ANALIZA IZVEDLJIVOSTI VZPOSTAVITVE 3D-KATASTRA IZ RAZLIČNIH VIROV PODATKOV NA PRIMERU PODZEMNE ŽELEZNICE V VARŠAVI

FEASIBILITY STUDY OF 3D CADASTRE IMPLEMENTATION USING VARIOUS DATA SOURCES – THE CASE OF WARSAW SUBWAY

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IZVLEČEK

V članku je predstavljen primer prilagoditve podatkov dvorazsežnega (2D) katastra za vzpostavitev 3D-katastra, pri čemer smo v skupnem referenčnem prostorskem sistemu združili podatke katastrske izmere in podatke zračnega laserskega skeniranja, da bi na tej podlagi prišli do predloga rešitve za izvedbo 3D-katastra. Primer se nanaša na podzemno železnico v Varšavi. V članku predstavljamo zasnovo 3D-katastra za predmete posebnega interesa, pri katerih je takšna rešitev potrebna za transparentno registracijo lastnine. Z namenom opisati številne posebnosti nepremičnine v 3D-prostoru, ki so povezane z železniškimi predori, samimi zemljišči s stavbami, ki so umeščene nad podzemno železnico, smo pridobili podatke zračnega laserskega skeniranja. Podatke smo uporabili za 3D-modeliranje stavb ter določitev območij nepremičnine. Za poenostavljene 3D-modele predorov smo uporabili podatke terestričnega laserskega skeniranja. Za združevanje raznolikih podatkov smo opredelili referenčni koordinatni sistem. Predlagani način povezovanja različnih podatkov omogoča prikaz nepremičnin v treh razsežnostih, ki je uporabnikom prijazen, hkrati pa omogoča nadaljnjo uporabo podatkov za prostorske analize.

ABSTRACT

The paper presents the example of an adoption of 2D cadastral data to 3D data from inventory measurements and airborne laser scanning data in order to integrate them in a common spatial reference frame and propose the solution for the implementation of the 3D cadastre. The example is related to the subway in Warsaw. The paper introduces the idea of the 3D cadastre for objects of special interest that need this type of solution for transparent legal registration of the property. In order to describe a range of the 3D properties related to subway tunnels and land properties with buildings located over the subway, airborne laser scanning data were provided. The data were used for 3D modelling of buildings and to define the buffer for 3D properties. Terrestrial scanning data were used to prepare generalised 3D tunnels. Aiming to integrate various data, the reference coordinate system was also defined. Such an integration of various data allows the visualisation of 3D properties, which is user-friendly and provides opportunities for further spatial analyses.

KLJUČNE BESEDE

kataster, 3D-kataster, nepremičnina, 3D GIS, 3D-prostorske analize, podzemna železnica, model stavbe

KEY WORDS

cadastre, 3D cadastre, real property, 3D GIS, 3D spatial analysis, subway, building model

1 INTRODUCTION

In recent decades, 3D geospatial models generated from geodetic data have become very popular. In most cases, they are associated with the 3D visualisation of cities and landscape. As a result of the development of information technology, they are often applied in many other applications. It cannot be denied that demands for the cartographic representation of reality are constantly growing; in particular this may be observed in urban areas. It results from the intensity of urbanisation, which requires three-dimensional, detailed and updated geospatial data. 3D models are used for spatial management, allowing for analysing the effects of shading, calculating volumes, determining the impacts of new investments on existing structures, etc. At present, CityGML is the most popular standard for the representation and exchange of 3D city models, developed by Open Geospatial Consortium (OGC). It is the application scheme of the GM language (Kolbe et al., 2005). It divides 3D models by the level of details – LoD (Biljecki et al., 2016a). Those levels may appear in several variants, which are standardised and described in detail by their creators (Biljecki et al., 2016b). Buildings maintain topology and their elements are classified (e.g. roofs, facades, footings). The focus of CityGML is on the semantic aspects of 3D city models, its structures, taxonomies and aggregations, allowing for advanced analysis and visualization in many application domains such as urban planning, indoor/outdoor pedestrian navigation, environmental simulations, cultural heritage, or facility management. This is in contrast to purely geometrical/graphical models such as KML, COLLADA, VRML, X3D, or DXF, SHP and 3D PDF, which do not provide sufficient semantics (Gröger and Plümer 2012).

