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The usage of DEM to create the 3D cadastre

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Abstract

The article presents the analysis of possibilities of using the Digital Elevation (Surface) Models for creation of the 3D cadastre. The authors present the characteristics and meaning of the three-dimensional modelling of objects in the context of solving problems occurring with the traditional two-dimensional cadastre. The paper presents imperfections of the 2D cadastre and indicates possibilities of their removal based on altitude data acquired from the laser scanning. It determines the accuracy of data obtained with lidar techniques and indicates their limitations in specifying the exceeding. As a result of the carried out analysis and theoretical considerations, the authors have indicated the potential possibilities of the usage of Digital Surface (Elevation) Models for the construction of the three-dimensional cadastre system.

Introduction

Cadastre systems are the information systems about the subjects, objects and rights, which combine the subjects and objects. Such data serve three basic functions [1]:

- fiscal;
- legal;
- geodetic – cartographic.

Development of numeric and cadastral maps makes the usage of cadastre become wider. Computerization of the graphic and descriptive part of the land and buildings register creates new possibilities of their use (database, analytical).

The use of electronic registration tacheometers, GNSS technique, photogrammetry methods or the laser scanning, and not only as it has been used so far the descriptive documentation about the object, enables now the acquisition of the third coordinate with the cadastre measurements, and what follows it significantly saves time with these types of studies. Another issue is the accuracy of generating 3D information referenced to the land surface, which is connected with the accuracy of measurement, approximation and representation of this surface.

Cadastral data are more often used for the needs of national economy, especially in the activities of the local administration and government. The existing method of geodetic determination of the height (exceeding) are the methods of measurement:

– levelling (geometry levelling (including precision), trigonometric, barometric, hydrostatic, satellite);
– gravimetric;
– based on Numeric Models (Surface) of the Land;
– combined.

In this publication the authors undertake the problem of specifying the accuracy of the height (exceeding) of the objects for the purposes of multidimensional cadastre, based on the available height models, with the special consideration of lidar techniques.

3D cadastre

The issues of the multidimensional cadastre was undertaken for a broad scale at the beginning of the XXI century, however, contemporary technical conditions and organisational ones did not allow its further development [2]. In the recent years the matters connected with the multidimensional cadastre, called the *3D cadastre*, were once again undertaken at first in the countries of the Western

Europe. In the spatial cadastre the digital models of the field with various levels of accuracy are used. Development of cadastre 3D registrations is caused most of all by a significant increase of the properties' values, the growing number of technical infrastructure and the development of modern methods of analysis and presentation of data using the GIS systems.

Classic cadastre system, containing the basic information about borders of the property and the way of its usage in 2D dimension, in such situations is no longer sufficient. Most of all, it prevents the spatial (three-dimensional) localisation of the object in relation to borders and the surface of the plot. These deficiencies are visible especially in situations, when [4]:

- in particular parts of the building there is a various number of storeys or there are other additional elements;
- buildings' shapes are untypical or irregular and there is a difficulty in presenting them on the map;
- owners or users of "irregular" properties are different (the owner of the plot is different than the users of the building);
- buildings are differently built in the ground and underground part and the presentation of such state on the map is difficult.

Creation of a uniform three-dimensional cadastre is not a simple matter, especially in the international or world scale. The way of complicating the cadastre in each country depends on many factors, such as legal and organisational conditions, or technical possibilities. That's why there are various ideas connected with the creation of 3D cadastre and its various terms.

