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Layer approach to ownership in 3D cadastre in the case of underground tunnels

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ABSTRACT

The paper focuses on approaches to the registration of real property rights in the case of underground or subway tunnels in different EU countries: Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia, and Sweden. The authors conducted analysis on the registration of rights to subway tunnels in the chosen countries, including its effectiveness in ensuring appropriate property rights to construct and exploit tunnels. Special attention was given to limitations related to the lack of legal provisions vertically dividing space, i.e. into layers, and referring to the ownership right to the layers. Benefits which might be achieved by the introduction of a 3D real property subdivision were pointed out. The analysis of the available data concerning the geometry of subway tunnels in particular countries was presented. The authors tried to answer the question whether the accessible data concerning the geometry of subway tunnels allows to generate a 3D geospatial model of a constructed object, and to specify the space which should be determined as a 3D parcel in the 3D real property cadastre, for the purpose of registering property rights for the object (the tunnel).

1. Introduction

At present, implementation of public transport investments (such as subway, railway lines in tunnels and on viaducts, roads on viaducts etc.) are performed in the so-called, "layer" system. This means infrastructure object, such as a tunnel or a bridge, is often allocated over or under a traditional 2D land parcel. Consequently, infrastructure objects are planned and realised at various levels (layers) within the space of a given land parcel. Several parties may be interested in the development of particular fragments of the parcel volume; each of them is interested in purchasing rights only to a specific part of the parcel (its specified layer) where a given investment is implemented by that party. Legal conditions which are binding in many countries do not allow for the implementation of subway type investments within the space of someone else's cadastral parcels, based on the ownership rights. The reason for this is the "superficies solo cedit" principle, which is binding in many EU countries. The ownership right extends above and below the land parcel defined on the Earth's surface, and cadastral systems do not allow to vertically divide a real property (Stoter, 2004; Paulsson, 2007).

The conventional land administration system based on 2D cadastre, which does not allow for vertical division of the parcel space, forces investors to purchase an entire parcel or to get other rights, which allow them to use a specified space of someone else's parcel, such as servitude

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rights. Implementation of such investments in cities, accompanied by purchasing entire parcels, generates additional costs; implementation of investments only below state or municipally-owned land may lead to a less optimal location of a tunnel. The fact that there is no legal capability of vertically dividing land parcels inhibits transactions in case of development of subway tunnels. Namely, following the "superficies solo cedit" principle, an underground infrastructure object is a component of the land parcel, the real property. Consequently, the urban space is not optimally exploited.

Establishment of servitudes for the development of subway tunnels is related to several disadvantages. First it is not subject to mortgage, therefore it cannot be used as credit for investments. The 3D cadastre allows delineating 3D parcels (within a complete volume of the traditional 2D parcels) referring to the specific fragments of the space, and to relate ownership rights to those delineated fragments. Within a 3D cadastre system, such objects can be registered as separate cadastral objects.This allows for the implementation of a line investment in the underground space in a flexible way, i.e. it is possible to get financing of an investment based on the mortgage charge of a 3D property and market transactions of the remaining space after delineation of the 3D subway parcels. The implementation of 3D cadastres brings benefits, but so far the research has not focused to a large extent on subway and tunnel related problems (Kitsakis et al., 2018; Dimopoulou et al., 2018), which, in the authors' opinion, makes this paper a novel contribution.

In this paper, the approaches to the registration of real property rights in the case of underground subway tunnels in the authors' countries are presented, i.e. Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia, and Sweden. The selected countries cover examples from the major legal systems in mainland Europe; the Napoleonic, Germanic and the Nordic legal systems, or combinations thereof. The authors are not aware of an official categorisation of legal systems or "families", but the taxonomy used here is based on Zweigert and Kötz (1998).

The examined countries include both traditional countries where a vertically indivisible land parcel concept prevails (based on the "superficies solo cedit principle"), and countries that have adopted 3D real property legislation (Sweden). This allows not only a comparison between different aspects of the "superficies solo cedit"-based approaches, but also between 2D and 3D real property unit concepts, applied to subway tunnel cases. Since not all of the examined countries have developed underground subway lines, reference is made on the provisions regarding roads or railway tunnels. Two pilot solutions are included in the description of the case study countries. They provide examples of the benefit of using 3D property formation in such cases.

For two of the countries, Poland and Sweden, we provide examples of 3D property formation and its benefits. Those two countries are in different stages of 3D property development. Sweden has already implemented 3D property formation, whereas Poland is still in the research stage. Those two countries did not cooperate in the field of implementation of 3D cadastre.

The paper can provide useful input for other jurisdictions interested in developing volumetric real property rights for underground public utilities. It identifies the different approaches for the establishment of property rights for subway networks, or a proposed 3D cadastral framework. Presentation of practical cases of real property rights for underground subways and tunnels of the examined countries is intended to provide clear insight of the legal limitations and capacities of the legal and cadastral framework deriving from each national legal approach.

The authors analysed the current method of the registration of rights to subway tunnels in the chosen countries, including its effectiveness in ensuring appropriate property rights to construct and exploit tunnels. Emphasis was given to limitations related to the lack of the possibility to vertically divide the space, i.e. to divide the space into layers, and to assign ownership rights to such layers. Benefits which might be achieved by the introduction of a 3D real property cadastre are furthermore pointed out. The authors tried to answer how the owner of a "traditional" 2D land parcel may claim for the ownership or use right to a part of the parcel, where construction of a subway tunnel is planned.

As a separate part, the analysis of the available data concerning the geometry of subway tunnels in the selected countries is presented. The authors tried to answer whether the accessible data concerning the geometry of subway tunnels allows for the generation of a 3D geospatial model of a constructed object, and to specify the space which should be determined as a 3D parcel in the 3D real property cadastre, for the purpose of registering property rights for the object (the tunnel). Therefore, both legal and technical aspects related to the modification of the approach to registration of the rights to the subway within the frames of implementation and operational use of a 3D real property cadastre are discussed.

2. "Superficies solo cedit" principle and "layer approach" to ownership in 3D cadastre

The modern urban environment is characterised by the development of horizontally overlapping constructions, of various land use, extending on multiple height levels, by various stakeholders. In terms of land tenure, statutory establishment of such types of overlapping developments does not comply with the principle of "superficies solo cedit" (right of accession). The "superficies solo cedit" principle dates back to Roman law and is one of the fundamental principles of Land Law, both in Civil and Common Law jurisdictions. According to its stipulation, ownership of land encompasses all developments constructed on it. Consequently, in case of constructions at various height levels, for various purposes and by various stakeholders, the right of ownership is to be assigned to the owner of the land-surface parcel. Similar limitations need to be faced for the registration of the real property rights related to each of the multilevel developments.

However, doctrinal principles cannot inhibit the practical necessities of everyday life, especially in the case of accommodation purposes (van der Merwe, 2010). Within this concept, stipulations regarding the extent and the content of real property were included in Civil Codes, aiming to leave room for real property stratification and to distinguish accession of movables and fixtures to immovable real property. This is also related to the Roman maxim "cujus est solum ejus est usque ad coelum et ad inferos" that describes the vertical extent of real property from the centre of the Earth to infinity. Civil Code stipulations provide characteristic examples both of the former, such as restriction of the vertical extent of real property ownership "to the height and depth that the owner has no interest in opposing against it" or similar stipulations (e.g. German Civil Code (1990), Art. 903; Greek Civil Code (1946), art. 1001), and of the latter, i.e. regulations regarding component parts and accessories of real property. In addition to Civil Code stipulations, specific legislation has been introduced in many countries, in the form of condominium, horizontal property, apartment or strata legislation, allowing vertical segmentation of real property to individually owned real property units, mainly serving residential purposes. However, different types of use may also be allowed. For example, the Uniform Common Interest Ownership Act (2008) of the United States provides that condominiums may consist of unenclosed ground or airspace while, depending on jurisdiction, they can be used for commercial purposes, parking, caravan sites, street markets, mooring spaces ("dockominiums"), and even graveyard condominiums can be established (van der Merwe, 2015; van der Merwe, 2016). More complexities arise in the case of underground infrastructure objects due to their cross-boundary characteristics. Circumventing of the "superficies solo cedit" principle is achieved by constructing underground infrastructures to such depth that surface parcel owners have no interest to exploit, thus no harm or loss to their surface property is considered to be caused. Specific minimum depth of disposal of underground land is not very common in national legislation. For example, in Malaysia, the

minimum depth of underground space disposal ranges from 6 to 15 m, depending on surface parcel land use (Zaini et al., 2013); in the state of Victoria in Australia, alienation of Crown land is allowed only up to the depth defined by the Governor in Council, while in Finland, underground land can be freely utilised up to a depth of 6 m (Vähäaho, 2014). The difference in the Finnish case is that the surface parcel owner owns the underground of his parcel, despite the depth limitation, but does not have the right to use it for construction purposes deeper than 6 m without a permit (Vähäaho, 2014). If the delimitation of the underground space is unclear, as is the case for the vertical start and stop height in China (Zhang et al., 2017), it will lead to ambiguous property rights and the relationship between surface and underground.

