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Transition from 2D to 3D real property cadastre: The case of the Slovenian cadastre

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ABSTRACT

The land administration system, providing a mechanism to support the management of real properties, is one of the most crucial infrastructures of any country. This infrastructure is needed to support planning and implementation of land-related policies, and in general to support human decisions and activities in our environment. The fundamental part of a modern land administration system is the land cadastre. Over the last decade, the demand for three-dimensional (3D) cadastre has increased significantly worldwide. The physical and legal complexities of the built and natural environment prompt new concepts and definitions of real property units in order to meet the demands of a today's society and to balance private and public spatial interests. Particularly in urban areas, including other areas with intensive human interventions into space, there is a tendency to use space above and below the Earth's surface, above and below structures, etc. Complex 3D objects cannot be defined and registered as cadastral objects in the traditional 2D land cadastre and represented in a 2D cadastral map. For this purpose, next to the land cadastre, in 2000, Slovenia introduced the building cadastre. From the juridical point of view, the current cadastral system is not sufficient for all 3D situations. In this paper, we discuss upgrade possibilities of data models of the land cadastre and building cadastre to introduce a unique 3D real property cadastre in Slovenia. We believe that the data available in the current cadastres will significantly contribute toward the 3D real property cadastre and 3D graphical representation of cadastral data; nevertheless, some additional data are needed. The minimum data required could be provided already through the current cadastral procedures.

1. Introduction

The relationship between land and people has been changing throughout history. To protect public and private interests concerning land, countries develop different solutions. In many countries, the land administration system (LAS), including the land cadastre as an important part of it, has been developed over decades, even centuries; first, for taxation purposes and then to provide legal protection to land-rights holders. Regardless of the differences, the LAS has always been an essential component of any nation's administrative portfolios, as land has always remained at the foundation of human life. In recent decades, it has been shown that a multipurpose LAS brings many advantages to the society and its prosperity (Enemark, Williamson, & Wallace, 2005; Larsson, 1997). Access to land and security of land-related rights are vital components of sustainable development and good land management practice (Larsson, 1991; Dale & McLaughlin, 1999; Lisec and Ferlan, 2012; Paulsson, 2013; Zupan, Lisec, Ferlan, & Čeh, 2014). Among others, the Bathurst Declaration (FIG, 1999) outlined the powerful link between appropriate land administration and sustainable development of the society. Therefore, LAS is often treated as a critical, public good infrastructure with a high importance for economy and planning (Bennett, Rajabifardb, Williamson, & Wallace, 2012; Navratil & Frank, 2004).

In the last two decades, we have witnessed many efforts worldwide to develop a contemporary LAS in order to support human decisions and sustainable activities in space. The land cadastre (also the real property cadastre), as the engine of land administration (Williamson, Enemark, Wallace, & Rajabifard, 2010), should underpin an integrated land administration and control system, effective land markets, protection of property rights, and documentation of public and private rights on land. In turn, these tools delivered, respectively, a common agricultural policy, institution building, an effective free market, protection of human rights, and environmental sustainability (Bennett, Tambuwala, Rajabifard, Wallace, & Williamson, 2013). Here, it must be emphasized that in many legal systems, land is traditionally defined as a physical thing that encompasses the surface of the Earth and all things attached to it, both above and below the Earth's surface (soil, buildings, other natural and built objects, etc.). From the legal point of view, land, i.e. real property, might be defined as an abstract entity that is manifested as a set of rights to its use, responsibilities, and restrictions (Dale & McLaughlin, 1999; Larsson, 1991). Cadastral subsystems within LASs

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often include data on land, buildings, and other immovable structures on, above, and below the Earth's surface – the term "land cadastre" could be therefore replaced by the term "real property cadastre."