Various standards, which are sometimes considered only as the format of models, can be compared in many aspects. In Stoter et al. (2011), the most common 3D standards were compared with respect to geometry, topology, texture, level of details, distinguishing objects, semantics, possibility to incorporate attributes, considering if the standard is based on XML, if it is optimized for web use and if it includes georeferencing. From this comparison, it can be concluded that each 3D standard has its own characteristics due to specific purposes and it can be used referring to selected application. Because of the support of semantics, objects, attributes, georeferencing and web use, the selection of CityGML is justified when 3D city models and their effective usage within GIS and similar applications is considered.

Models of buildings may be generated from various data. The most popular and the most efficient ones include: airborne laser scanning data (ALS) (Elberink et al., 2011; Cisło-Lesicka et al., 2014; Jarząbek-Rychard and Borkowski, 2016) and automatic matching of aerial photographs (Förstner, 1999; Shi et al., 2011). The simpler solution, which requires only cadastral data to build a 3D model is the extrusion of a building outlines to the height corresponding to the assumed number of storeys and the average height of a storey or from the height attribute (if it has been assumed). However, this source will not make it possible to build models to a high level of details (Mróz et al., 2014). Other sources of data, which may be used for the generation of 3D models include time-consuming, manual stereoscopic measurements of photogrammetric photographs (Pasco and Gruber, 1996) or satellite images (Kocaman et al., 2006; Bujakiewicz and Holc, 2012), different model reconstructions based on the detection of corners and the analysis of aerial images (Fischer et al., 1998; Suveg and Vosselman, 2004), as well as radar data (Simonetto et al., 2005) or, finally, precise models and architectural designs and results of direct field measurements. However, 3D data may be more frequently found in different, urban, regional and national repositories of data once they have been prepared within various projects with mentioned techniques and now they can be shared with potential end-user (see Drobež et al., 2016). Geoinformation has been rapidly expanding in recent times. Serious technical difficulties related to the generation of 3D models of large objects do not exist nowadays (if the reasonable level of generalisation is assumed); the same applies to the storage, visualisation or spatial analyses of such models. Users are more frequently and willingly searching for solutions that are connected with three-dimensional data.

As Karabin (2016) stated, the reduction of land real property resources required for the implementation of new investments may be often observed in big cities. This forces more reasonable operations performed by investors and the use of all accessible space of building lands in all their "layers". The growing urbanisation and the necessity to use the urban space of high financial value, as well as the specific features of many urban investments (railway and subway tunnels, subway lines on viaducts etc.), which ensure that the city operates correctly, forces operations of the "layer" nature. In other words, this involves the construction of different objects on many levels, i.e. "layers" of the space of a land parcel. This in turn forces the introduction of new objects into the real property cadastre, i.e. spatial 3D real properties, which will include those layers and make it possible to assign the property rights to those layers. This depends on the implementation of the 3D real property cadastre, where also the legal aspect has to be considered (see. Paasch et al., 2016).

Karabin (2016) have noticed that in many cities, including Warsaw, the construction of subway tunnels encounters some obstacles since, in the process of construction, the investor is not always interested in gaining property rights to the entire land parcel, also including the underground part, where the discussed tunnel is to be located. If this space is not vertically divided (for example divided into layers) when the tunnel is constructed, it is not possible to sell the surface parcels located above the tunnel. Thus, in order to be prepared (from the technical perspective) for implementation of the 3D cadastre in Poland, in relation to the subway, the authors assumed it is necessary to geometrically represent objects located on the ground, above the subway tunnel: the cadastral data and geometric data of the subway tunnel. Data concerning the Warsaw Subway were used as a case study. The obtained results were presented as visualisations in the GIS environment, both as 2D views, and as 3D views, presenting possible interpretations of the results and the usefulness for the creation of a 3D cadastre. The paper discusses the analyses of the technical possibilities to use multisource geospatial data in order to collect additional information, which might be potentially utilised for developing a 3D cadastre in relation to the construction of the subway.