Despite practically addressing the problem by developing underground infrastructures to a depth that surface parcel owners have no practical interest to oppose, when the exploitation of a real property over a public utility needs to expand at a new, greater depth, complications arise, resulting either in the cancellation of the planned exploitation or to the expropriation of the surface parcel (Kitsakis and Dimopoulou, 2017). Depending on the jurisdiction, this may imply that, although surface parcel owners cannot exploit their surface parcel to its full extent, there is no compensation provided for the restrictions imposed on the exploitation of the surface parcel's depth (Kitsakis and Dimopoulou, 2017).

The idea of the "layer" approach to the rights and their spatial ranges, registered in the cadastre, has been presented in Dimopoulou and Elia (2012). The necessity to define the range of property rights necessary for implementing the "layer" approach was stressed, among others, by Acharya (2011); Dimopoulou and Elia (2012) and Erba and Graciani (2011). Dimopoulou and Elia (2012) presented such a division of space of the traditional cadastral parcel as seen in Fig. 1.

As a result, space will be divided into the space accessible by the owner, and space, which will be reserved for the State or Local Authority. Karabin (2013) proposed a small modification and considered the necessity of registration of the space owned by the State which will never be a subject of private ownership (for example space necessary for assurance of the air traffic or space where natural resources occur, below the depth accessible by owner the of the surface parcel). It will allow for the introduction of 3D cadastral properties and also for implementation of the 3D cadastre.

It is clear that Roman principles on the extent and the content of real property ownership, form a restrictive framework regarding the establishment of real property rights destined for the development of utilities, especially underground subway networks.

3. Registration of a subway and underground tunnels in selected EU countries

In this section, registration concepts for subway and underground tunnels are presented in the selected countries. The countries are listed in alphabetical order as follows: Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia, and Sweden.

3.1. Subway registration in Austria

Vienna is the only Austrian city with a subway network. The construction started in 1969 and the first section was opened in 1976. The tunnels mainly follow public roads but parts of the tunnels intersect private property. The Austrian cadastre is purely based on 2D-representation of land parcels. Thus, it was and still is not possible to register the tunnels as separate property. Easements are documented in the land register in order to protect the rights of the landowner and the subway authority. A major problem with this approach is that easement extents are not visible on the cadastral maps. Negotiations with the landowners on compensations start during project planning, and contracts on this matter are signed before constructions start, although the final easement documents are established after finishing the construction to prevent changes to easement documents due to minor changes during construction of the tunnels.

The easement document consists of a text document describing easement in detail and the compensation paid for it, as well as a graphical appendix defining the spatial extent. This document is part of the document database of the land register. Documents registered after 2012 are available in digital format, those registered before are only available in analogue format. The vertical extent is typically shown in the form of one or more cross-sections with heights based on "Wiener Null" (152.68 m above level Trieste). This would allow for a 3D geospatial model with higher quality in plane coordinates than in height. The document shows data on both the actual construction and the protected volume (Fig. 2).

A detailed 3D documentation would be necessary to simplify future planning of infrastructure which is a spatial 3D object. However, the Austrian cadastral authority (BEV) is currently not planning any change from 2D to 3D, although BEV president Hoffmann recently identified it as an important topic for the future (Hoffmann, 2018).

3.2. Subway registration in Bulgaria

After the totalitarian regime, a new Bulgarian civil law was written and accepted. The development of the digital cadaster started in the 1990s when a huge part of the territory of the country was restituted. The new Law on ownership and Cadastre and property act (CPRA) was accepted. The Agency of Geodesy, Cartography and Cadastre (GCCA) established in 2001 is the legal institution responsible for Cadastre and property register acts for the whole country. Currently, around 20 % of the country has digital 2D cadastre. For some complex buildings, 3D drawings are attached in the 2D cadastre system as supplementary materials.

The capital, Sofia, is the largest city of Bulgaria and the 12th-highest

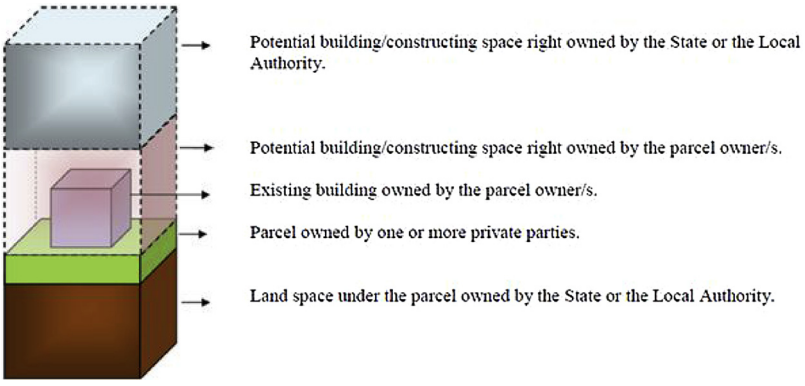

Fig. 1. 3D legal and spatial ownership right clarification (Source: Dimopoulou and Elia, 2012).

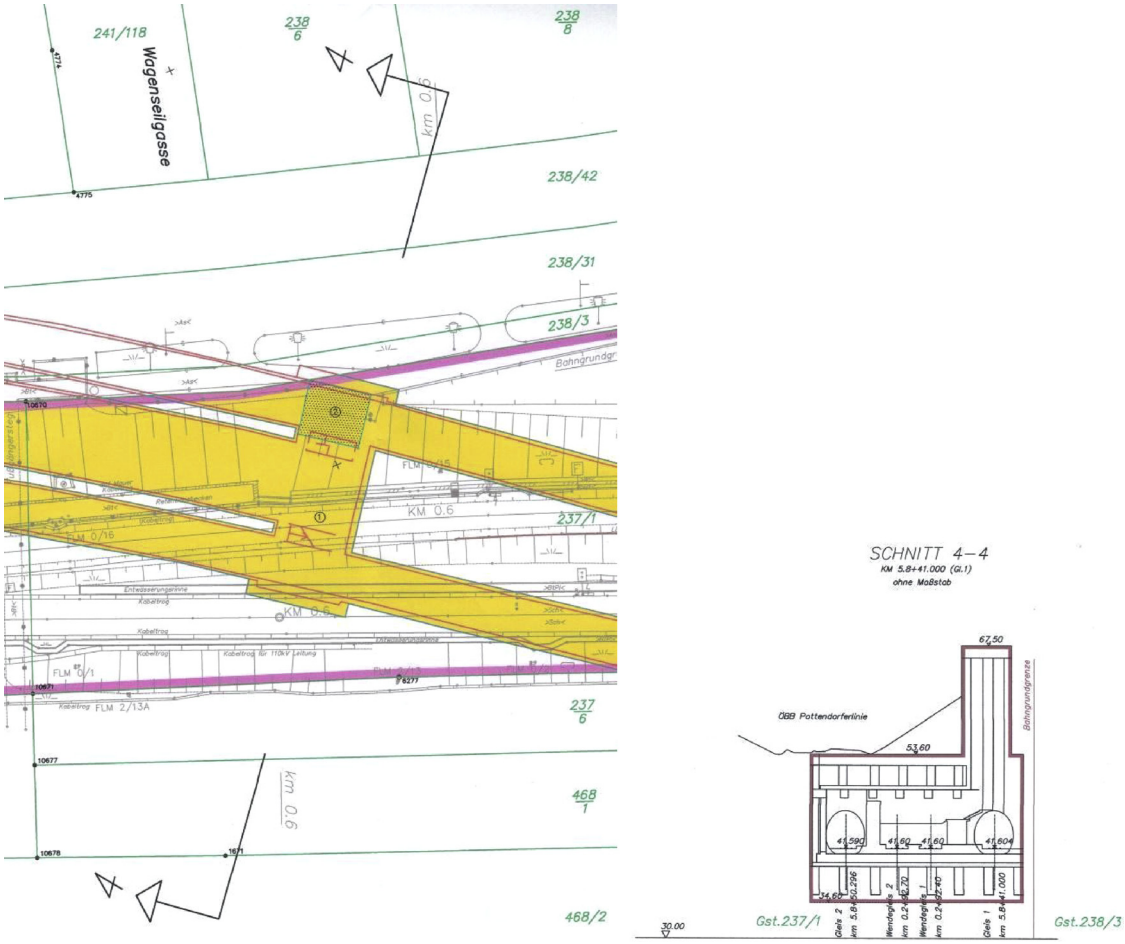

Fig. 2. Details from the easement plan for the subway line, U6 (Source: Korschineck & Partner Vermessung ZT-GmbH).

