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Practical verification of Polish 3D cadastral model

Jarosław BYDŁOSZ, Artur WARCHOŁ, Monika BALAWEJDER and Agnieszka BIEDA, Poland

Key words: 3D cadastre, 3D land administration, Polish cadastral model, Terrestrial Laser Scanning – TLS, UML

SUMMARY

The 3D cadastre model in Poland has been developed for several years. The summation of these works is the proposal of the model of the Polish cadastre developed using the UML language on the basis of the existing legal regulations, presented in detail in the work (Bydłosz and Bieda, 2020). The aim of the current research was practical verification of this model. This work was performed on the example of a semi-detached building located near Cracow in a housing estate of family houses.

The modelling of relationships between already existing elements (parcel, building) and proposed 3D cadastre objects was performed in UML language. Problems encountered in proposing 3D cadastre objects resulted mainly from a complicated legal situation. The twin building is located on a parcel of land that is jointly owned by the building owners. The paper proposes to solve such a problem by dividing the cadastral parcel so that the building owners have separate properties. The corresponding UML diagrams are presented here.

The second part of the research concerned the application of laser scanning for practical verification of the 3D cadastre model. For this purpose, the building was measured using laser scanning. This measurement was made outside and partly inside the building. During this research, however, it was not possible to fully apply scanning for the verification of this model. According to the authors, this topic requires further research.

STRESZCZENIE

Model katastru 3D w Polsce był rozwijany od kilku lat. Podsumowaniem tych prac jest propozycja modelu polskiego katastru opracowana z wykorzystaniem języka UML na bazie istniejących przepisów prawnych, szczegółowo przedstawiona w pracy (Bydłosz i Bieda, 2020). Celem obecnych badań była praktyczna weryfikacja tego modelu. Prace te wykonano na przykładzie budynku bliźniaczego położonego niedaleko Krakowa w osiedlu domków jednorodzinnych.

W języku UML wykonano modelowanie zależności między istniejącymi już elementami (działka, budynek) i proponowanymi obiektami katastru 3D. Problemy jakie napotkano przy propozycji obiektów katastru 3D wynikały głównie ze skomplikowanej sytuacji prawnej. Bliźniaczy budynek jest położony na działce będącej wspólną własnością posiadaczy budynków. W pracy zaproponowano rozwiązanie takiego problemu poprzez podział działki ewidencyjnej tak, aby właściciele budynków mieli osobne nieruchomości. Przedstawiono tu odpowiednie schematy UML.

Druga część badań dotyczyła zastosowania skaningu laserowego dla praktycznej weryfikacji modelu katastru 3D. W tym celu wykonano pomiar budynku za pomocą skaningu laserowego. Pomiar ten wykonano na zewnątrz oraz po części wewnątrz budynku. W trakcie tych badań nie udało się jednak do końca zastosować skaningu do weryfikacji tego modelu. Temat ten wymaga dalszych badań.

Practical verification of Polish 3D cadastral model

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1. INTRODUCTION

Information on real estate in Poland is recorded in two independent systems, which are the land and building cadastre and land and mortgage register. The legal basis of the former is the Law on Geodesy and Cartography (Act, 1989) and the regulation concerning the Land and Building Cadastre (Regulation, 2021). Land and building cadastre objects are land parcels, buildings or separate premises (apartments). The information collected in the land and building cadastre primarily concerns their location in the orthogonal coordinate system, but the database also contains a number of attributes describing the physical and legal status of the cadastral objects (Puniach et al., 2018). The only reference to the three-dimensional space can be considered descriptive information on the number of underground and aboveground floors.

The most numerous objects of the land and building cadastre are the cadastral parcels. In the real world, a parcel is a three-dimensional surface that is part of the earth's surface. A parcel of land can be used "vertically" both upwards and downwards, subject to compliance with the law and possibly obtaining the relevant permits. It follows that, in fact, a registered parcel of land is a solid with boundaries that are not fully defined the vertically.

In the conceptual model of land and building cadastral data, a parcel of land is defined as a polygon with enclaves, and for its description the geometry type GM_Surface is used. The representation of the parcel both in the cadastral database and on the map is a simple two-dimensional polygon (possibly enclaves), and the height component (z) is generally not collected and reported.

Another cadastral object is a building. Geometrically, in the real world this object is a solid or a group of solids, parts of which may be located both above and below the ground surface. Edges of such a building are more and more often not straight lines, but curves of various types, and boundary walls are not only parts of a plane, but surfaces of other types. In the land and building cadastral data model, a building is defined as a set of polygons with enclaves and for its description the geometry type GM_MultiSurface is used. The building attributes are among others the information related to the height dimension such as the number of floors above or below ground.

The last in the order of the cadastre object is the premises, which are independent residential premises or premises for other purposes (Act, 1994). In geometric sense a premises is one or more solids, located in the outline of a building. The features related to the spatial reference of the premises are characterized by attributes such as the area of the premises, the area of the appurtenant rooms or the number of the storey on which the premises are located. In addition, a share in the common parts of the building and in the land parcel on which the building is built are generally associated with premises.

Detailed considerations of the actual land and building cadastral objects in terms of their mathematical notation and the recording of their geometry in the cadastral database are presented in (Bydłosz, 2017).

The land and mortgage register operates on the basis of the Act on Land Register and Mortgage (Act, 1982). Land and mortgage register objects are real estates. Real estate can consist of land parcels, buildings or separate premises (apartments). Buildings and premises may be separate properties or may be part of another object. The building may make the same real estate as land parcel and the premises may be part of a building.

