	0,52	ob72	0,71	0,73
ob62	0,21	0,22	ob73	0,36	0,44
ob63	0,38	0,51	ob74	0,15	0,16
ob64	0,38	0,44	ob75	0,32	0,35
ob65	0,52	0,59	ob76	0,48	0,50
ob66	0,33	0,34	ob77	0,70	0,80
ob67	0,25	0,29	ob78	0,73	0,78

Both histograms of the computed mean value of linear deviations and the root mean squared error (RMSE), presented in figure 10, show the empirical distribution of the above mentioned features, expressed by the frequency. Based on these charts, it can be noticed that the most percent of the features are within the average ranges, which are 0,35-0,4 m for the mean value of linear deviations and 0,45-0,5 m for the root mean squared error (RMSE), whereas the least percent of features are mainly within the greatest values of ranges and no more than 1m.

Better results, both in the context of accuracy and completeness, can be achieved if combined point cloud consisting of ALS data and terrestrial laser point cloud are used for the modelling (e.g. Borkowski & Jóźków, 2012)

Several factors have an influence on accuracy parameters given in the table 1. The accuracy of building outline depends on: planar point cloud accuracy, point cloud density, generalization and regularization processes. The first two factors seem to be the most important. Since we have performed generalization and regularization simultaneously it is difficult to assess impact of these error sources. In this study, we have determined building outline accuracy as a result of several factors, because we are interested in the resulting accuracy in comparison to EGiB database and in the context of BDOT10k requirements. In order to study the impact of several error sources on the resulting accuracy of topographic objects, that have been modelled using ALS data, additional research is needed.

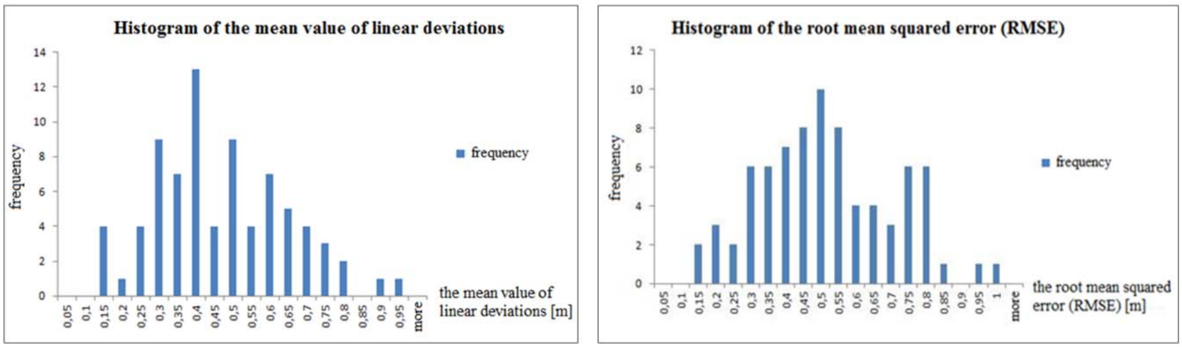
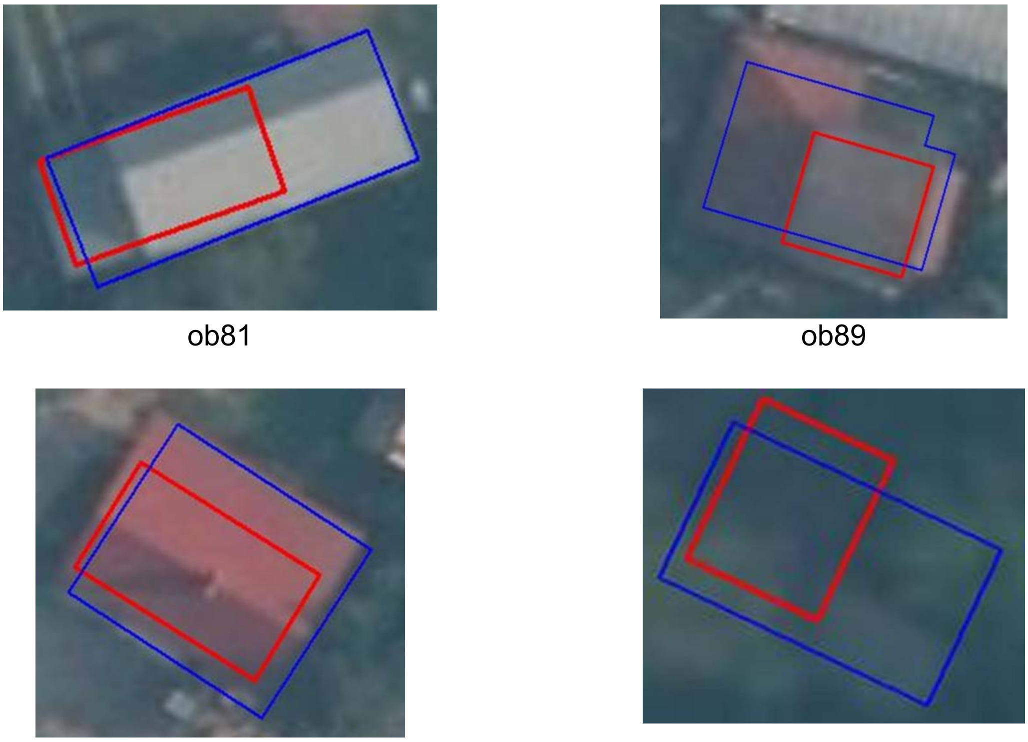