populated city in Europe. Its population is 1.4 million. The increased population of Sofia forced the construction of the underground metro system. The planning of the metro started in the 1960s and was executed for the first time in the 1990s. It was designed to provide quick and safe transport to the citizens. Bulgarian Metropolitan-Sofia JSC is the operator of the metro system (Metropolitan, 2018). According to the technical and economic report on the metro and the approved General City Plan, the General scheme should consist of three lines, with a total length of 65 km, 63 metro stations, and a 1.2 million daily passenger capacity at the final stage of implementation. The length of these three lines is 29 km, 17 km and 19 km. The first line serves 23 stations, while the second and third will serve 17 and 23 stations respectively. All three lines intersect triangularly in the city centre. Line M1 and M2 are fully operational and it is expected that at the end of year 2019, the third line will be opened.

In Bulgaria, the registration and recording of the underground utilities are not different from the land parcels. It is still in 2D, despite the high level of complexity in the city. The geometric information is limited and is not enough for the generation of 3D geospatial models, therefore, there is no legal 3D space distribution. There is no formal registration of the underground tunnels, only the ownership of the surface parcels are considered and discussed. Usually, underground constructions, such as tunnels, follow big public roads. However, there are parts intersecting with private properties. The Bulgarian system is a deed system, which means that for the transfer of legal rights, a private notary is needed. When the planning for the underground metro development started, the owners whose properties intersected with the territory for metro construction ownership were contacted. Therefore, negotiations for compensation for transferring the property from the private owners to the municipality were made. Sometimes the offered compensation is monetary, however, it can be with another property of similar value. After the agreement with the owners, new, detailed contracts were signed. For each new line of the metro, 30–50 parcels needed to be negotiated between the Sofia municipality and the private owners. (Dnes, 2018)

The Sofia underground is shown on the cadastral map in 2D. It can be freely accessed from the geoportal maintained by GCCA as shown in (Fig. 3). For several parts, 3D plans and visualisations are attached in the 2D system to the respective parcel, however, such models require special access.

The data visible in Fig. 3 is publicly available, according to the Cadastre and Property Register Act which has been adopted in 2000, in 2D form only (Law on Cadastre and Property Register, 2006). In the blue colour, the outline of the property for the underground metro is underlined. What is visible is the current owner, the municipality, and the functionality, which is the construction for transport and includes 16 self-constrained objects (SCO) objects (apartments, studious, shops, garages, recreation and health centres etc.) covering an area of 4948 m^2, as well as the address. The numbers of the neighbouring parcels are also accessible. If someone requests an official report for this particular metro station an automatic output can be generated. However, all information about the former owners is not available to the public. It can be provided only to the owner or notary upon request.

In Bulgaria, it is not expected to have changes in terms of 3D registration of the underground in the regulatory framework. The future plans for the underground are related to the extension of the current lines and building of new ones without changes in the cadastral and legal procedures for this purpose. In the future, it is planned that Sofia's

Fig. 3. Central metro station Serdika extracted from the GCCA system requested by Emilia Angelova.

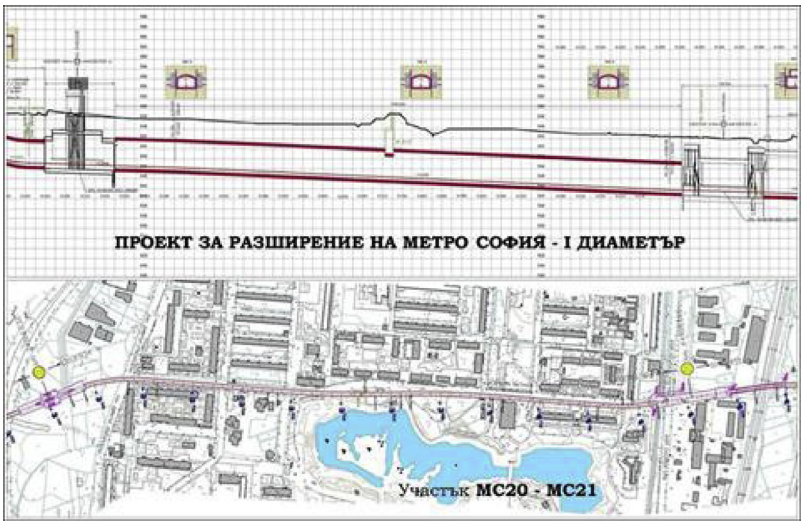

Fig. 4. Project for the extension of the line leading to Sofia airport (Source: https://www.metropolitan.bg/razshiryavane/istoriya-razvitie-metro/razshirenie-etap-3 accessed on April 2, 2019).

Metro Line 1 will be extended towards the south-east leading to the airport by 2020 (Fig. 4). However, the plans for the extensions are still in 2D and are related to the overground parcels.

3.3. Underground tunnels registration in Croatia

In the Republic of Croatia there are no cities with a subway network, except the City of Split, where a short subway line has been operational since June 2019. Underground traffic objects, such as road or railway tunnels, are registered in the Croatian Land administration only on topographic maps.

The tunnel, which was built under several cadastral parcels, would, in a vertical sense, belong to those cadastral parcels. However, in practice, it is permanently connected to the land where the entrance to the tunnel is located, and not to the cadastral parcels extending above it (Vučić et al., 2017). Therefore, according to legislation, the tunnel is permanently connected only to the land parcel where its entrance is located, which makes it one property. Further development of software and hardware technologies for spatial information has made it easy to combine geodetic and cartographic products in the modern digital environment. Today, all Croatian cadastral offices maintain digital cadastral maps overlapped with orthophoto images, and all other geodetic and cartographic products are available on the Croatian SGA Geoportal (https://geoportal.dgu.hr).

At this point, tunnels are not recorded in the land register, although the number of inquiries for registration of such or similar situations is rising, particularly regarding underpasses and overpasses, where they overlap with natural objects or private, while in cadastre, tunnels are recorded only on the cadastral map (with topographic symbols).

Currently, Croatian legal framework is not well-regulated regarding tunnels, bridges and underpasses, although it is undeniable that these buildings should certainly be entered into the land administration system (in the cadastre and land registry).

There are no changes anticipated in the Croatian regulatory framework regarding registration of RRRs (rights, restrictions and responsibilities) and cadastral registration of subway lines. Currently, there are no serious plans to build a subway in any of the 4 largest cities of the Republic of Croatia, but the situation in the City of Split entails some good projects and plans for the near future.

3.4. Subway registration in the Czech Republic

Prague is the only city in the Czech Republic with a subway network. The subway network is the core of the entire public transit system

with 61 stations on three lines (A, B and C) with a total length over 65 km. Presently, the subway network is going to be extended for the new line D.

The Civil Code (Act No. 89/2012 Coll.) considers that the underground construction is characterised by separate special-purpose use (like a subway) as real property. However, in practice, many underground constructions are not registered in the cadastre. Currently, underground constructions are only registered when some part(s) of the construction is located above the ground.

The subway is often located below the parcels of other owners. There are in principle several ways of negotiating with landowners during project planning: the landowner can sell his or her parcel or a servitude can be established. The last option is the so-called temporary land take (a kind of lease contract). The owner of the parcel can potentially claim for financial compensation. The established easements are then registered in the cadastre and visualised on a 2D cadastral map. The right of easement is related to the (part of) 2D surface parcels. The (2D) spatial extent of the easement depends on the agreement between the parties (participants). The formalities of the proposal for entering the easement into the cadastre consists (among others) of a document, based on which the right should be registered, an indication of participants and an indication of real properties to be registered. The underground parts (tunnels, stations) of the subway network are neither registered in the cadastre nor drawn on the cadastral map. Only the parts of the subway network (partially) located above the ground are registered in the cadastre and displayed on the cadastral map in the same way as are the buildings or bridges. In spite of that, the solid geometry could be constructed from the project documentation, which generally is not publicly available.

To build a new underground construction, detailed documentation also containing 3D geospatial data has to be created. Such 3D geospatial data can then be used for the construction of the 3D geospatial model, for example, using BIM (Building Information Management, see Fig. 5).