Ideas about a 3D cadastre have gained widespread popularity in Poland. In 2010, a questionnaire on a 3D cadastre for Poland was completed within the activities of the FIG Joint Commission 3 and 7 Working Group on 3D Cadastres (Questionnaire, 2010). Such questionnaires were subsequently completed in the years 2014 (Questionnaire, 2014) and 2018 (Questionnaire, 2018).

Since then, much research concerning 3D cadastre has been conducted in Poland. Their scope encompasses theory, practice or very often are the combination of both. The more detailed description of these studies performed till 2020 is presented in (Bieda et al., 2020). In 2020 two papers on 3D cadastre concerning Poland were published. In (Bieda et al., 2020) made a trial of implementing 3D cadastral objects on the example of historical objects. In (Bydłosz and Bieda, 2020) the existing UML cadastral model in Poland is extended, resulting in creating UML model for 3D cadastre. This model is strictly theoretical, without practical verification. The main idea of this research is to verified UML model for 3D cadastre on the example of building surveyed with the application of laser scanning.

2. LASER SCANNING

Much research has been carried out on the registration of ground-based structures. In particular, they relate to general 3D cadastre issues. In the literature, we can meet such issues as visualization (Cemellini et al., 2018) or registration (Dimopoulou et al., 2018). General issues in the field of 3D Cadastre are dealt with, among others, by scientists such as: Adi et. al (2018), Gursoy Surmeneli et al. (2018), Jaljolie et al. (2018) Larsson et al. (2018) and Radulović et al. (2017). There are many limitations when registering 3D objects. The 3D limitations of registration for cultural heritage features are described by Kitsakis and Dimopoulou (2017). On the other hand, 3D restrictions resulting from registration in connection with underground facilities are described by Bieda et al. (2020).

Nowadays, registration of 3D objects is performed with the use of modern geodetic technologies. Primarily, these methods include laser scanning (Warchoł et al., 2019; Warchoł, 2013; Warchoł et al., 2011). Depending on the platform, scanning can be divided into: terrestrial (Terrestrial Laser Scanning – TLS), mobile (Mobile Laser Scanning – MLS), airborne (Airborne Laser Scanning – ALS), or satellite (Satellite Laser Scanning – SLS). The primary task of all laser scanners is to measure the distance of an object from the device. In the case of time-of-flight (TOF) instruments, this distance is a function of the time it takes the beam to travel all the way to the object and back. A special optical system, with a given frequency, sends light beams (most often in infrared) of a specific wavelength and a specific direction. Each reflection from an obstacle is recorded as the location of a point in space, with three coordinates. In the first step in Scanner Own Coordinates System (X,Y,Z) (triad with Sp on Fig. 1), after registration all scans into the project in Project Coordinates System (triad with pr in Fig. 1) and finaly after fitting into National Coordinate System as geodetic coordinates (X, Y, h) (triad with gl in Fig. 1).

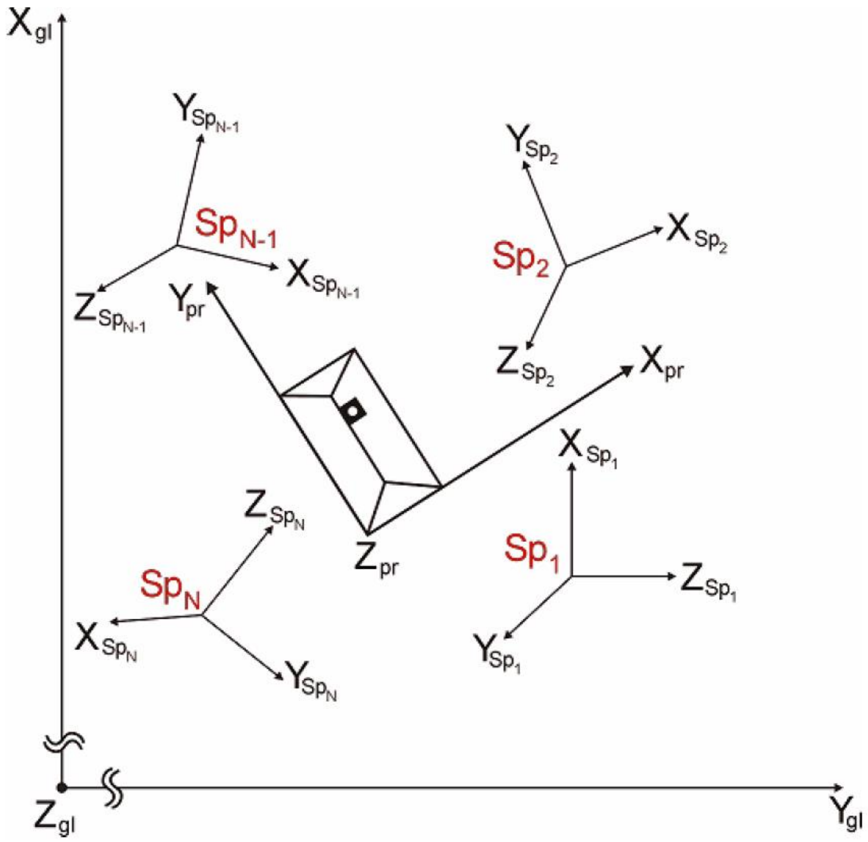

Figure 1. Scheme of changing coordinates from scanner to global coordinates (Riegl et al., 2003)

The advantages of TLS devices over even the most advanced geodetic instruments include on the enormous efficiency of data acquisition (the fastest devices can record up to 2 million points/s), independence of measurements from lighting conditions and high automation of field work, which significantly reduces the interpretive subjectivity of the researcher.