Presently, many new interests in real property are different when compared with traditional ownership rights concerning land. Consequently, new concepts and definitions of real property units are required. In addition, our built environment is becoming increasingly complex and the traditional land cadastre cannot meet all the requirements of a contemporary LAS. Approaches to the development and implementation of modern LAS differ among countries, and are conditioned by formal and informal institutional factors (Lisec & Ferlan, 2012). Several international studies have shown that traditional two-dimensional (2D) registration of real properties no longer meets the demands of modern society and that there is a need for 3D registration of real properties (Aien, Kalantari, Rajabifard, Williamson, & Wallace, 2013; Döner et al., 2010; Kalantari, Rajabifard, Wallace, & Williamson, 2008; Karki, Thompson, & McDougall, 2013; Onsrud, 2003; Paulsson, 2007; Stoter, 2004; van der Molen, 2003; van Oosterom et al., 2006; Stoter, Ploeger, & van Oosterom, 2013). As already proposed in the publication Cadastre 2014, thinking in "land objects" is the future of modern cadastral systems (Kaufmann & Steudler, 1998). Although 3D registration of real properties already exists in many countries, including Slovenia, the data on spatial extension of real property gathered within the registration process and their graphical representations are limited to 2D or 2.5D spatial data models (see also FIG, 2016). 2D graphical cadastral data representation is already reused for other purposes in a different GIS (geographic information system) environment. These data are a part of the National Spatial Data Infrastructure (Geoportal, 2016), but are often not sufficient for a clear representation of the complexity of built environment (Fig. 1).

The land cadastral data model and its graphical representation based on the physical land parcel (2D land parcel) or its parts need to be replaced by a spatially referenced data model based on the legal property object (3D real property unit). A well-functioning cadastre for 3D property units will improve not only land taxation but also land tenure security, land market, land-use planning, and spatial development (Paulsson, 2013). The need for the fourth dimension of real property registration and representation has also been recognized (Döner et al., 2010). In this paper, we focused on a 3D cadastral data model and a 3D cadastral data representation. The fourth dimension (time) is semantically already integrated in many cadastral systems as an attribute (i.e., the date of cadastral changes); however, a 4D graphical representation of the data remains a major challenge.

When dealing with a multipurpose 3D cadastre, the graphical representation with a spatial extension of land parcels is not enough; real-world data about physical objects (i.e., land and things permanently attached to it) have to be included in the conceptual and data model of the real property cadastre. 3D representations of models of physical objects such as buildings, traffic and utility infrastructure, watercourses, etc. make real property cadastre easy to understand for users and provide the basis for developing a multipurpose cadastre.

In our paper, we are focusing on data requirements to upgrade the current graphical cadastral subsystem (2D) into a 3D real property cadastre. Our research question is: "*How to upgrade the existing cadastral system to enable cadastral data representation in a 3D environment?*" We claim that the "*introduction of the third dimension in the existing cadastre is possible, and the necessary data could be gathered in the current cadastral procedures*."

The proposal for introducing the third dimension into the existing cadastral data model is based on the Slovenian LAS. The proposed approach can also be used internationally, in particular, in the countries renovating their existing parcel-oriented LASs with common or similar history of the cadastre as in Slovenia (the countries in the territory of former Austrian Monarchy and in the countries of former Yugoslavia).

2. 3D real property cadastre — a literature review

During the last decade, the demand for 3D real property cadastre has increased significantly worldwide. Particularly in urban areas, including other areas with intensive human interventions into space, there is a tendency to use space above and below the Earth's surface, above and below structures, etc. Although some legal systems provide the possibility to create property rights with 3D boundaries, the main registration entity is mostly still a 2D land parcel, the concept of real property is still land (surface) oriented (Stoter, 2004). At the juridical level, some countries, including Slovenia, have solved the problems of 3D real property registration by establishing multilevel ownership no longer related to surface land parcels (condominium right and right of superficies). However, the requirements for surveying and mapping 3D real property units are very general and the possibilities for 3D geometric representations of the real property unit are limited (Aien, 2013; Stoter, 2004; Stoter et al., 2013; van Oosterom, Stoter, Ploeger, Thompson, & Karki, 2011).

Traditional LASs based on 2D cadastral maps (plans) are still appropriate in some areas where the built environment is not complex; in rural areas with agricultural land and forests, 2D cadastral data and 2D cadastral maps are sufficient for land tenure security, land market, land-use planning, as well as for supporting spatial development and other decisions in space. In the complex built environment, however, land cadastral data, without a clear and effective description or visualization of the third dimension, are inefficient for land tenure security and real property valuation (Twaroch et al., 2015; Wessely et al., 2013); they are inappropriate for quality spatial analyses and decisions (Lisec, Ferlan, Čeh, Trobec, & Drobne, 2015). In addition, multiple-layered 2D cadastral maps, referring to complex building structures cannot be easily understood or visualized outside the domain of highly specialized professional land surveyors (Jazayeri, Rajabifard, & Kalantari, 2014).