The 3D geospatial model is a private ownership of the company and it was not available even for research purposes. Only the visualisations of the 3D model was available.

The Law on Railways (Act No. 266/1994 Coll.) defines the protected zones around the constructions. The boundaries of the protected zone could potentially serve to determine the spatial extent of the 3D parcel. Currently, there are no planned changes in concerned regulations.

3.5. Subway registration in Greece

Greece is currently under cadastral survey in order to complete the Hellenic Cadastre project. Hellenic Cadastre is regulated by Law, 2664/, 1998, while cadastral survey procedure is regulated by Law 2308/1995 and its later amendments. According to Law, 2664/, 1998 (art. 12), Hellenic Cadastre records all deeds that establish, transfer, change or abolish rights on real property. Inheritance, seizures, long-term leases, administrative acts and court decisions are among the registrable rights on the Hellenic Cadastre. Registrable rights' declaration is required by every natural and legal person that has such rights on real property. Real property is regulated by the Greek Civil Code (Book 3), which is in accordance with the Roman principles on real property (art. 948, 952, 1001). However, the same articles limit the vertical extent of surface parcel owners' rights to the height and depth "that the owner has no practical interest in opposing against it".

The subway system is established to serve mass transit to the conurbation of Athens, while another subway system is under construction in the city of Thessaloniki in Northern Greece. The subway system of Athens (Attiko Metro, 2018), comprises of two lines, while it has also incorporated the former railway line joining Athens with the port city of Piraeus. Currently, the Athens subway network covers the length of 85.4 km with 61 operational stations, while its main part is underground, at a depth ranging from 14 − 31 m, to protect archaeological antiquities. Further extension of the subway system is already on-going, while a fourth line has been designed and construction works are anticipated to begin in 2019 (Attiko Metro, 2018). Development of each subway system is regulated by specific legislation covering property rights, expropriation, protection of utilities and other issues.

In Greece, cadastral registration of subways does not differ from this of contemporary land parcels. However, there is no provision regarding registration of underground subway tunnels, but only of surface parcels where subway stations are constructed, and of privately-owned land parcels (or land parcel parts) that were expropriated for the construction of the line. It is noted that the greatest part of Athens' subway system is developed below public roads, while a smaller part is developed below private properties, which were expropriated (when required) according to the Expropriation Law. Even in such cases, expropriation applies to surface parcels (or surface parcel parts) as a whole, not to volumes of subsurface space. Owners of land parcels affected by the development of the subway line, are obliged to tolerate the construction of tunnels and all other works related to the development of the subway network without any compensation, as long as current use of the land surface parcel is not affected (Law, 1955/, 1991Law /, 2020Law, 1955/, 1991, art. 10, par. 2). Given the depth that subway lines are developed in Greece, it is considered that there can be no property rights of land surface parcels to that extent (although there is no such provision in law, this issue is addressed indirectly based on the Greek Building Code provision that permits the construction of up to two underground floors (which range from 6 to 8 m depth) (Papageorgiou, 2015). However, this restricts the capabilities of land exploitation by the surface parcel owner when exploitation of a real property over public utilities needs to expand at a new, greater depth (Kitsakis and Dimopoulou, 2017).

There is no difference in recording the subway system from recording a traditional land parcel. However, geometrical information is required only regarding surface parcels (where the subway stations are

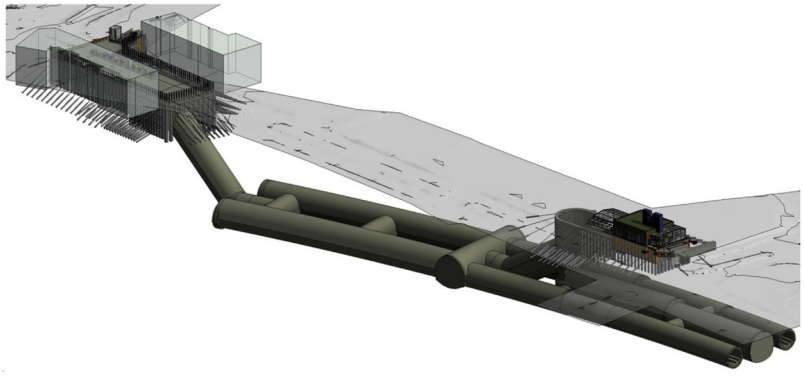

Fig. 5. The usage of BIM data for the creation of a 3D geospatial model of the metro (Source: METROPROJEKT PRAHA, a.s.).

situated) and expropriated land parcels, or land parcel parts. There is no geometrical information registered regarding underground tunnels. Therefore, available cadastral geometrical information is not sufficient for 3D geospatial modelling of the subway line. Within the same context, there is no available cadastral geometrical information to specify the legal space of subway tunnels.

There are no changes anticipated to the Greek regulatory framework regarding registration of rights, restrictions and responsibilities (RRRs) and cadastral registration of subway lines. Regulation of real property issues regarding the subway is based on specific legislation, therefore there is no general regulatory framework to amend. Moreover, given that the Hellenic Cadastre project in Greece is in progress, potential amendments in the legal and cadastral framework are anticipated to be discussed after the project's completion. Besides, Cadastral Law (2664/1998) provides for the principle of "open cadastre", which leaves room for further enrichment of cadastral databases with additional land-related information in the future (Art. 2), such as land values, or Public Law Restrictions. In the context of 3D Cadastre, "open cadastre" principle may refer to the registration of height information of cadastral objects on the cadastral database, and to the introduction of 3D cadastral objects (provided that statutory legislation allowing volumetric RRRs is established).

3.6. Subway registration in Poland

Warsaw is the only city in Poland with a subway network. The subway network consists of 2 lines (M1 and M2). M1 line consists of 21 stations and has a length of about 23 km, while M2 line is now under construction (7 stations from 21 are finished and fully operational, the total planned length is 31 km).

The entire route of the underground railway is traced under land owned by the Capital city of Warsaw. The route of line M1 runs under the main streets of the city and it exceeds the streets only in subway stations. The route of line M2 is crossing parcels with buildings which are located on land owned by the city. Therefore, it was not necessary to establish limited rights related to tunnels, which are not cadastral objects (Karabin, 2011). Private property cannot be divided into spatial properties - in other words into layers, so the only way to build a subway is by expropriation of the whole or part of the land parcel, which includes the space above and below the ground. According to the principle "superficies solo cedit", it is not possible to sell a ground parcel without space below a ground which includes a tunnel. As it was stated in Karabin (2011) in the context of the subway in Poland – the only information accessible in the cadastre refers to subway stations which have the nature of buildings, as well as about accompanying technical buildings related to ventilation of the tunnel etc.

According to the regulation of the Ministry of Administration and Digitisation (dated October 21, 2015) on the district and the national Geodetic Database of the Technical Facilities (GESUT), the subway tunnels are the objects of the GESUT database and they are presented on base maps only. Full technical documentation of tunnels is stored at Metro Warszawskie company. Those documents are post inventory documentation deriving from tachymetric surveys for stations and tunnels, realised via strip methods and laser scanning. Finally, the publicly accessible information about tunnels is included only in the base map in the form of projections of tunnels' edges (Fig. 6).

The basic surveying data, which exists at the Metro Warszawskie Company, are the data of the post-implementation inventory of the tunnels. The terrestrial laser scanning (TLS) method was used for inventory surveys for M2 line. The measurements were performed using Imager 5006i of Zoller + Fröhlich GmbH with reference to points of the geodetic control (PUH "GeoCad" Sp. z o.o., 2014). This documentation is classified "for internal use only" for security purposes and due to the "top secret" status of the subway. It is generally forbidden to publish any detailed information concerning the precise location of a subway using the national reference frame and provide such information to the public.

There were several initiatives in the Ministry of Infrastructure concerning the introduction of a new category of the property i.e. independent building construction (tunnels, viaducts etc.). In the long-term, this could result in the introduction of 3D cadastre, as a necessary tool for registration of the geometry and the extent of new categories of property. Currently, it is not possible to establish tunnels as separate real property units. The Ministry is being pressed by many parties to provide legal instruments that allow layer division of a property space. Railway companies and Metro Ltd. are very interested in such changes.

The new draft act, the so-called, "City Planning and Building Code" which is not yet in force, reads, in its Article 82; "Resolutions of a local plan may identify different destination and ways of development of the space below, over and at different levels in relation to the terrain surface. In such a case the local plan explicitly defines the altitude and depth of a given destination". As it turns out from opinions of lawyers, presented in Krzyżanowska (2016), most lawyers dealing with building law have interpreted that as a forerunner of important changes in legislation, expected for many years, which will finally allow for effective investing on lands being a property of another entity, such as for example, the State Treasury. However, it is expected that proposed regulations will not revolutionise the current situation, they will only remind municipalities that - when local plans are developed - it is possible to "break out" of the terrain surface and to design constructions in a 3D manner, with consideration of different destinations at different altitudes, below and over the terrain surface.