As 3D cadastre, apart from objects of traditional cadastre, we also understand the systems of registration of the infrastructure network in parts of underground buildings, ground and above ground ones. The accomplishment of the cadastre is possible as [2]:

- minimal 3D cadastre, which will not consider the infrastructure network, such as roads and railways and underground objects, and information about the flats will be available through layers;
- topographic 3D cadastre, which will define objects by the reference to their physical boundaries without the creation of own geometry for legal objects;
- polyhedral 3D cadastre, in which plots in 3D will have own geometry, represented by polyhedrons, limited by flat surfaces;
- non-polyhedral 3D cadastre, similar to polyhedral one, however allowing also other surfaces;
- topological 3D cadastre, in which plots having the volume will be topological structures, based on bonds, edges and surfaces;

Currently, the objects of land and buildings register are the plots, class-uses, buildings and flats, and the introduction of the 3D cadastre requires the application of the right measurement techniques, resulting from the demand for information (legal requirements, user requirements, etc.). In the opinion of the authors of this publication, the construction of the three-dimensional cadastre is only the matter of time, and its foundation will be the altitude data acquired by Digital (Surface) Models.

DEM and DSM

For the creation of 3D cadastre (on large areas), it should consider the method of determining the altitude based on the Digital Elevation Models. Due to the specificity and construction of numeric altitude models, it should take into consideration most of all models considering the surface of the land, together with the anthropogenic objects (ground and underground infrastructure for the description of which it can use the technical documentation of the object) and the covering of the land (trees, bushes, etc.), and not reflecting only the delevelling of the land. Due to the accuracy of the determining of the exceeding, it should consider the use of lidar techniques – laser scanning. In order to three-dimension model the objects it can perform the air or ground laser scanning. The method of the air laser scanning ALS (Airborne Laser Scanning) is based on the cooperation of the following elements [5]:

- airship – on which there are placed essential transmitting-receiving devices and operators;
- laser rangefinder with the recorder – performing measurements and recording the reflected signals – scanner;
- recorder of the image – video camera or multispectral photographic camera, in some cases also theatre camera, where the recorded images may be used in filtering of the cloud of points as well as to attribute the points with colours, including the contractual ones, and when necessary the temperature;
- INS, GPS systems – determine the location of the scanner and angle leans;
- ground part in the form of reference stations.

The points recorded during the raid have XYZ coordinates, and data files are usually registered in the LAS format and reflect these elements, from which the reflection of the laser beam started. Filtering the selected points with specific assumptions, it obtains the following products:

- Digital Elevation Model (DEM);
- Digital Surface Model (DSM);
- Orthophotomap and the so-called true-ortho (by using additional photos and further transformations).

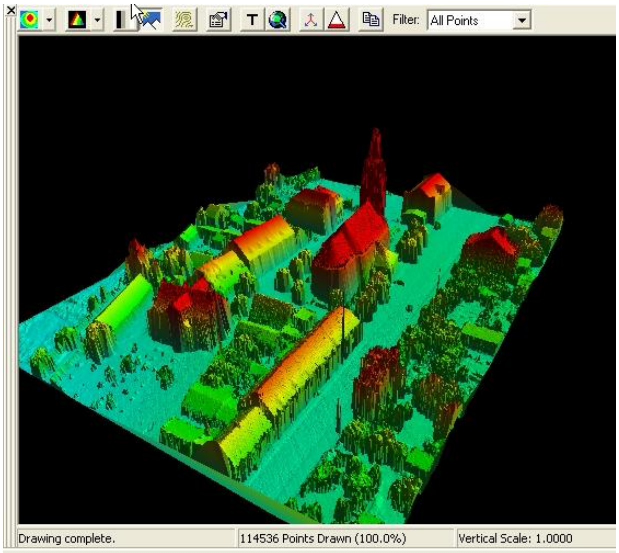


Fig. 1. Digital Surface Model created as a result of the laser scanning [5]