It is worth noting that laser scanning made in LiDAR (Light Detection and Ranging) technology is one of the modern and fast methods of obtaining information about the geometry of objects (Warchoł, 2015; Warchoł and Szwed, 2019; Warchoł, 2019). Therefore, TLS or MLS instruments can be used to acquire 3D spatial data for cadastral purposes. But MLS is difficult to use in dense cities and cannot be reached everywhere with a mobile measurement platform. Therefore, in order to carry out this research for the inventory measurement of the object in question, was performed using terrestrial laser scanning (TLS).

The point clouds were acquired with the Faro Focus 3D X130 terrestrial laser scanner. The entire project consisted of 26 scanner positions, of which scans 1st to 8th covered the facades of two buildings (64A/1 and 64A/2), while scans 9th to 26th covered the interior of one of the twins (64A/2). All point clouds were acquired together with RGB photos. Nominal cloud densities were set at 6.1mm by 10m for the facade and 7.6mm by 10m for the interior of the building. The individual scans were registered into one coherent project in Trimble Real Works 11.3 using the c2c method with an overall Cloud-to-Cloud Error at 1.69 mm. The entirety of the acquired data is almost 680 million points in 26 files with a total volume of 16.3 GB in LAS 1.2 file format.

Then the entire cloud was trimmed to the boundaries of the parcels on which the buildings were located. Then manual cleaning – getting rid of the "noises points" was done. Finally, about 612 million points remained, which were next used to create a 3D BIM model.

3. PRACTICAL EXAMPLE

3.1. General description

In order to carry out a practical verification of the Polish 3D cadastre model, an example was chosen, which is one building situated on one cadastral parcel. This object is located in a housing estate of single-family houses in one of the communes near Cracow (Cracow County, Małopolskie voivodship). The location of the Cracow County is presented in Figure 2.

Figure 2. The location of the Krakow county

The top view of this settlement is shown in Figure 3. The objects for which the 3D cadastral model will be built are marked in red. In addition, their photograph is included in Figure 4.

Figure 3. Top view of the estate, based on data obtained from developer

Figure 4. Photo of the object

As can be seen, the building which is the subject of the study consists of two identical parts with a floor area of approximately 111 square metres each. Both of them could constitute a separate building. As mentioned before, the analysed building is located on one cadastral parcel (1134/10). This parcel is shown in Figure 5. The area belonging to the buildings, identical to Figure 2, is marked in red on it. It consists of two registered parcels (1133/10 and

1134/10). The total area of these two parcels is 408 square metres (including parcel 1133/10 – 50 square metres and parcel 1134/10 - 358 square metres).

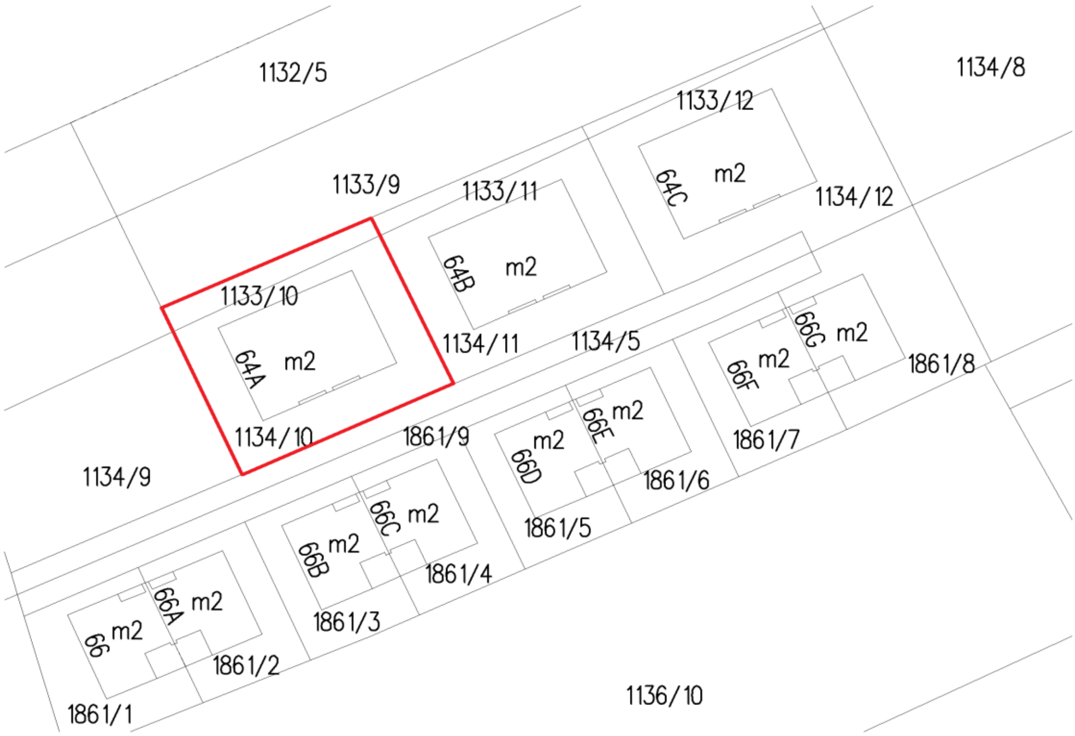

Figure 5. Cadastral map, based on data from the state geodetic and cartographic centre

According to the Polish law, a building (even one consisting of two identical and separable parts), as a component of the land, always belongs to the entity (or entities), which has the ownership perpetual usufruct right to the land on which it stands (Fig. 6a). The existing configuration of the cadastral boundaries makes it impossible to sell part of the building to different entities. In the presented situation, it would only be possible to sell the whole to two entities in fractional parts. In this way, each of these entities would have a share in the parcel, but also in the whole building and its individual parts. Each entity would thus be able, and sometimes even required, to decide on the part of the building that it does not use. Such a situation is clearly unacceptable from the point of view of potential buyers.