The experts have been stressing that, as a result of the introduction of the possibility to establish the "layered property rights", it would also be possible to implement the multi-plane development of attractive spaces in city centres, where development capacities considerably exceed their current use (for example, areas located close to the cross-town railway line in the Ochota District in Warsaw). Therefore, the above solution would be advantageous for the Polish State Railways (PKP). As a result of the "layered property rights", it would be easier to construct underground parking areas - under roads and other public areas, as well as under private real properties. However, considering the lack of relevant legal institutions, implementation of such plans is highly difficult and it requires legally balancing efforts. Difficulties are caused by financial issues (some problems are related to establishing mortgage financial security – red.), as well as by the later commercialisation of such investments.

To conclude, fragments of the article" *Should the layered property be permitted by law?*" can be cited (Tycner, 2014): "Large areas of undeveloped spaces even in centres of *towns*. Many Polish cities look like this. As urban planners say, spatial gaps are clearly visible in Warszawa, Krakow, Poznań, or the Tricity. They are the result of lack of ideas or investors, but also of lack of relevant regulations. This concerns the layered property".

The Warsaw University of Technology conducted experimental works concerning the integration of data from terrestrial laser scanning of the interior of two subway tunnels with cadastral data (cadastral map) and ALS data and DTM data of terrain above tunnels. As a result, integrated 3D models of underground and terrain were created (Figs. 7 and 8). 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 detail, it is described in Karabin et al. (2018).

Experimental works proved that it is possible to get sufficient accuracy for the visualisation of metro tunnels and use it in cadastral studies and works. Finally, it is possible based on the created 3D model to divide the space of cadastral parcels into layers and delineate 3D properties, which include subway tunnels. The GIS software used also allows performing complete 3D analyses, which can be useful for designing other underground objects and crisis management etc. (See also Karabin et al., 2018)

Experimental studies show that there are technical possibilities of 3D cadastre implementation in the case of the subway. On the other

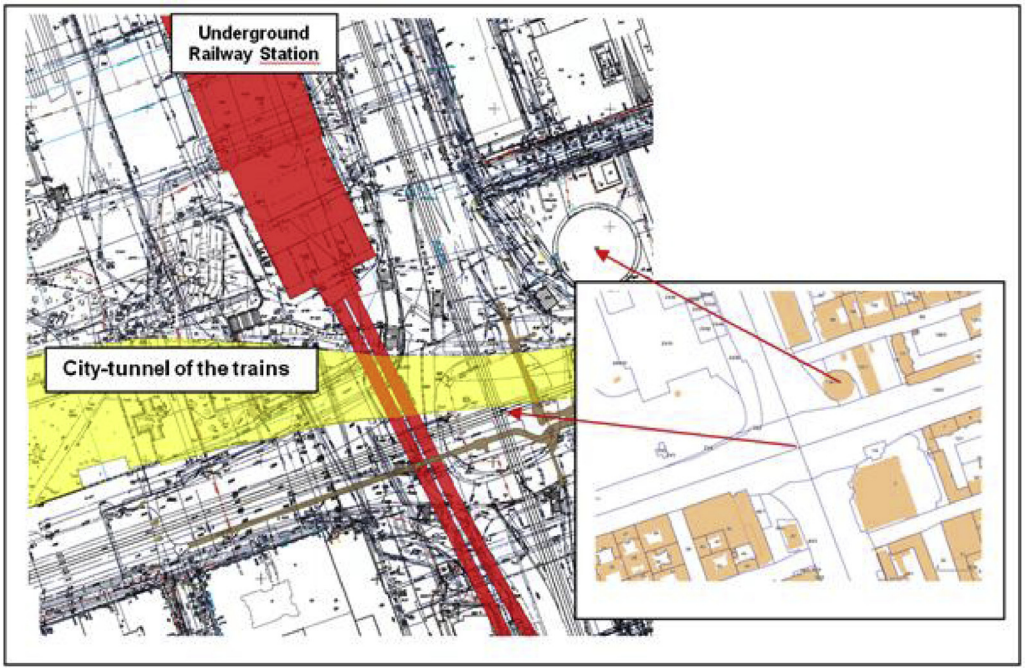

Fig. 6. Subway data on a cadastral and base map Source: The Office of Geodesy and Cadastre for the City of Warsaw – published in Karabin (2011).

hand, it is not possible from a legal point of view. As it was stressed in Karabin et al. (2018), there were some initiatives concerning the introduction of independent ownership of the built objects such as underground tunnels, viaducts etc. but those ideas did not pass the legislation process. The principle "superficies solo cedit" is still operating in the case of the subway.

3.7. Underground tunnels registration in Slovenia

In Slovenia, there are no cities with a subway network. This does not mean that there are no challenges in registering underground traffic objects, such as roads or railway tunnels which cross the complex urban environment and are often intersecting private properties. Like in the other countries included in the study, the Slovenian land administration system is based on the principle "superficies solo cedit", that is, the ownership of a piece of land generally comprises also the ownership of all constructions erected on the land. Exceptions to this principle are (1) the right of superficies (the right to own a building above or beneath the land owned by a third person), and apartment ownership (condominium). The right of superficies and apartment rights separate the ownership of physical objects from the land itself.

The roots of the Slovenian land administration system are in the Austrian cadastre and is still based on a 2D-graphical representation of the land parcels. This traditional 2D-cadastral approach did not allow the registration of real property if a traditional land parcel needed to be vertically divided. For the purpose of registering parts of buildings (condominium), an additional database, linked with the land cadastre - the building cadastre - was established based on legislation from 2000 (Drobež et al., 2017). It is planned that the land cadastre and the building cadastre will be merged into the real property cadastre by 2020.

According to Slovenian legislation, a building is a construction where a person may enter and is designed for a person's permanent or temporary residence, conducting a business or any other activity, and cannot be moved without damage of its substance. The problem arises where the overlapping horizontal interests appear to be related to other construction objects, that are not classified as "buildings". For the registration of tunnels, as an example, there is no particular solution in the current land administration system. Registration of rights, in this case, might be different from case to case as it is dependent on the time

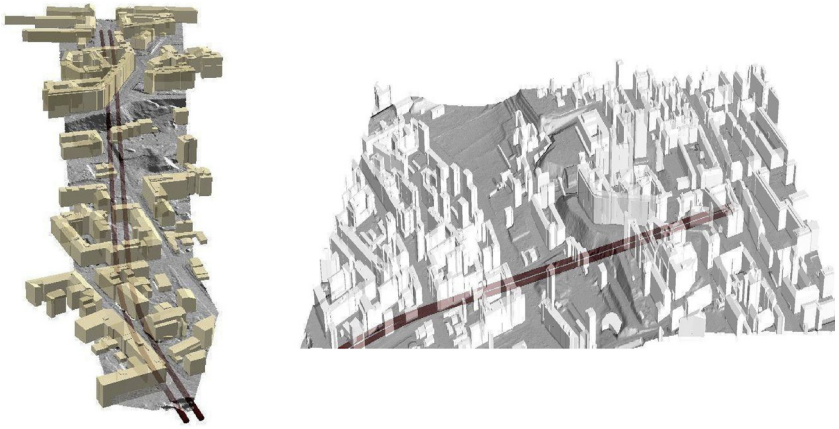

Fig. 7. Data visualisation - a perspective view generated with the use of data from "Metro Warszawskie Sp. z o.o." and models of buildings based on ALS data, (made by K.Bakuła, A.Fijalkowska, at Warsaw University of Technology).