1.1 The concept of the 3D cadastre

According to Karabin (2013), the essence of the 3D cadastre is the registration of the third dimension of a real property in such a way that, besides parcel boundary lines in the horizontal plane, it is also defined in the vertical dimension. The 3D cadastre might be characterised by the possible registration of property rights in the system of "layers" (Karabin, 2013), while the definition of volume 3D units might also be an option. The necessity to define the range of property rights was also emphasized, among others, by Acharya (2011), Dimopoulou and Elia (2012), Erba and Graciani (2011).

In our research, we decided for the "layer approach". As it was stressed in Karabin (2013), in order to solve the task of the "layer" reference of rights to real properties, the new type of cadastral objects should be registered in the 3D cadastre. They are real properties according to the three-dimensional approach, the so-called 3D real properties (both, rights and extensions of those rights, i.e. the geometry of such real properties). As it may be inferred from the analyses of the 3D cadastres existing in the world, performed by Paulsson (2012), legal definitions in the horizontal and vertical planes are usually specified as the feature of a 3D real property. Paulsson (2012) quotes the classification of the types of rights to real properties, which concern the space. Predominantly the property right to an independent 3D real property is considered. Paulsson (2012) reviews the definitions concerned 3D real property used in on a global scale. Based on many publications the definition of the 3D spatial property, the so-called "independent 3D property" was developed by Paulsson. This term generally refers to the space of the specified volume, which is distinguished and separated from the space of the remaining part of the property. This leads to the registration of a separate cadastral object. It is not necessary to combine that object with a land parcel. The author distinguishes two types of such real properties, the first of which may include the air of the specified volume ("air-space parcel"), and the second must be referred to a building or another construction ("3D construction property"). The idea to distinguish 3D parcels which include a subterranean tunnel (from a space of ground parcels owned by different persons) – is presented in Figure 1. After subdivision process it will be possible to consolidate 3D parcel #4, 3D parcel #5 and 3D parcel #6 into one cadastral parcel (one owner of three subway's parcels).

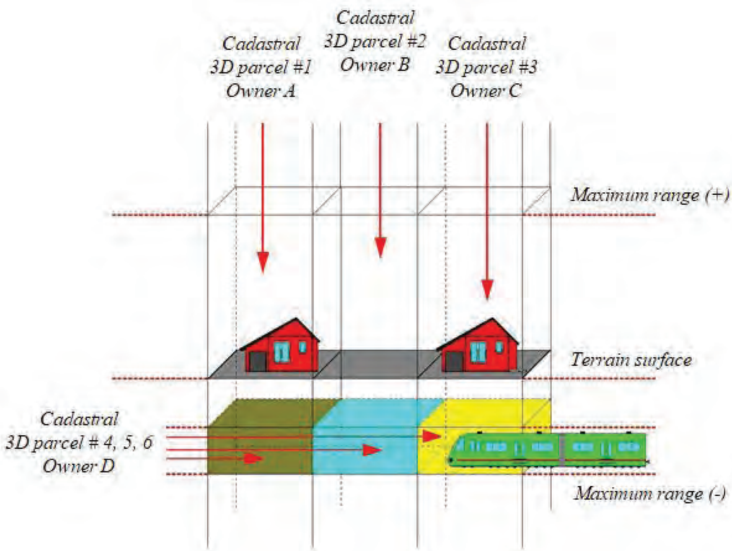

Figure 1. The concept of the 3D cadastre – an example of extraction of 3D parcels covering the underground tunnel. Source: Karabin (2013).

Ploeger (2011) stresses the inseparability of legal and technical aspects when the 3D cadastre is implemented. Ploeger (2011) states that if the legal instruments for the creation of 3D properties are not delivered by the legal system, there is no need to implement the 3D cadastre (in technological terms, i.e. implementation of required software tools). However, on the other hand, the implementation of the 3D cadastre itself (in technological terms, i.e. implementation of the required software tools) will not ensure the possibility to create both the 3D properties as well as the rights to those properties. Regardless of the above opinions, the authors decided that it is worth indicating that, in technological terms, it is possible to register 3D objects in the cadastre and to effectively manage such information.