In order to be in a position to sell the rights to these buildings to different entities, the simplest thing would be to divide parcels 1133/10 and 1134/10. The surveying division would lead to a pair of identical cadastral objects (the building and the two parcels under it). The boundary between them would be drawn along the wall separating the two parts of the analysed building.

However, for reasons unknown to the authors, the developer did not opt for such a subdivision. We can only presume that it was most likely impossible due to the regulations on divisions of real estate (Act, 1997) in force in Poland. Pursuant to these regulations, a subdivision must comply with the conditions set forth in the local spatial development plan. The parcels in question are designated for single-family residential development with services (Resolution, 2007). In this area, the area of the parcel after division may not be less than 800 square metres. The area comprising plots 1133/10 and 1134/10 is already significantly smaller than this value.

Subdivision may also be carried out regardless of the plan's provisions, but only for the purposes specified in the Real Estate Management Act (Act, 1997). In this situation, two cases could apply:

1) abolition of co-ownership of real estate developed with at least two buildings, erected on the basis of a building permit, if the division is to consist in separation for individual co-owners, indicated in a joint application, of buildings together with parcels of land necessary for proper use of those buildings;
2) to separate a building parcel necessary for the use of a residential building.

In the first case, the entire building and parcels 1133/10 and 1134/10 would first have to be sold to the new owners in fractional parts and only then would they be able to order a partition to cancel the joint ownership. In the second case, the authority approving the division (the head of the municipality) would have to consider the two parts of the merged building as separate buildings that require the separation of parcels necessary for their use.

In order to make the division of parcels 1133/10 and 1134/10 unnecessary, the developer decided to establish, in clearly separate parts of the building, independent residential premises (Fig. 6b), which meet the conditions of the Apartment Ownership Act (Act, 1994). That is, each of them is formed by a room or a set of rooms separated by permanent walls within the building and intended for permanent residence of people, which together with auxiliary rooms serve to satisfy their housing needs.

The right to any premises may be transferred to another entity. Such premises include the right to the common parts of the building and the right to the land on which the building in which the premises are situated is located. In this particular case, there are no common parts in the building. However, the owners of the premises must have a share in the right to the parcel of land located under the building (Fig. 6c). This share depends on the useful area of the premises. Since it is identical in both buildings (exactly 111.33 sq. m), the share in the right to the parcel for those who have the right to each premises is the same, i.e. 1/2. After acquiring the right to the premises with the fractional right to plots 1133/10 and 1134/10, the new owners will be able to independently order a division in order to dissolve the joint ownership (Fig. 6d). After the division, however, only the parcels of land with the buildings as their components will belong to them. Premises will cease to exist because for them to have a right to exist there must be some other parts in the building. Furthermore, they can carry out a merger of parcels 1133/10 and 1134/10 as part of the subdivision procedure (Fig. 6e). The new parcels that will arise from such a merger will be given completely new numbers. These numbers will, of course, depend on what numbers have already been used previously in that cadastral area. They will be the next available natural numbers.