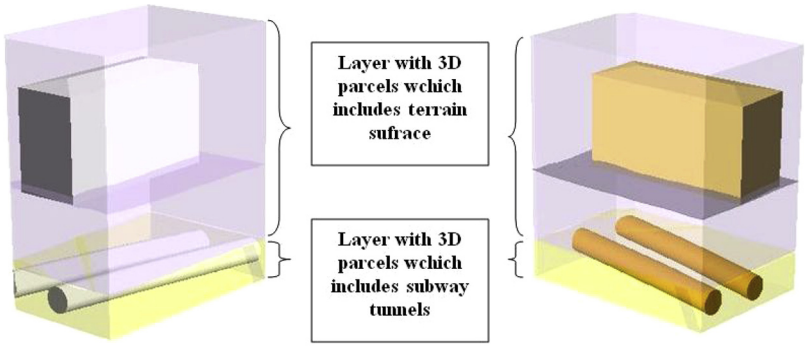

Fig. 8. Visualisation of subway tunnels at the level of individual cadastral parcels; Source: with the use of data from "Metro Warszawskie Sp. z o.o." and ALS data published in (Karabin et al., 2018).

of the registration as well as from the negotiations between the land plot owners and investors. Purchasing of land plots in the cases of tunnels (as well as bridges or viaducts) are not a common solution, and is not appropriate for the dense urban environment. The most common solution is a registration of easements in the land registry, where land plots over a tunnel (under the bridge/viaduct) are encumbered. Unfortunately, there is no graphical presentation of infrastructure objects ("occupied space") either in the land cadastre nor in the building cadastre. Easement boundaries are not included in the cadastral maps and thus the extent of the easements is only evident from the documents in the land register.

3.8. Subway registration in Sweden

When legislation allowing the formation of 3D property was introduced as an addition to existing 2D property formation in 2004 (SFS, 1970:994), it was partly as a response to needs from the building industry and for fulfilling certain demands. Apart from requesting the possibility of adding one or more additional separately owned storeys on top of existing buildings in cities for housing purposes, the implementation of major infrastructure projects was another specified need for the introduction of 3D property formation (Eriksson, 2005, p. 12).

Even though there is no fixed delimitation of the volume of the traditional real property unit above or below the ground surface, it is still possible for the property owner to construct infrastructure facilities above or below ground within the volume of his/her property. This can even be done by another party with the consent of the owner or without consent through expropriation means, normally providing compensation for the take. When the subway in Stockholm was constructed during the 20th century, 3D property formation did not exist and because of that another legal solution had to be used to secure rights, which was not very suitable for the purpose. This entailed the creation of an easement for the entire subway tunnel system, connected to one small property unit belonging to the subway system (Julstad, 1994, p. 120).

One example of the use of 3D property formation mentioned in the legal ordinance (Proposition 2002/03:116, pp. 31-32), where the introduction of 3D property formation was considered to be a valuable tool for solving complicated problems within building projects and for various purposes, was covering railway areas with buildings for housing and offices and using space below ground for garages and archives, as well as for dividing ownership within different communication areas with terminals, bridges, railway stations, etc. By using 3D property formation, it is possible to construct residential buildings on top of railway tracks or public space. It is also possible for authorities, mortgagers and others to receive knowledge about the property right through the national real property register.

There are no specific rules provided in the legislation regarding where the boundaries surrounding the underground tunnels, and thus delimiting the 3D property unit, should be drawn; it is decided in each specific case. The recommendations (Lantmäteriet, 2003, p. 68), however, give the possibility to include a protective area around the physical tunnels in the 3D property unit, for protection from damage by surrounding properties or for management purposes. A 3D easement can also be created for this purpose, thus being a protective volume included in the surrounding property unit.

The 3D property units are registered in the cadastral index map (Lantmäteriet, 2004), which is part of the national Real Property Register, and in the textual part of the register. The registration does however, not differentiate between different types of tunnels. Today, in total, 52 3D property units are registered with the purpose "tunnel" in the register. At present, it is not possible to create a 3D geospatial model based on data stored in the real property register, but this is currently a subject for research (Andrée et al., 2018a, 2018b).

Since 3D property formation is already introduced in Sweden and applicable to infrastructure objects such as tunnels, there is no real need for major changes in the regulations at the moment or to change the current solutions. There are, however, currently ongoing research projects concerning the digitalisation and visualisation of 3D property registration and the 3D property formation process (Andrée et al., 2018a,b).

One urban example of 3D property formation for infrastructure purposes is the Stockholm City lane in Sweden. It is a large project which contains a new railway tunnel below Stockholm city where four connected 3D property units for railway purposes are formed for the railway tunnels (Jarnestedt, 2009, pp. 2–3). The space containing the tunnel forms a separate 3D property unit, surrounded by the ground space of the traditional property units that also includes the land surface. This is what it looks like in the case of the Stockholm City lane. The majority of these 3D property tunnels are not used for subways, but some in the Stockholm region are, as mentioned above. 3D property formation is currently also being used when new tunnels and stations are constructed, for example within the Stockholm City lane. However, for the new subway lines and stations that are to be constructed in Stockholm, at the moment it seems like solutions other than 3D property formation, such as easements, are planned to be used (Fig. 9).

A pilot study which is part of the aforementioned research in section 3.5 focuses on the digitalisation and visualisation of 3D property registration and the 3D property formation process (Andrée et al., 2018a, 2018b). An initial result is that the visualisation of detailed legal boundaries is not possible in the national digital cadastral index map, which is only used for overview purposes. 3D data has to be collected from the legal sources, i.e. the cadastral formation dossiers, consisting of text–based descriptions and 2D analogue cadastral boundary plans. It may be difficult to obtain this information due to the need to manually interpret some of the plans and/or the text part of the cadastral decision often describing the location of the 3D boundaries. It is, therefore, in order to interpret the analogue cadastral boundary plans in an effective way, an advantage to have access to detailed digital building plans as

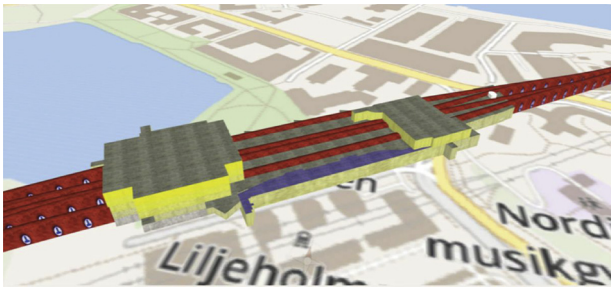

Fig. 9. 3D property formation of a subway station in Stockholm (Source: http://www.sl4d.se/pilotprojekt-3.html).

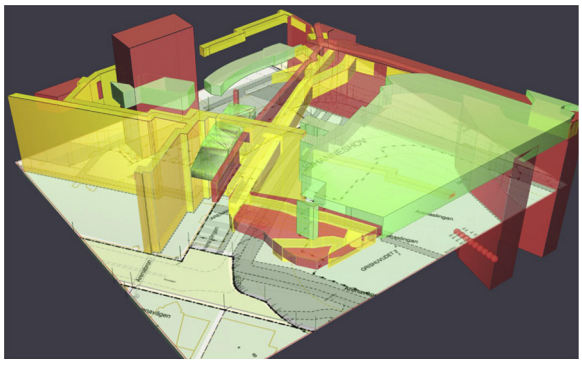

Fig. 10. 3D model visualising RRRs (Illustration by prof. Stefan Seipel).

well as a textual description(s) in the cadastral dossier.

The 3D visualisation can also be used to identify and find the location of easements and other types of rights for pipes, etc. for construction within a 2D property, i.e. it is easier to see the different layers of the parcel (See Fig. 10).

3.9. Subway registration – summary and discussion

The presented concepts of subway (tunnels) registration in the selected countries are summarised in Table 1. The limited number of underground subway projects in all the examined countries (mostly subway network is developed in one city of each country) does not provide sufficient experience on registration of stratified, underground space. "Superficies solo cedit" operates restrictively on real property stratification. However, the Czech Civil Code circumvents the aforementioned principle by regarding underground special-purpose constructions as separate real property. In the majority of the examined countries, a subway network is developed, partially or entirely, below municipal or state owned land. In the case of land parcels owned by private individuals, two options are identified. The first one involves the establishment of servitudes, e.g. Austria and the Czech Republic, while in the second option, the whole land parcel gets expropriated for public benefit purposes, e.g. Greece. Land parcel expropriation in Greece applies only in the case that private real properties are necessary for carrying out subway construction. Otherwise, it is considered that property rights are limited to the depth allowed by the construction regulations (which lies much higher than the depth of the subway lines).

Cadastral registration of underground infrastructures is not required in most of the examined countries, except for Bulgaria, therefore, the subway network is not presented on cadastral maps. Exceptions may refer to the presentation of subway stations lying on the surface parcels. However, registration of servitudes remains limited to 2D space, potentially including cross-section diagrams as well. It needs to be noted that despite the lack of cadastral documentation of subway networks, detailed diagrams of subway networks are maintained by the agencies responsible for each network's operation. A different approach can be traced within the Swedish framework, deriving from the statutory establishment of 3D real property units in Sweden. In such cases, 3D real property units are established for the vertical partition of the 3D space required for the development of subway tunnels, and are also registered in the Swedish cadastral index map.