Development of the existing, two-dimensional cadastre towards the 3D cadastre may be performed according to three scenarios mentioned by Stoter and Salzmann (2003):

– The complete, 3D cadastral registration (True 3D cadastre) – as the final solution which will be characterised by the elimination of two-dimensional cadastral parcels and the substitution there of with 3D parcels,
– The hybrid solution which assumes the co-existence of two-dimensional (existing 2D parcels) and three-dimensional (3D parcels) objects in the cadastre,
– Development of the existing solutions with the, so-called, "3D tags" which remain the existing, conventional 2D cadastral solution and create references to 3D objects, represented in digital documents (e.g. DGN files, DXF files etc.).

At present, according to the opinions of researchers who deal with the 3D cadastre issues, the most realistic solution would be to introduce the 3D cadastre in the hybrid form, which would ensure the integration of 3D objects with two-dimensional objects, registered in the existing 2D cadastral databases.

1.2 Underground tunnels in selected countries and their registration in the cadastre

In general, the 3D cadastre is maintained in those countries where the real property rights idea was not based on the Roman rule "superficies solo cedit". In those countries, it is even possible to register the, so-called, "air space parcel" and, following van Oosterom et al. (2011) it concerns countries such as: Australia (Queensland, Australian Capital Territory, New South Wales, Northern Territory, South Australia, Tasmania, Victoria and Western Australia), and Canada (Quebec).

Similar solutions may also be found in China and Singapore. As it turns out from Guo et al. (2014), more than 800 3D real properties have been registered in Shenzhen, China since 2007 when the 3D cadastre was introduced. Advanced GIS tools, which allow for the 3D visualisation of objects were also implemented there.

In Singapore, The State Land Act and The Land Titles (Strata) Act provide for 5 main types of lots to define property ownership: land, airspace, subterranean, strata and accessory lots. The main reason of introducing the so-called airspace and subterranean lots in Singapore was in order to develop a subway system known as the Mass Rapid Transit (Khoo (2011).

According to Khoo (2011), in current cadastral survey practice, airspace and subterranean lots are defined by 2D coordinates. The height component, referenced to a stratum, is also developed. Multiple views depicting these lots are shown on the certified plans to enable a better visualisation of the lot under survey. As also resulted from Khoo (2011), in the cadastral software (2D GIS) all the parcels which include subterranean lots and airspace lots can be shown. Additionally, many cross-sectional views are needed to represent a 3D situation i.e. ground parcels with airspace or subterranean lots in their space. There are high demands for 3D visualisation in Singapore's cadastre.

At present, when the processes of urbanisation and development of subterranean and overground buildings are rapidly developing all over the world, the task to register such objects has also occurred in Europe.

Some European countries have initiated legislative initiatives, which allowed for the registration of 3D properties in the cadastre and in the property registers of the countries.

As it was stated in Boncok and Kui (2017), current real property development trends and the growing demands for the identification and registration of objects constructed under or above the surface - that often overlap and cross each other - have forced the Hungarian legislator to introduce a 3D land registry in Hungary, expected to be effective from 1 July 2018. Boncok and Kui (2017) also stressed that in addition to introducing the 3D registration concept and setting out the general requirements the new legislation also proposed a concept for defining 3D properties. Under the proposed definition, underground and above ground objects and structures, which have single ownership, would be taken into account as separate properties and thus they would be registered in the land registry on separate land registry sheets.

According to Kitsakis et al. (2016), in Sweden, a 3D property is defined as a property unit, which in its entirety is delimited, both horizontally and vertically (Swedish Land Code, Chap. 1, Section 1a). It can be separated and play different functions, such as units consisting of several apartments or offices, commercial premises, but it also often consists of infrastructure objects, e.g. tunnels or other large underground facilities. The 3D unit must relate to the whole or a part of a built construction or another physical facility. The Swedish 3D property may extend under or over one or more ground parcels. It is therefore not bound to be located within the boundaries of a 2D property.

In the Netherlands (Ploeger and Stoter, 2004), according to the rule "superficies solo cedit"(vertical accession) as described in the Civil Code, the right of ownership contains all constructions that are permanently fixed to the land. So, the owner of the parcel becomes the owner of underground constructions, since they are permanently fixed to the land parcel (verticalenatrekking). In the case of a cross-boundary infrastructure, the horizontal accession may be important. In the case of a tunnel it can be uphold that the ownership of a tunnel must not be divided over the intersecting parcels, but that the owner of the tunnel itself is the owner of the point, and thus the parcel, where the main part of the tunnel is fixed to the surface.