Analysis of the accuracy of the altitude model

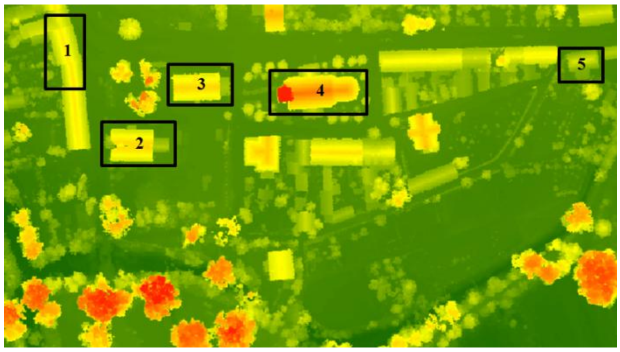
The use of the laser scanning for the construction of the 3D cadastre is limited most of all by the accuracy of determining the differences of altitude, and not the absolute accuracy of determining the altitude in the global altitude system. This results from the fact that, e.g. for the determination of the building's volume it needs the precise determination of the altitude difference, and the absolute determination of the altitude in the altitude system has no influence on the size of this volume. While in case of the insufficient accuracy of altitude binding of measurements to the global altitude system, it can use the traditional method of geometric leveling (in respect also of the precise needs) and bind the building (object) to the altitude points (level marks) with the right, demanded accuracy. In this respect the authors subjected to the analysis the use of the lidar model in respect of the accuracy of the specification of exceeding.

Checking the accuracy of determining the altitude differences based on the lidar model was made with the geometric levelling on the selected test objects (embankment, elements of the building).

Tab. 1. Measurements of altitude differences with various techniques (average values)

Flood banks	Measurements of altitude differences of the bank [m]
Difference of the altitude on the LiDAR model [m]	1.76
Difference of the altitude from field measurements [m]	1.83

Flood bank was measured at length of about 100 m. On the LiDAR model the altitudes of the bank top-bottom on 20 pairs of points selected at random were measured. Differences of exceeding were also obtained as a result of geometric levelling on 20 pairs of pickets selected at random (top-bottom). Levelling measurements were taken from three locations. Accuracy of determining the exceeding of the flood bank fit in the borders of 0.1 m (tab. 1).



Rys. 2. Digital Surface Model with the indicated objects used for testing

For measurements of the building's elements five test objects (among others the church tower – object No. 4) according to figure 2 were selected. The average value of the obtained error of the average measurements of exceeding was 0.33 m. For measurements objects with various construction, with sloping roofs and various number of storeys were subjected. The values of the obtained errors (tab. 2) indicate that the explicit identification of single elements of the buildings (roof's edge) causes difficulties, what translates into the obtained values of average surface (mean) errors, proving the relatively large deviations of the obtained (single) values from the average value. In case of altitude measurements on single, flat elements of buildings the values of surface mistakes of altitude measurements of these elements (but not the exceeding) fit the borders of 0.1 m. These values are coincident with the values obtained with measurements of the exceeding along the flood bank. This gives us a fact that in case of measurements of flat elements, the accuracy of the altitude / exceeding measurement equals about 0.1 m, while in case of diversified surfaces this accuracy falls to about 0.3 m. This difference also results from the spatial resolution (thickness of the cloud of points) of the used model, which equalled 0.5 m.

Tab. 2. Average (mean) errors of the exceeding measurement on the model Fig. 2 /LiDAR/

No. of the object (acc. to Fig. 2)	Average error (surface) of determination of altitude differences [m] on the LiDAR model
1	0.24
2	0.41
3	0.34
4	0.29
5	0.36

From the above results that for the analysis of the usefulness of the given altitude model for the purposes of 3D cadastre it should also take into consideration the second parameter, connected with the thickness of the cloud of points. This parameter has significance in case of numeric study of the lands intensively developed or the inventory of buildings with diversified shape. On the lands developed in a smaller degree, or on objects with a smaller diversification of constructions the number of points per square meter of the surface is sufficient on the level of 3–5. For the purposes of accurate inventory, the reproduction of the architecture objects, this accuracy depends on specific needs and requirements, assumed accuracies of the reproduction of the surface and determination of the exceeding or altitude (creation of smaller or larger surfaces, in which the values are interpolated) and should be increased to at least 10 points/m^2. This resolution has also importance in modeling the flood phenomena. In figure 3 the simulation of the increase of the water level by 6 m is presented.