It needs to be noted, that several solutions are implemented to address multilevel and overlapping real property rights. Such solutions include limited real property rights, e.g. servitudes/easements, rights of superficies, emphyteusis, or apartment ownership concepts. Each of these rights is characterised by specific attributes (based on national legislation), such as use or time restrictions, necessary relation to the surface parcels, as well as share on common parts of constructions and land parcels. Such characteristics limit the capacity of developing cross-boundary, underground subway lines, given that they provide inferior legal protection (in case of limited real property rights), they do not allow multi-level, volumetric subdivision of specific underground space for the development of underground subway lines (Kitsakis, 2019). Apartment rights could be considered as the only right allowing the development of individual volumes of space. However, such rights cannot be exploited within the context of underground subway lines, both due to use restrictions (related mainly to residential and commercial purposes) and to the necessary share to the ownership of common building parts (which do not exist in case of underground subway lines) and to surface parcel ownership (which is not needed in case of underground subway lines). Therefore, the unique nature of underground subway lines is distinct from other volumetric real

Table 1
Subway (tunnel) registration.
Source: authors

	Subways	*Do tunnels intersect private properties?*	*Geometry of subway tunnels in cadastre*	*Rights established for subway in a case of different owners of surface parcel and tunnel*
Austria	*Vienna*	*Yes*	*No*	*Servitude/Easement registered in Land Register 2D documents*
Bulgaria	*Sofia*	*Yes*	*Yes still in 2D, sometimes 3D plans and visualisations are attached*	*Servitude/Easement registered in Land Register*
Croatia	*None*	*Yes*	*No*	*Automatically connected to land owner of tunnel entrance*
Czech Republic	*Prague*	*Yes*	*Yes in 2D, only parts located above the ground*	*Servitude/Easement or so called temporary land take (a kind of lease contract)*
Greece	*Athens Thessaloniki*	*Yes*	*No*	• *Only land parcels owned by subway's operator are registered.* • *No rights are registered for subway tunnels crossing below privately owned parcels.*
Poland	*Warsaw*	*Yes/No*	*No only on base maps (outlines)*	*None (Servitude/Easement registered in Land Register is an option)*
Slovenia	*None*	*Yes*	*No*	*None (Servitude/Easement registered in Land Register is an option)*
Sweden	*Stockholm*	*Yes*	*Yes*	*Independent 3D Property – ownership right*

property objects, and different legal tools need to be employed compared to those used for other cases of real property stratification

4. Conclusions

In this paper, the approaches to the registration of real property rights in the case of (subway) tunnels in the selected EU countries are presented, e.g. Austria, Bulgaria, Czech Republic, Croatia, Greece, Poland, Slovenia, and Sweden. Examined countries include both countries where the traditional vertically indivisible land parcel concept prevails (based on the "superficies solo cedit principle"), and countries that have adopted 3D real property legislation. This allows a comparison between different aspects of the principle "superficies solo cedit" and between 2D and 3D real property units concepts, applied to subway (tunnel) cases. Since not all of the examined countries have developed underground subway lines, reference is made on the provisions regarding roads or railway tunnels. The findings of this work provide insight on national legal backgrounds and their limitations in case of stratifying real property for underground subway lines purposes, which constitutes the first step towards the implementation of cost-benefit analyses and implementation of 3D cadastral approaches not only to subway lines, but also to other major, cross-boundary, underground developments.

Based on the presented research, there may be difficulties involved with combining different activities within the same surface property unit, which are not suited to management by the same owner. If the possibility of 3D property formation is not present within a legal system, other less secure and lasting forms will have to be used. Such forms can be different types of indirect ownership or granted user rights, such as joint facilities, easements, utility easements and leaseholds (Paulsson, 2013). These solutions are however, not always optimal, and involve certain disadvantages or will not be suitable for the purpose. One of them is the missing visibility of rights including public law restrictions, which has a dramatic effect on land value (Twaroch and Navratil, 2016). In this case, a division into 3D property units will be a good tool to separate these activities with independent ownership for these activities, where each part can be mortgaged and used as collateral.

The transaction costs occurring when purchasing, exchanging, transferring or in other ways changing the rights are also higher when using different kinds of rights, or may need the consent of the property owner before transferring them (Ekbäck, 2011). Benefits that can come from legally securing the three-dimensionally delimited parts of the property include securing the value of the real property for the users by removing obstacles such as the limitation of rights, that can lapse and increase the possibilities for the right holder to make changes to the property according to needs.

A benefit of a 3D cadastre is thus the improved documentation of rights. In the context of subways, this guarantees durability and accessibility through standardised interfaces and therefore improves information for future underground development. It opens the path for 3D spatial planning. Currently, zoning plans are only completed in 2D. This can cause problems when trying to develop underground space because constructions may be realised between the planning and the implementation of some infrastructure project, which prevents the realisation of the project.

Based on recent research we can say that Europe needs 3D cadastre but for historical reasons it is difficult to change (psychologically) the main approach to ownership rights and its extent – which are based on roman rules. The civil codes in Europe are in most countries the oldest acts along with Country's Constitutions.

Registration of underground infrastructures constitutes a challenge for national land administration systems, due to national legal specifications and the unique characteristics of underground objects. The experiences in Sweden have already shown the benefits that might be achieved by the introduction of 3D property formation. The introduction of the 3D property formation into the Swedish legislation has increased the possibilities of more secure and clear ways of constructing, financing and managing in particular large and more complex facilities, such as infrastructure objects, by separating it legally from other types of use within the space of the same ground property

Establishment of rights for the development of subway networks constitutes a characteristic case that needs to be dealt with within a 3D Cadastre context. In terms of land tenure, a subdivision of the real property to individual volumes allows the creation of separate ownership parcels, which can be exploited according to their right-holders' needs. Although subdivision of land volumes for subway networks' development restricts exploitation capabilities of the rest of the land parcel volume (or volumes), it allows for clear and unambiguous delimitation of the space where individual real property rights apply. Moreover, "excision" of a spatial volume from the original land parcel volume leaves room for more efficient exploitation of the remaining space, since the exact encumbered space is defined. The impact may also be traced in case of land value and compensation for the expropriation, or the acquisition, of spatial volumes instead of land parcels as a whole. This is related to the establishment of volumetric RRRs, since volumetric restrictions provide more flexibility both in exploiting restricted volumes, and the remaining ones; consequently, restricted, or excised, volumes can be evaluated and compensated accordingly, thus limiting compensation costs, objections and litigation procedures, compared to those regarding land parcels as a whole.

CRediT authorship contribution statement

Marcin Karabin: Conceptualization, Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing, Supervision. **Dimitrios Kitsakis:** Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing. **Mila Koeva:** Investigation, Resources, Writing - original draft. **Gerhard Navratil:** Methodology, Investigation, Resources, Writing - original draft. **Jesper M. Paasch:** Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing. **Jenny Paulsson:** Methodology, Investigation, Resources, Writing - original draft, Writing - review & editing. **Nikola Vučić:** Investigation, Resources, Writing - original draft. **Karel Janečka:** Investigation, Resources, Writing - original draft. **Anka Lisec:** Investigation, Resources, Writing - original draft.

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References

Acharya, B.R., 2011. Prospects of 3D cadastre in Nepal. In: 2nd International Workshop on 3D Cadastres. 16–18 November 2011, Delft, the Netherlands.

Andrée, M., Paasch, J.M., Paulsson, J., Seipel, S., 2018a. BIM and 3D property visualisation. In: Proceedings of FIG Congress 2018. Istanbul, Turkey.

Andrée, M., Darell, F.N., Larsson, K., Malm, L., Norrsell, J., Paasch, J., Paulsson, J., Seipel, S., Tullberg, O., Wallberg, A., 2018b. Slutrapport för projektet Smart planering för byggande: Delprojekt 3 – BIM som informationsstöd för 3D fastighetsbildning [Final Report for the Project Smart Planning for construction Project: Sub–project 3 – BIM as information support for 3D property formation] (In Swedish). Smart Built Environment. IQ Samhällsbyggarna, Stockholm, Sweden.