As Ploeger and Stoter (2004) stipulated, for the metro, the right of long lease has been used. For instance, for a part of the Amsterdam subway network, the bare owner of the parcel (municipality of Amsterdam) is the 'user' of the subway tunnel. The leaseholder (a private party) has the right to use all of the parcel above the construction, but must tolerate the tunnel under the surface of his land. By means of the conditions imposed to the leaseholder (described in the deed), the use and protection of the construction can be arranged together with the dimensions to which the right of long lease applies and which cause a factual stratification of land ownership. Again, the geometry of the space where the right applies is not maintained in the cadastral registration and it can only be specified in a drawing attached to the deed.

In conclusion, in many countries, including Europe, the development of the 3D properties, including subterranean railway and subway tunnels, is permitted by the legislation of those countries. In some places such as Singapore it was the development of the underground transport system that forced the implementation of the 3D cadastral solutions. The basic issue which arises from the analyses performed by the authors is the registration of the geometry of such objects in existing cadastral databases and their effective 3D visualisation.

2. 3D MODELLING OF A SELECTED SUBWAY LINE - EXPERIMENTAL WORKS

In this section, an experiment which consisted of the analysis of possibilities to integrate different geodetic and cartographic data concerning subway tunnels and their neighbourhood, as well as possibilities for the 3D visualisation of such data, were described. The experiment was to answer the question whether the applied data were of the sufficient accuracy to use them for the future development of the 3D cadastre and for the delimitation of spatial parcels which covered the subway tunnels. Another important aspect concerned the analysis of the possibilities of visualisation of 3D analyses, including necessary analyses for the future geodetic-and-legal procedures in the 3D cadastre, such as the 3D division of real properties etc.

2.1 Datasets in experiment

Within the experiment, a 3D model of subway tunnels was created for selected sections of the subway lines. The basic surveying data, which exist at the Metro Warszawskie Company, are the data of the post-implementation inventory of the tunnels. The inventory was performed using the terrestrial laser scanning (TLS) method and it sought to determine the real deviations of the distance between the inner coating of the tunnel and the designed tunnel axis, i.e. deviations from the distance equal to 2.70 m (the inner radius of the subway tunnel). The measurements were performed using Imager 5006i of Zoller+Fröhlich GmbH with the reference to points of the geodetic control. Moreover, in order to reference scans into the height system, coordinates of centres of signalling targets were determined; thus the reference to the geodetic system was performed (PUH "GeoCad" Sp. z o.o. (2014)).

After referencing the point cloud into the geodetic system, one, common point cloud was obtained in the geodetic reference system. The obtained, maximum error of georeferencing of the point cloud into the geodetic system - on the tie point (the point of the geodetic control) equalled to 0.007 m. The mean standard error scans orientation into the geodetic system was 0.002m for the left tunnel and 0.003 m for the right tunnel. Then, the contractor generated sections orthogonal to the tunnel axis, every 1.5 m and in characteristic points of the tunnel (8 points on the circle for each section). For each point, the x,y,z coordinates were determined and the distance between the point and the theoretical tunnel axis (including the deviation from designed values) was calculated (PUH „GeoCad" Sp. z o.o. (2014)). x,y point coordinates were originally recorded in "Warszawa 75", the local coordinates system, and the z coordinate was recorded in the "0 Wisły", the height reference system.

Instead of a point cloud from the scanning of tunnels, only points from created sections (8 points for each circle) were used as initial data for the generation of the 3D tunnel model; the density of those points was sufficient (every 1.5 m or in characteristic points of the tunnel). The ArcGIS 10.5 and ArcGIS Pro software applications were used for the generation of the 3D tunnel models and for the spatial analyses.

In order to create the 3D representation of the terrain above the subway line, airborne laser scanning data were used. Data were acquired by the Head Office of Geodesy and Cartography within the framework of the project "IT System for Country Protection Against Extraordinary Hazards" – ISOK in 2012 (Kurczyński and Bakuła, 2013). Point clouds were characterised by the average density of 12 points per square meter and by a height accuracy below 10 cm. Figure 2 presents the view of all data in the form of the Digital Terrain Model (DTM) and the Digital Surface Model (DSM) with the outlines of exterior edges of the subway tunnels.