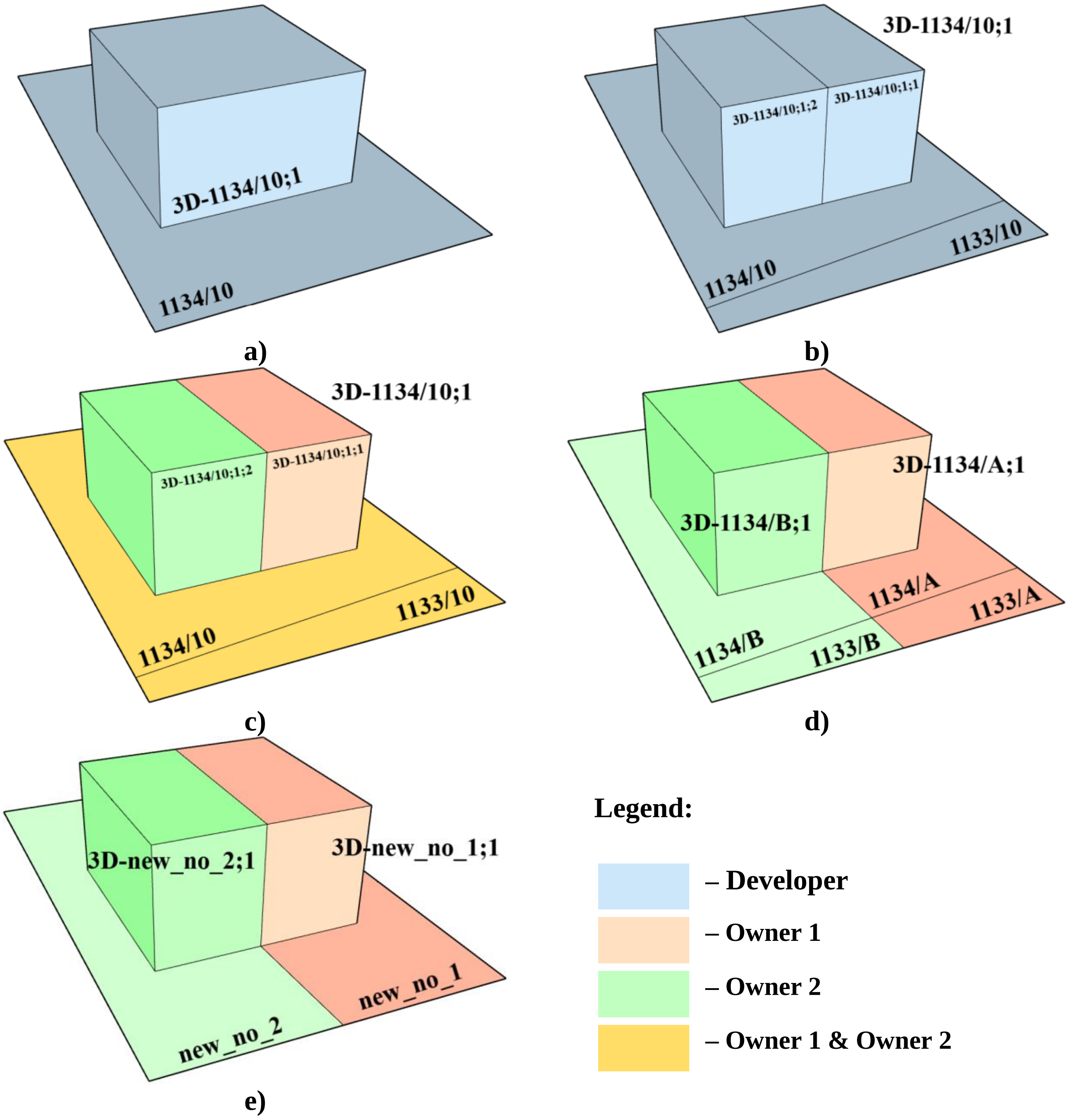

Figure 6. Diagram of the situation: (a) anticipated – one building and one parcel of land belonging to the Developer; (b) actual before the sale – one building with two units and two parcels of land belonging to the Developer, (c) actual after the sale – one building with two units belonging to new entities and two parcels of land co-owned by the owners of the units; (d) obtainable through subdivision – two buildings which are components of parcels resulting from the subdivision of parcel 1134/10 belonging to different entities and "belonging" to them according to the development plan of the estate parcels resulting from the subdivision of parcel 1133/10; (e) obtainable through merger and subdivision – two buildings which are components of parcels belonging to different entities

3.2. Laser scanning

The point clouds were acquired with the Faro Focus 3D X130 terrestrial laser scanner (Fig. 7). The entire project consisted of 26 scanner positions, of which scans 1st to 8th covered the facades of two buildings (64A/1 and 64A/2), while scans 9th to 26th covered the interior of one of the twins (64A/2). All point clouds were acquired together with RGB photos. Nominal cloud densities were set at 6.1mm by 10m for the facade and 7.6mm by 10m for the interior of the building.

Figure 7. TLS instrument Faro Focus X310 during point cloud acquisition

The individual scans were registered into one coherent project in Trimble Real Works 11.3 using the c2c method with an overall Cloud-to-Cloud Error at 1.69 mm. The entirety of the acquired data is almost 680 million points in 26 files with a total volume of 16.3 GB in LAS 1.2 file format (Fig. 8).

Figure 8. Point cloud of the research object coloured by RGB values

Then the entire cloud was trimmed to the boundaries of the parcel on which the buildings were located. Then manual cleaning – getting rid of the "noises points" was done. Finally, about 612 million points remained, which were next used to create a 3D BIM model.

3.3. Models

There are different ways to get a 3D model. The most correct model will be obtained when the designer / architect, translating his idea into an object, performs the project immediately in BIM technology. Other methods are: creating a model based on 2D documentation (vector or paper), or making inventory measurements that will then be used to create a 3D BIM model. In the context of modelling and BIM technology, it is worth remembering that the BIM model is not only geometry but also an information layer in the form of attributes / parameters of individual objects. As a rule, the design documentation and the actual state of the building differ after the building is constructed. Therefore, in order for the developed model to reflect the actual state of affairs as much as possible, it was decided to perform a laser scanning which will be the basis of 3D model.

3.3.1. Models from scanning

Based on the previously prepared point cloud, a 3D BIM model was made. Modelling consists in recreating the real state in digital form, using the elements available in the program and libraries. Bearing in mind the purpose of creating the model and the actual state of the object, the LOD was setting up at level 100. The main structural and architectural elements were modelled – walls, ceilings, beams, roof, doors and windows. However, the inventory did not cover any elements of technical equipment – pipes, conduits nor ducts etc. The final model is shown on Fig. 9.