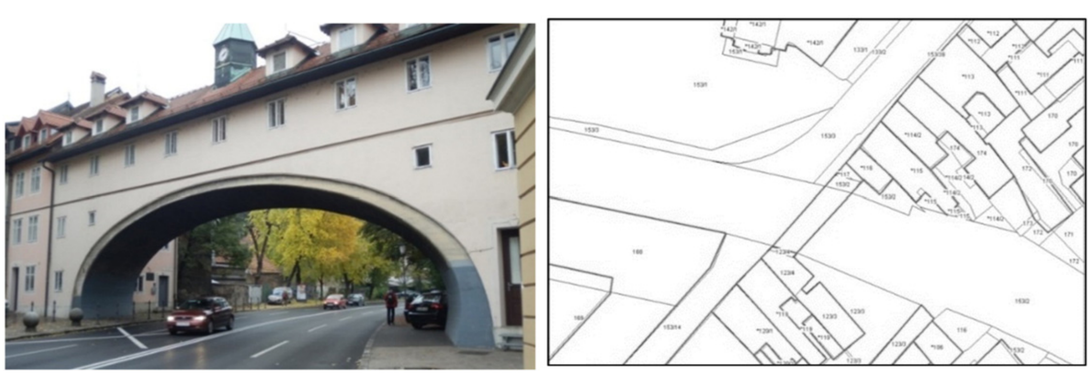

Fig. 1. In the Slovenian cadastral system, a building can be graphically represented on the cadastral maps in a 2D environment (thicker lines) as a projection of the building on the ground. (Source of cadastral data: Surveying and Mapping Authority of the Republic of Slovenia).

Several studies on 3D cadastre models have been conducted over the last decades (Benhamu & Doytsher, 2003; Kalantari et al., 2008; Karki et al., 2013; Onsrud, 2003; Paulsson, 2007; Stoter, 2004; Stoter & Ploeger, 2003; Stoter & Salzmann, 2003; Stoter et al., 2013; van Oosterom et al., 2006) that focus mainly on legal and cadastral frameworks. Döner et al. (2010) presented an idea of a 4D cadastre and its implications for utility networks. Navratil and Unger (2013) discussed the challenge of introducing the third dimension in the existing land cadastre system – the problem of height systems. Recent studies follow the direction of integrating 3D legal and physical objects in cadastral conceptual and data models (Aien, 2013; Aien et al., 2013), and 3D data sourcing methods for land (real property) information (Jazayeri et al., 2014).

An important aspect of implementing 3D cadastres is the legal one. 3D cadastres cannot exist without a proper legal framework. According to and adapted from Paulsson (2013), legislation is a foundation of 3D property. All transferred, registered, and visualized information is based on legislation. Properties are strongly connected with rights, restrictions, and responsibilities (RRRs), which represent the legal part of the cadastre. The law must support the geometric definition and location of RRRs in a clear and consistent manner. This requires some guidelines (legal or regulatory) to standardize methods for the definition of 3D property RRR boundaries and to locate its position relative to boundaries of other RRRs (van Oosterom et al., 2011). Namely, the traditional (2D) property concept can also be termed 3D because in most legislation, there is no delimitation of property's extension below or above the surface (Paasch & Paulsson, 2011). Furthermore, it should follow the international standards (ISO), and it should be as simple as possible in order to be useful in practice (Enemark, 2004; van Oosterom et al., 2006). The 3D cadastre scope is covered by the Land Administration Domain Model (LADM). The LADM is a generic conceptual model providing the concepts and terminology to describe land administration data (ISO/TC211, 2012; Lemmen, 2012). It is noteworthy that LADM is not intended to be complete for any particular country. It is important to realize that a 3D cadastre solution always depends on the local situation and is driven by user needs, land market requirements, the legal framework, and technical possibilities (van Oosterom, 2013).

2.1. Land cadastral data

When focusing on the countries with a parcel-oriented LAS, land cadastre holds a variety of data about land parcels that are necessary for the different tasks the cadastre must solve (Navratil & Frank, 2004). These are legal data that refer to RRRs and other property interests, and technical data for positioning, taxation, and planning, which relate to coordinates of boundaries, property size, and land use. The spatial unit of a legal object can be demarcated by 2D or 3D properties in the land cadastre, while their legal descriptions (legal documents and information of the party) are often kept in the land registry (Aien et al., 2013).