Another data source for the experiment was the cadastral data; especially boundaries of parcels and outlines of buildings from cadastral map, delivered by the Office of Geodesy and the Cadastre of the Warsaw, were used for the experiment.

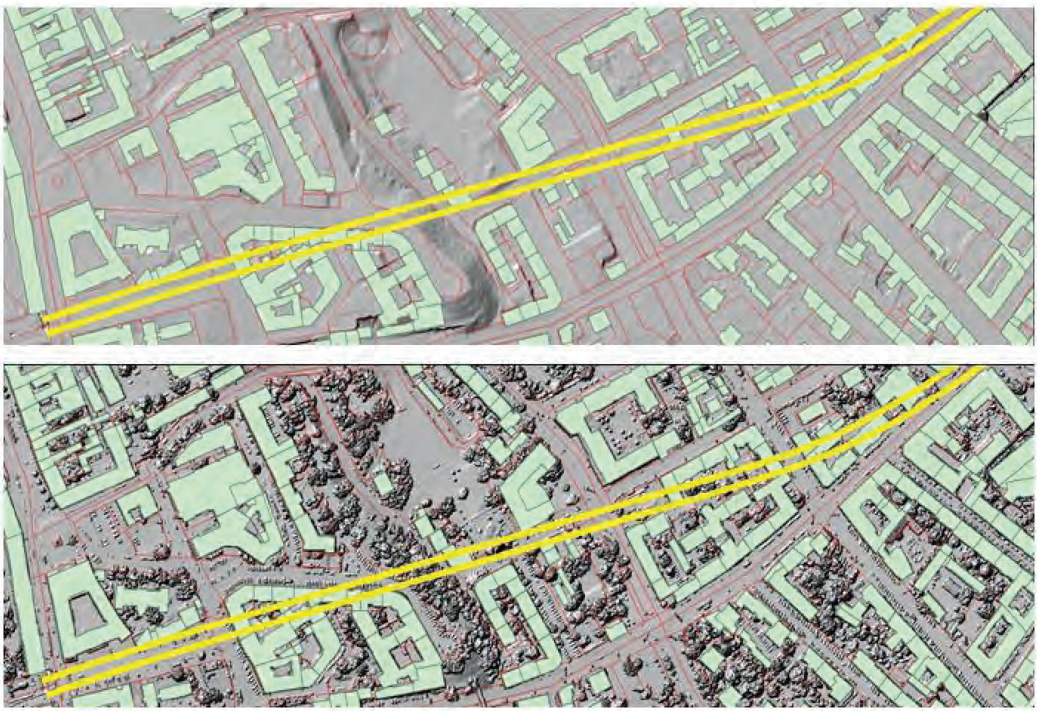

Figure 2. Visualisation of the ALS data in the form of the Digital Terrain Model (above) the Digital Surface Model (below) including the visible, geometric data on the subway tunnel (yellow lines) and cadastral parcel data (red lines) and buildings (green polygons). Source: with the use of data from "Metro Warszawskie Sp. z o.o." and Head Office of Geodesy and Cartography. Figure 2. (below) published in Karabin et al. (2017).

The used data were characterised by very high accuracy, which exceeded the requirements of visualisation and possible analyses aiming at the use of 3D information for the 3D cadastre (see Navratil and Unger, 2011). Geodetic data from the inventory of the subway tunnel makes it possible to create the model of the tunnel interior with the accuracy below 1 cm. It should be stressed that - following PUH "GeoCad" Sp. z o.o. (2014) - points of the geodetic control which were the basis for scanner measurements were characterised by the horizontal error smaller than 3.5cm and vertical below 0.1 cm. Aerial data could be the basis for the generation of the 3D models of buildings of an accuracy similar to the points cloud accuracy, i.e. 10 cm. The accuracy of cadastral data plays the least important role since their accuracy characteristics may be improved in geodetic procedures (boundary marks and boundary traces are accessible for direct field measurements).

2.2 Methodology of 3D modelling

It was assumed that the created digital terrain model of neighbourhood might be generalised for the implementation of the task of generation of the 3D cadastre including spatial parcels with the subway tunnels. Therefore generalisation was only applied for airborne laser scanning data, which were used to create the DTM and models of buildings with details corresponding to the CityGML LoD2 standards.