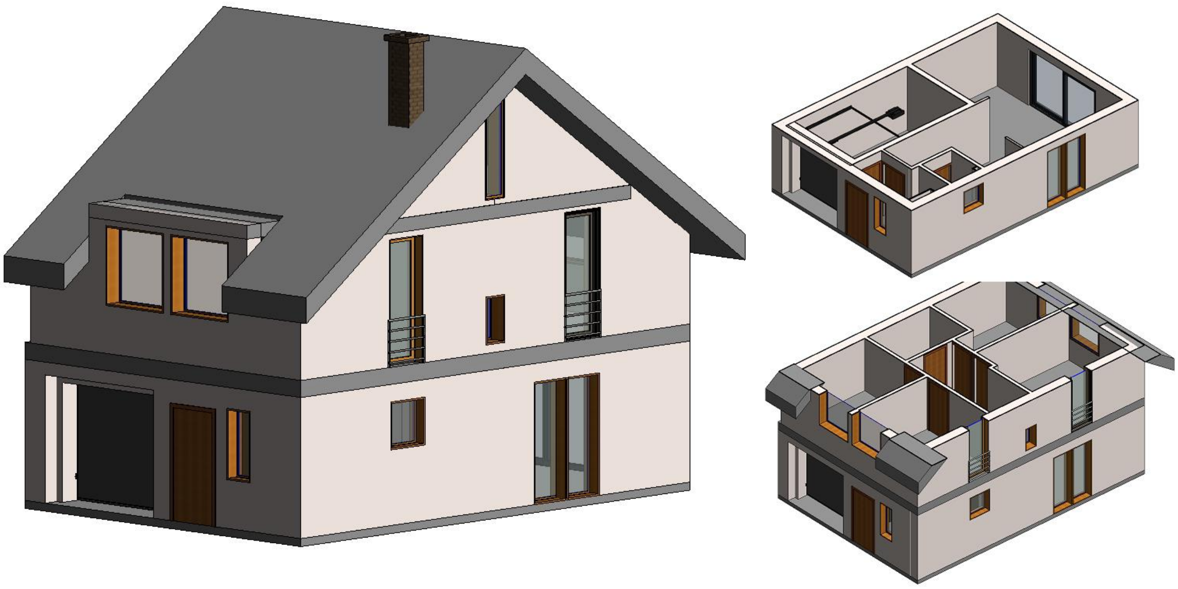

Figure 9. 3D BIM model of the research object (whole on the left) and parts of model divided by levels (right)

The modelling accuracy was estimated at the level of 2 cm on the basis of randomly selected places where the position of the point cloud and the model were compared manually.

3.3.2. Schemas, UML models

General diagram defining the relationships between ‘Cadastral Parcel’, ‘Cadastral Parcel 3D’ and both 2D and 3D building objects was defined in (Bydłosz and Bieda, 2020) and is presented in Fig. 10.

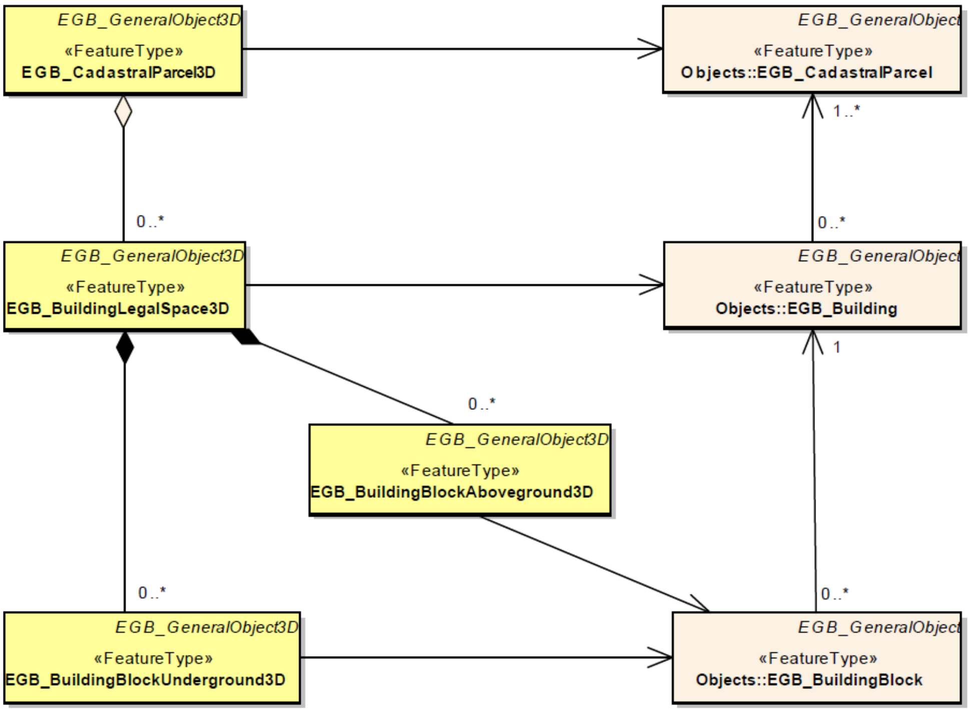

Figure 10. Diagram of defining the relationships between ‘Cadastral Parcel,’, ‘Cadastral Parcel 3D’ and both 2D and 3D building objects, based on (Bydłosz and Bieda, 2020)

As already stated above the subject site consists of two registered parcels 1133/10 and 1134/10 which are built up with two semi-detached houses. The buildings are only located on the parcel 1334/10. In this case there are neither premises and nor building blocks. The parcel is co-owned by the owners of both buildings. In this case it is possible to create ‘Building Legal Spaces 3D’, being part of ‘Cadastral Parcel 3D’ for both buildings. The schema of such situation is presented in Fig. 6b and the UML diagram for this case is presented in Fig. 11.