Attiko Metro http://www.ametro.gr (Accessed on: July 2018).
Dimopoulou, E., Elia, E., 2012. Legal aspects of 3D property rights, restrictions and responsibilities in Greece and Cyprus. In: 3rd International Workshop on 3D Cadastres: Developments and Practices. 25–26 October 2012, Shenzhen, China.
Dimopoulou, E., Karki, S., Roić, M., Duarte de Almeida, J., Griffith-Charles, C., Thompson, R., Ying, S., Paasch, J., Oosterom, P., 2018. Chapter 2. Initial registration of 3D parcels. Best Practices 3D Cadastres - Extended Version. Copenhagen, Denmark, International Federation of Surveyors, pp. 67–94.
Dnes (2018). https://www.dnes.bg/sofia/2011/08/21/stolichnata-obshtina-se-byrka-dylboko-za-otchujdavane-na-imoti.126915 (Accessed on August 20, 2018).
Drobež, P., Kosmatin Fras, M., Ferlan, M., Lisec, A., 2017. Transition from 2D to 3D real property cadastre: the case of the Slovenian cadastre. Comput. Environ. Urban Syst. 62, 125–135. https://doi.org/10.1016/j.compenvurbsys.2016.11.002.
Ekbäck, P., 2011. Towards a theory of 3D property rights – with an application to Nordic legislation. Nordic J. Surv. Real Estate Res. 8 (1), 65–80.
Erba, D.A., Graciani, S.D., 2011. 3D cadastre in Argentina: maps and future perspectives. In: 2nd International Workshop on 3D Cadastres. 16-18 November 2011, Delft, the Netherlands.
Eriksson, G., 2005. A New multi-dimensional information system introduced in Sweden. In: Proceedings of the FIG Working Week 2005 and GSDI-8. 16-21 April 2005, Cairo, Egypt. International Federation of Surveyors (FIG).
German Civil Code, 1990. Federal Government of Germany.
Greek Civil Code, 1946. Government of the Hellenic Republic.
Hoffmann, Wernher, 2018. 50 Jahre Grenzkataster Vortrag beim Österreichischen Geodätentag, Mai 2018 in Steyr. Vermessung & Geoinformation (VGI) 106 (4), 251–255.
Jarnestedt, J., 2009. Tredimensionell fastighetsbildning för underjordiska järnvägsstationer – Förslag på fastighetsrättslig utformning av stationerna inom Citybanan (in Swedish). Master thesis. Fastighetsvetenskap. KTH Royal Institute of Technology, Stockholm, Sweden.
Julstad, B., 1994. Tredimensionellt fastighetsutnyttjande genom fastighetsbildning. Är gällande rätt användbar? (in Swedish). (Doctoral Thesis. KTH Royal Institute of Technology, Stockholm) Juristförlaget, Stockholm.
Karabin, M., 2011. Rules concerned registration of the spatial objects in Poland in the context of 3D cadaster's requirements. In: Proceedings 2nd International Workshop on 3D Cadastres – Delft Netherlands. 16-18 November 2011. pp. 433–452.
Karabin, M., 2013. A concept of a model approach to the 3D cadastre in Poland. D.Sc. Thesis. Warsaw University of Technology – Scientific Work – Geodesy Series, Number of Book 51 (116 p.). Oficyna Wydawnicza Politechniki Warszawskiej, Warsaw May 2013.
Karabin, M., Bakuła, K., Fijałkowska, A., Karabin-Zych, M., 2018. Feasibility study of 3D cadastre implementation using various data sources – the case of Warsaw Subway. Geod. Vestn. 62 (3), 445–457 2018, 10.15292/geodetski-vestnik.2018.03.445-457.
Kitsakis, D., 2019. Legal Requirements for Real Property Stratification. National Technical University of Athens.
Kitsakis, D., Dimopoulou, E., 2017. Addressing public law restrictions within a 3D cadastral context. Int. J. Appl. Earth Obs. Geoinf. 6 (182), 14.
Kitsakis, D., Paasch, J.M., Paulsson, J., Navratil, G., Vučić, N., Karabin, M., El-Mekawy, M., Koeva, M., Janečka, K., Erba, D., Alberdi, R., Kalantari, M., Yang, Z., Pouliot, J., Roy, F., Montero, M., Alvarado, A., Karki, S., 2018. 3D cadastres best practices: chapter 1 – legal foundations. Paper to FIG Congress 2018, Istanbul, Turkey. May 6-11, 2018.
Krzyżanowska, A., 2016. *Kodeks budowlany: Trudne inwestycje na cudzym.* [The Building code: Difficult investing on someone else's field]. https://prawo.gazetaprawna.pl/artykuly/983188,kodeks-budowlany-nie-ucieszy-deweloperow.html.
Lantmäteriet, 2003. Handbok Tredimensionell fastighetsindelning. [Guidelines, Three-dimensional Real Property Formation]. (In Swedish). Version 2003-12-30. Lantmäteriet, the Swedish mapping, cadastral and land registration authority.
Lantmäteriet, 2004. *Handbok registerkarta* [Digital Cadastral Index Map Handbook] (In Swedish). Handbook Digital Cadastral Index Map]. (In Swedish). Lantmäteriet, the Swedish mapping, cadastral and land registration authority. the Swedish mapping, cadastral and land registration authority, Lantmäteriet Report no. LMV-Rapport 2004:6. With later amendments. Version 2014-06-04.
Law 1955/1991, Government of the Hellenic Republic.
Law 2664/1998, Government of the Hellenic Republic.
Law on Cadastre and Property Register, 2006 http://www.unece.org/fileadmin/DAM/hlm/prgm/cph/experts/bulgaria/documents/LCPR.pdf (Accessed on August 3, 2018).
Merwe, C. van der, 2010. The doctrinal clog on the historical development of condominium by the maxim superficies solo cedit. Fundamina 16 (1), 459–471.
Merwe, C. van der, 2015. European Condominium Law 2015. In: Van Der Merwe, C. (Ed.), *European Condominium Law* (The Common Core of European Private Law, p. I). Cambridge University Press, Cambridge.
Merwe, C. van der, 2016. European condominium law: nine key choices. In: Lehavi, A. (Ed.), Private Communities and Urban Governance: Theoretical and Comparative Perspectives. Springer, New York, pp. 127–149.
Metropolitan (2018). https://metropolitan.bg (Accessed on March 8, 2018).
Papageorgiou, M., 2015. Networking underground archaeological and cultural sites: the case of the Athens metro. ISOCARP, ITA/ITACUS In: Han, A., Shipra, N.S. (Eds.), Think Deep: Planning, Development and Use of Underground Space in Cities, pp. 110.
Paulsson, J., 2007. 3D Property Rights – An Analysis of Key Factors Based on International Experience. Doctoral Dissertation. Royal Institute of Technology (KTH), Stockholm 351 p.
Paulsson, J., 2013. Reasons for introducing 3D property in a legal system – illustrated by the Swedish case. Land Use Policy 33 (2013), 195–203.
Proposition (2002/03:116). Tredimensionell fastighetsindelning [Three-dimensional Property Formation] (In Swedish). Proposition no 2002/03:116. Swedish government.
PUH "GeoCad" Sp. z o. o, 2014. Inventory Documentation - Geodetic Inventory of an Underground Tunnel Using Laser Scanning – the 2nd Subway Line - the Left Tunnel d13 and the Right Tunnel D13. Katowice, February 2014. .
SFS, 1970:994. Jordabalken [Land Code]. SFS (1970:994).
Stoter, J., 2004. 3D cadastre. Doctoral Dissertation. Publications on Geodesy 57. Netherlands Geodetic Commission, Delft, TU Delft 327 p.
Twaroch, C., Navratil, G., 2016. Unsichtbare Grundstücksbelastungen [Invisible Encumbrances on Land] (In German). Forum - Zeitschrift des Bundes der Öffentlich bestellten Vermessungsingenieure e.V. 42 (1), 8–16.
Tycner, A., 2014. Czy prawo powinno dopuszczać własność warstwową? [Should the layered property be permitted by law?]. https://budownictwo.wnp.pl/czy-prawo-powinno-dopuszczac-wlasnosc-warstwowa,224407_1_0_0.html.
Vähäaho, I., 2014. Underground space planning in Helsinki. J. Rock Mech. Geotech. Eng. 6, 387–398.
Vučić, N., Roić, M., Mađer, M., Vranić, S., van Oosterom, P., 2017. Overview of the Croatian land administration system and the possibilities for its upgrade to 3D by existing data. ISPRS Int. J. Geoinf. 6 (7), 223. https://doi.org/10.3390/ijgi6070223.
Zaini, F., Hussin, K., Suratman, R., Abd Rasid, K., 2013. Review of the underground land ownership in Malaysia. Jurnal Pentadbiran Tanah 3 (1), 39–52.
Zhang, Z., Tang, W., Gong, J., Huan, J., 2017. Property rights of urban underground space in China: a public good perspective. Land Use Policy 65, 224–237.
Zweigert, K., Kotz, H. (Eds.), 1998. Introduction to Comparative Law, 3rd revised edition. Oxford.