As a result of the performed processing of geodetic data from the inventory of subway tunnels, a solid model of the tunnel was generated. For that purpose, points were transformed to the state coordinates system PL-2000 and to the state height system Kronsztadt-86. Then the tunnel centre was determined for each profile (using 8 points which created a profile) and then the axis of each tunnel and two solids which represented tunnels were generated (Fig.3). The developed 3D model was generated with the average accuracy of 0.001m for both tunnels. The points of the sections were not located directly on circles which created the solids (the maximum deviations equalled to 0.015 m and 0.009 m for the right and the left tunnels, respectively). Considering the accuracy requirements of topographic and height measurements in Poland, as well as the requirements concerning cadastral data, in the authors' opinion, the achieved accuracy of 3D modelling was sufficient for further analyses.

Based on accessible references covering the issues of the accuracy of determination of the third coordinate which defines the extension of cadastral rights, it may be stated that only two authors, i.e. Navratil and Unger (2011) were dealing with those issues; they considered the use of an appropriate height system in the 3D cadastre and the accuracy requirements, depending on the type of a 3D object and its surroundings. For a railway line, located within an urban area, including a subway line, where the terrain above the tunnels was used for housing development, the accuracy at the level of 16 cm was estimated.

Figure 3: Points in profiles from the laser scanning of tunnels (left) and generated 3D objects representing tunnels (right); Source: with the use of data from "Metro Warszawskie Sp. z o.o.".

Data processing also included the generation of models of buildings. Fig.4 presents the perspective projections of the generated models of buildings located on the DTM with the presentation of the subway tunnels location within the space of the cadastral parcels. The models were generated using the Terrasolid software from classified ALS point cloud by automatic solid models generation and their manual corrections providing product in accordance with CityGML standard. After that they were visualised in ArcGIS. The integration of data could be performed in the GIS environment through "on the fly" data transformation or as a result of changing the data reference system. Data integrated in one system of coordinates allows to visualise the data of the subway tunnels, proceed them in spatial analysis and it also creates the possibility to introduce the 3D cadastre.

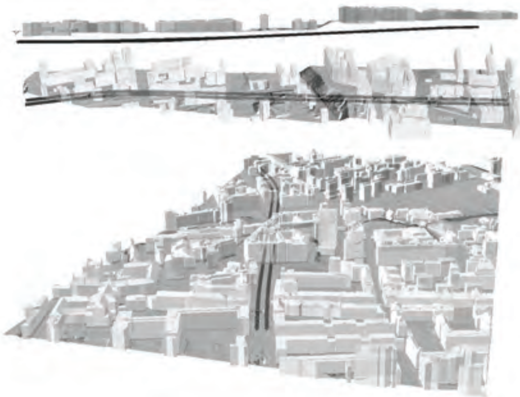

Figure 4: Data visualisation - a perspective view generated with the use of data from "Metro Warszawskie Sp. z o.o." and models of buildings based on ALS data.

3. THE USE OF 3D MODELS OF SUBWAY TUNNELS IN THE DEVELOPMENT OF THE 3D CADASTRE IN POLAND

Standard, two-dimensional data concerning subterranean constructions, installations and infrastructure allow to determine the space of those parcels where those items are located. Their lengths and areas covered by projections of their edges on the horizontal plane may be specified. However, if the task aims at conducting comprehensive analyses of such items, it should be also noted that their locations are changing vertically. Therefore the use of two-dimensional maps and heights of characteristic points, i.e. the analysis in the 2D environment, is not full featured.