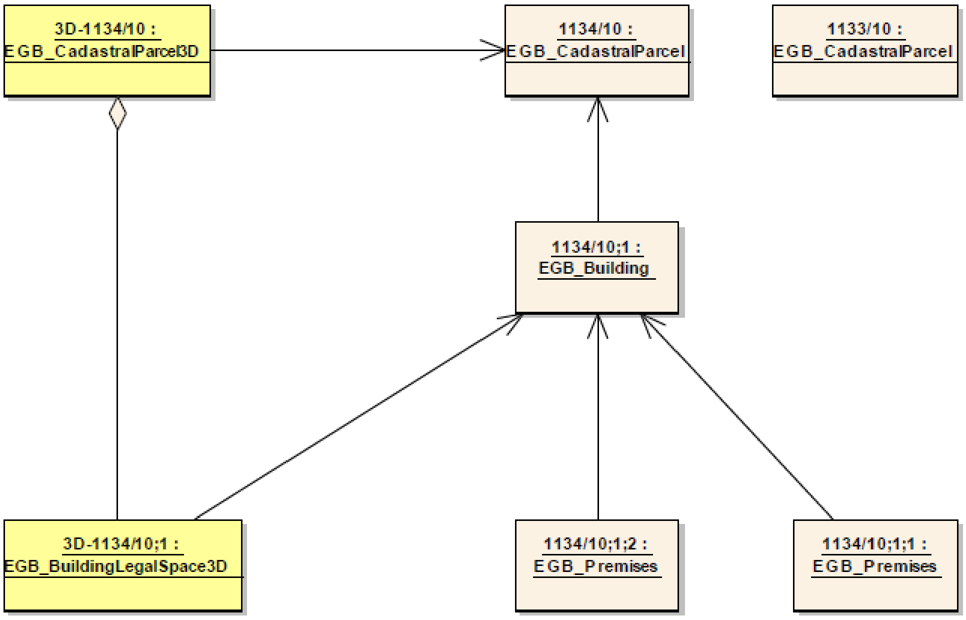

Figure 11. UML Diagram defining the relationships between 2D and 3D cadastral parcels, buildings and its legal spaces for parcels 1134/10, 1133/10 and buildings – corresponds to Figure 6b

The case like this with semi-detached houses and co-ownership of cadastral parcel may be source of problems as theoretically both owners have the right for the whole space above the cadastral parcel (represented by Cadastral Parcel 3D – 3D-1134/10:), except for buildings (represented by corresponding 'Building Legal Spaces 3D').

The possible solution of this problems is creating two separate real estates. It can be done by dividing the parcel in a such a way that every building is situated on the different parcel. A UML schema of subdivision is presented in Fig. 12.

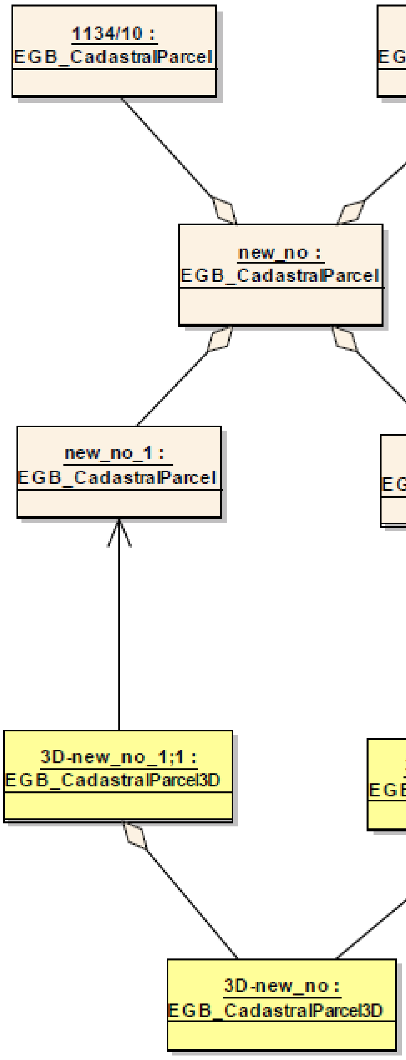

Figure 12. Schema of subdivision and merging of 2D parcels 1134/10, 1133/10 and new 3D cadastral parcels

UML model for such situation (after subdivision of parcel 1134/10 into two parcels) is presented in Fig. 13. The result are two separate real estates. I means that there are different objects like ‘Cadastral Parcel’, ‘Cadastral Parcel 3D’, ‘Building’, ‘Building Legal Space 3D’ for both new parcels.