Fig. 10. Histograms of the mean value of linear features and the root mean squared error (RMSE)


ob81 ob89

ob86 ob91

Fig. 11. The incorrect geometric representations of buildings in the EGiB database (ob81, ob86, ob89, ob91, vide Tab.2) [red] with building models generated by the α-shape algorithm (blue) and a digital orthophoto in the background

In Table 2 there have been presented the outcomes of the quantitative assessment of geometric discrepancies between building models generated from ALS data and their corresponding EGiB objects, that have been recognised as incorrect. From values given in this table results that the mean value of the root mean squared error is 1,70 m.

Tab. 2. The quantitative accuracy assessment of buildings that have incorrect geometric representations in the EGiB database

the number of the object	the mean value of deviations [m]	the mean error (RMSE) [m]	the number of the object	the mean value of deviations [m]	the mean error (RMSE) [m]
ob79	1,18	1,35	ob89	1,88	2,26
ob80	1,35	1,85	ob90	1,18	1,77
ob81	2,47	3,43	ob91	1,57	1,96
ob82	1,26	1,29	ob92	1,56	1,91
ob83	1,28	1,60	ob93	1,16	1,62
ob84	0,65	0,90	ob94	1,37	1,83
ob85	0,92	1,26	ob95	0,96	1,32
ob86	1,88	2,05	ob96	1,28	1,57
ob87	1,12	1,50	ob97	1,24	1,92
ob88	0,93	1,16	ob98	1,32	1,47

5. Conclusions

Maintaining of the topographic database (e.g. BDOT10k) is a challenging issue because it has to be up-to-date. This is necessary for an effective use of the informative potential stored in this database. Several data sources can be used for verification and updating of the topographic database. In Poland the topographic database is manly expanded with geometric information related to buildings by the cadastral EGiB database. In this study, the ALS is considered as supporting information source about building outlines. For verification and updating of geometric information related to buildings and provided by topographic database there has been proposed a simply methodology. This methodology consists of:

- thresholding of normalized ALS point cloud,
- identification of building outlines by the alpha shape algorithm,
- generalization and regularization of buildings outlines using GIS software.

The conducted numerical experiments have shown that building outlines determined by the proposed methodology fulfil accuracy requirements of the Database of Topographic Objects (BDOT10k). The computed average RMSE value is 0,49 m. At the same time there has been demonstrated that ALS data can be used for both verification and identification of errors in the main cadastral EGIB database. Based on the conducted experiments there can be stated that actual ALS data can be used as a source for verification and updating of topographic databases.

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