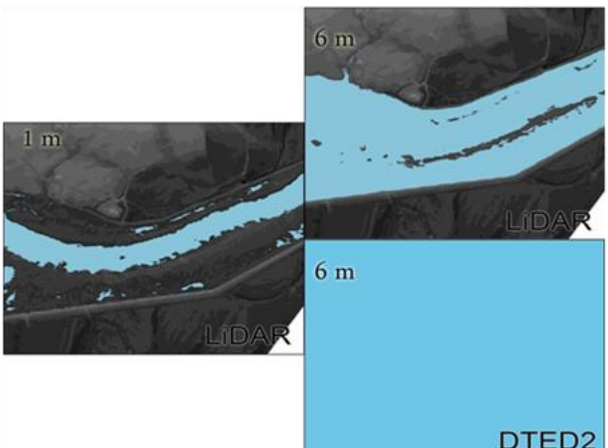


Fig. 3. Model's resolution (thickness of the cloud of points) in modelling the exceeding

The obtained results show that using the model with too low spatial resolution (horizontal and altitude) – DTED2, which vertical accuracy fluctuates in the borders of 5–10 m, and the spatial resolution equals 30 m, may lead to incorrect results. Thus, for the precise modelling of the land shaping, especially for the purposes of 3D cadastre, it should use data from the laser scanning, where both the vertical accuracies and the spatial resolution are usually one-decimetre.

Conclusions

As a result of the performed analyses and considerations, it was stated that:

- accuracy of determining the exceeding based on the LiDAR model on the analysed area (for the analysed set of data) fits the borders of 0.10 m for the flat elements and 0.33 m for elements with the complex and diversified surface;
- altitude models not taking into consideration the surface of the land (natural and anthropogenic) should not be considered in the process of the creation of 3D cadastre (only as the supplementing material, e.g. for the goals of specifying the flood land);
- possibility of using the lidar model of the land for purposes of the 3D cadastre limit two factors: altitude accuracy of the model (specifications of the exceeding) and spatial resolution (thickness of the cloud of points);
- use of the laser scanning for the construction of 3D cadastre depends on the accuracy of specification of altitude differences, and not the accuracy of specification of altitude in the global altitude system.
- altitude models constructed based on the laser scanning enable the solution of problems of the 3D cadastre connected with the modelling of objects with irregular shapes and various number of storeys.
- with the help of the air laser scanning it can identify objects with the complex structure and indicate which ones of them, depending on the further needs and desired accuracy, should subject to further measurements with the help of ground scanning.

Moreover, the authors of this study think that the construction of the three-dimensional cadastre will enable its implementation to the GIS environment, taking into consideration the database specificity of the cadastre and the spatial (topological) relations of the objects presented in “three-dimensions”. The construction of the 3D cadastre based on the tools and GIS techniques will enable the fuller management of the data resources, faster acquisition of information from it (combined) and the potential integration of the cadastre with other spatial systems. Creation of the three-dimensional model of objects (and land) this way may constitute valuable supplementation of the developed Database of Topographic Objects by order of the Main Office of Geodesy and Georeference Cartography (in Poland). Currently the objects in this database do not have altitude data, which are acquired from DEM (DSM), constituting the separate part of the system, and the specification of the buildings' altitude takes place through their "projection" on DEM. Such solution from the point of view of the creation of 3D cadastre is not satisfactory. The projected altitude is not the attribute of the building in the database, but it only depends on the accuracy of the used model of the land. Such structure prevents, in addition, the creation of attribute analyses in the system and makes this georeference databese constitute the limited source of data for the 3D cadastre.

Due to the above, it is suggested to construct the three-dimensional cadastre model based on the laser scanning with the attributed ordinates to particular elements of the buildings directly in the base of the cadastre data.

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