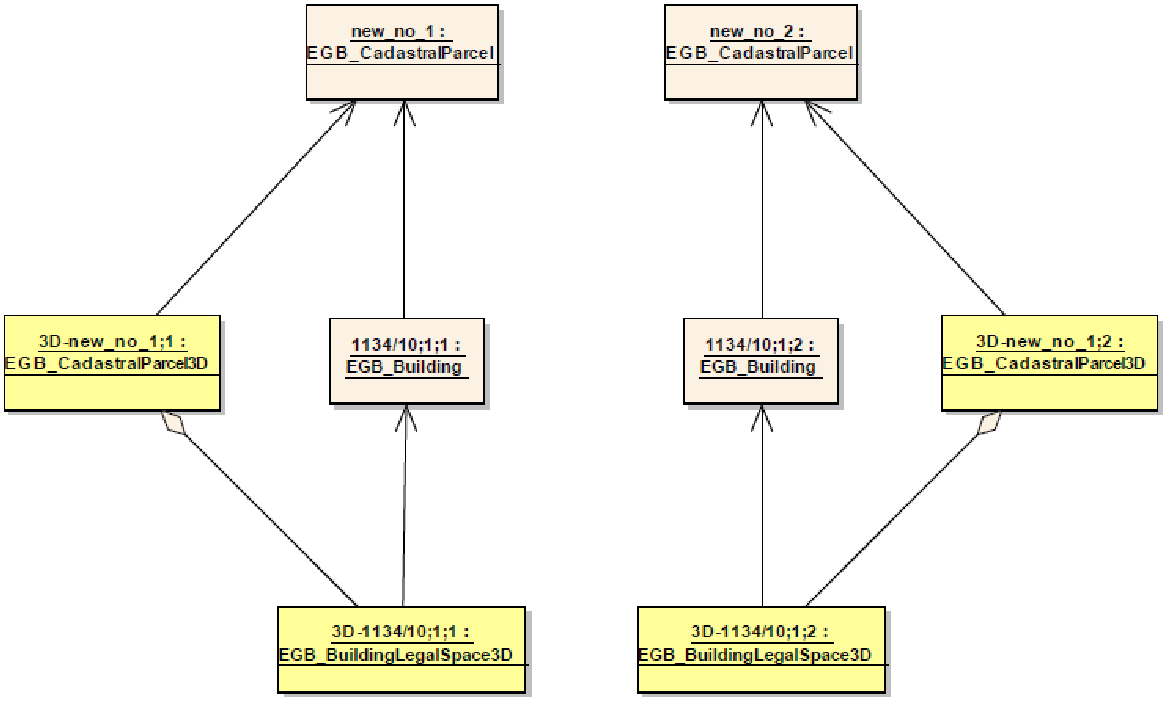

Figure 13. The situation after subdivisions and creating new parcels – corresponds to figure 6e

4. DISCUSSION AND CONCLUSIONS

Some possible problems independent from applied surveying method but resulting from the analysed case appeared. The proposed solution is the division of parcel to create two independent real estates and correspondingly all 2D and 3D cadastral objects.

Preparing a 3D BIM model of an object based on a point cloud from terrestrial laser scanning is more expensive and requires more time than preparing a model based on the design documentation. However, it allows to significantly reduce the risk of improper reproduction of reality, because it is a measurement in nature. During construction works, changes to the design are possible that do not require the consent of the Department of Architecture of the competent authority. There are also changes made by the owners on their own, without the consent of the designer. For this reason, the constructed object may differ from the designed one. Therefore, it is safer to make a model based on direct measurements, among which the fastest and most accurate technology is Terrestrial Laser Scanning (TLS).

However, in the course of this research, the authors did not fully succeed in applying scanning to verify the 3D cadastre model. This topic requires further research.

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BIOGRAPHICAL NOTES

Jarosław Bydłosz obtained PhD at the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow, Poland, in 1997. He has been a faculty member since 2001. Jarosław Bydłosz obtained postdoctoral degree (habilitation) in June 2016. His scope of interests are Geographic Information Systems, cadastre and standardization. The recent activities concern 3D cadastre and issues concerning ISO 19152 "Land Administration Domain Model". Presently, he works as an associate professor at the Department of Photogrammetry, Environmental Remote Sensing and Spatial Engineering, AGH University.

Artur Warchoł obtained PhD at the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow, Poland, in 2014. He completed postgraduate studies in "Airborne and terrestrial laser scanning" (2011) and "BIM - modeling and management of information about facilities, infrastructure and construction processes" (2017) at the AGH University of Science and Technology in Cracow, Poland. At the same time he worked in surveying companies in Krakow. His scope of interests are: laser scanning, 3D and BIM models, GIS. Presently, he works as an adjunct assistant professor at the Faculty of Environmental, Geomatic and Energy Engineering Kielce University of Technology, Poland and in ProGea 4D, Kraków as a TLS and BIM Manager.

Monika Balawejder obtained PhD at the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow, Poland, in 2014. In 2020 she completed her postgraduate studies in soil science and land classification, at the Institute of Soil Science and Plant Cultivation - State Research Institute, Pulawy, Poland. Her scope of interests are real estate management and cadastre as well as land consolidation, land classification, soil science and TLS. Presently, she works as an assistant professor at the Department of Integrated Surveying, the Bronisław Markiewicz State University of Technology and Economics in Jarosław, Poland. She is a member of the Organizing Committee of the FIG Congress 2022, which will be held in Poland.

Agnieszka Bieda obtained PhD at the Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology in Cracow, Poland, in 2011. She has been a member of this faculty since the same year. In 2016 she completed her postgraduate studies in spatial planning at the Cracow University of Technology, Poland. She received her habilitation (postdoctoral degree) from the Faculty of Geodesy and Cartography, Warsaw University of Technology, Poland, in 2019. Her scope of interests are spatial planning, revitalisation and cadastre as well as real estate valuation and market analysis.

Presently, she works as an associate professor at the Department of Photogrammetry, Environmental Remote Sensing and Spatial Engineering, AGH University.

CONTACTS

Dr Jarosław Bydłosz, Assoc. Prof.
Department of Photogrammetry, Environmental Remote Sensing and Spatial Engineering
AGH University of Science and Technology
Al. Mickiewicza 30
30-059 Krakow
POLAND
Tel. +48 12 617 34 31
Mail: bydlosz@agh.edu.pl

Dr Artur Warchoł
Institute of Technical Engineering
The Bronisław Markiewicz State University of Technology and Economics in Jarosław
16 Czarnieckiego St.,
37-500 Jarosław
POLAND
Mail: artur_warchol@o2.pl

Dr Monika Balawejder
Institute of Technical Engineering
The Bronisław Markiewicz State University of Technology and Economics in Jarosław
16 Czarnieckiego St.,
37-500 Jarosław
POLAND
Mail: monika.balawejder@pwste.edu.pl

Dr Agnieszka Bieda, Assoc. Prof.
Department of Photogrammetry, Environmental Remote Sensing and Spatial Engineering
AGH University of Science and Technology
Al. Mickiewicza 30
30-059 Krakow
POLAND
Tel. +48 12 617 34 30
Mail: bieda@agh.edu.pl