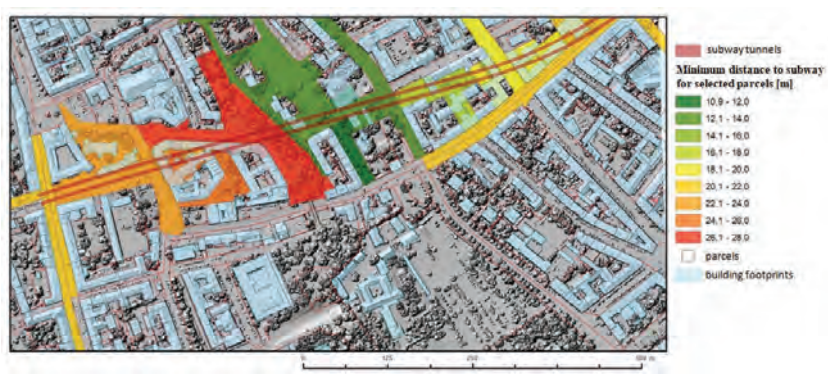

Figure 5. Spatial analysis of the minimum depth to the subway tunnel, performed for parcels where the subway tunnels are located; Source: with the use of data from "Metro Warszawskie Sp. z o.o." and ALS data from Head Office of Geodesy and Cartography.

The generation of 3D models of subterranean engineering constructions and installations allows not only to visualise the real location of such objects in 3D, but also to perform analyses which are not accessible in the 2D approach, such as the determination of the depths of the objects within the selected cadastral parcels, determination of minimum depths (see Fig.5), the maximum and average depths; such data may be used to analyse the risks and impacts of subterranean objects on neighbouring buildings, as well as for the purpose of crisis management etc.

Such technological possibilities meet the requirements of the practical implementation of the idea of the three-dimensional cadastre. Based on models of the subway tunnel generated this way, it is possible to divide the space of conventional cadastral parcels and delineate 3D properties, which include subway tunnels. The space of the existing cadastral parcels, which remains after distinguishing those 3D properties will become the subject of sale to another entity than the owner of the tunnel. Therefore, the possibility to free the areas above the subway tunnels could be achieved; those areas could be used for the investment purposes of other entities, which are not the owners of the subway tunnel, giving them the strong right to the area - the property right.

The GIS software, which was used to integrate and visualise data, allows to perform complete, three-dimensional analyses, which may also be useful for designing other objects of the subterranean infrastructure, for crisis management etc. Figure 6 presents some insights into the spatial conditions of an individual parcel. As a result, the buffer may be designed around the subway tunnels or a prism may be created within the space of a given parcel, which would encompass the subway tunnels, i.e. the 3D property.

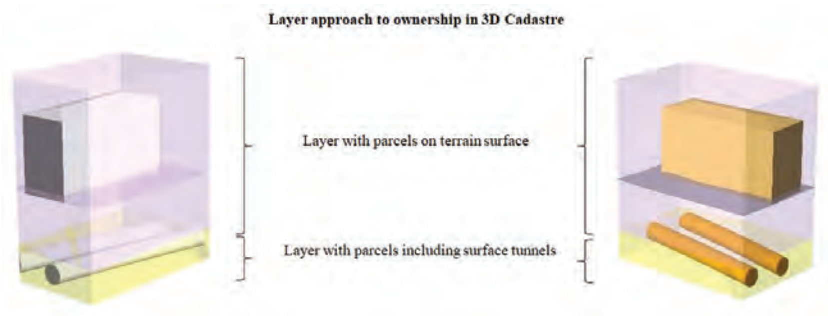

Figure 6: Visualisation of subway tunnels at the level of individual cadastral parcels; Source: with the use of data from "Metro Warszawskie Sp. z o.o." and ALS data.

4. CONCLUSIONS

The integration of cadastral data and 3D subway data makes it possible to enrich the state geodetic and cartographic resources with data which were not accessible in many cases. At present, data presenting locations of the subway tunnels are available in the form of lists of points, used for the discussed experiments (8 points in each cross section) and in the form of point cloud of from terrestrial laser scanning of the tunnel interior, acquired in the process of the post-implementation inventory. The original set of data (points in cross sections) does not allow for any analyses without transformation to the state coordinate system, which is obligatory in the cadastre. Also the "raw" data after transformation do not allow for a complete analysis of the 3D space within the area influenced by the subway tunnels. On the other hand, the second set of data - the point cloud from terrestrial laser scanning requires the use of photogrammetric software LIDAR (which is less available than the GIS software), large disk volumes and data processing skills. Data processing performed within the discussed experiment create the technological basis for the introduction of 3D cadastral parcels, which encompass the subway tunnels, including the possibility to perform further spatial analyses and data visualisation required for effective operations of the 3D cadastre.

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