The basic unit of a 3D cadastre is a 3D real property unit. 3D property usually refers to real property that is legally delimited both horizontally and vertically (Paulsson, 2007). It is a volume of space on, above, or below the ground that defines and represents a particular RRR (Aien et al., 2013). The property object is more flexible than the legal concept of a right because it is inclusive of all interests: it does not focus solely on ownership (Bennett, Wallace, & Williamson, 2008). 3D property objects can combine an interest and its spatial dimension into an entity: an entity defined by a law or regulation, which relates to a physical space on, below, or above the Earth (Kalantari et al., 2008). All property objects have a spatial extent (Bennett et al., 2008) that represents a legal space within a cadastral system. The legal objects are normally described by boundaries, which demarcate where a right or a restriction ends and where the next begins, and the contents of that right (Kaufmann & Steudler, 1998). Users expect 3D properties to be visualized in a 3D cadastre (Aien et al., 2013). The mapping of legal and physical objects in 3D will prove beneficial for a range of purposes and have been linked to multipurpose cadastres and broader urban applications (Rajabifard, Kalantari, & Williamson, 2012).

3D cadastres should be equipped with integrated cadastral data models that can maintain both 3D legal and physical objects, although an integrated cadastral data model is not available that can maintain both 3D legal and physical objects (Aien et al., 2013). A cadastre should be simple and reliable, the reliability of the cadastral system depends on the completeness of the cadastral data (Navratil & Frank, 2004). If physical objects are not registered, then the cadastre is not simple and user-friendly, because users are not able to locate their properties in the real world and therefore do not know where their property ends, and the property of their neighbor begins.

Furthermore, it is necessary to register real-world objects in the cadastre, although they are not treated as a real property unit because of land cadastre functions that are based on property value. For example, in general, a property with a house might be worth more than a farmland, and a farmland is worth more than a forest. The size of the piece of land and data on the land use are therefore also important elements of the data model (Kalantari et al., 2008; Navratil & Frank, 2004). Land-use data are also important for urban space management and planning and for the prevention and management of natural and other disasters. It is the information to achieve the objective of sustainable development. Other data in 3D cadastre may relate to an airspace surrounding the property (Jazayeri et al., 2014).

2.2. Spatial reference frame and cadastre

The idea of systematic cadastral mapping in the spatial reference coordinate system goes back to the 18th and 19th centuries when most European countries tried to implement land taxation reforms based on quality land data. This influenced also the cadastral mapping on other continents through European colonies. For the purpose of cadastral as well as topographic mapping, countries defined and realized the national geodetic reference systems. In the first stages of cadastral mapping, the horizontal coordinates in the national reference 2D coordinate system were important (reference ellipsoid and cartographic projection) in order to define the correct area of the land just for taxation and/or to provide quality data for legal security (Kain & Baigent, 1993).

With the development of GIS technology, the allocation of the data in the common spatial reference coordinate system has become important. In addition to the national reference spatial coordinate systems, the need for continental and global reference spatial coordinate systems has been recognized in order to facilitate spatial data exchange at the international level and to support measurements using global navigation satellite systems – GNSS. Together with the idea of a multipurpose cadastre, the international (continental) reference geodetic frames are becoming more and more important and, at least in Europe, the continental geodetic reference frame has influenced cadastral systems in many countries.

The defined spatial reference coordinate system is closely connected with the introduction of the third dimension (height) in the cadastre. Heights in 3D cadastres help to represent the reality in three dimensions. They give users information about height and slope of the land property, height of buildings, terrain insolation, and free-view. The heights in the land cadastre should be given in the common (national) height reference system in order to support connectivity of different national spatial data sets (as it is the case for the geodetic horizontal, i.e. plane reference coordinate system). The height definition in the cadastre must, at a minimum, satisfy the accuracy requirements of the cadastre (Navratil & Unger, 2013).

In 3D cadastres, absolute and relative heights should be used. Absolute heights, important for data reuse within spatial data infrastructure (SDI) and different GIS applications, are independent of the reference surface. For example, if the reference surface is the terrain next to the house, the roof height does not change if the terrain becomes higher or lower. The relative height is a difference between two absolute heights. The advantage of relative heights is that they are easily visualized by users (e.g., building height, height of a bridge, depth of a tunnel, and depth of pipelines). In the case of slope, terrain insolation, and free view, heights have a great impact on the property value. Here, it must be mentioned that for topographic mapping and other geodetic as well as geodynamic applications, countries have in general already developed the national height reference system, but cadastral data (coordinates) are often still represented in just two dimensions.

3. Implementation of a 3D real property cadastre in Slovenia

The studying of real property legislation reveals that the Slovenian law is based on the Romanian principle *superficies solo cedit* (the building follows the legal fate of the land), that is, the ownership of a piece of land generally comprises also the ownership of all buildings erected on the land. Exceptions to this principle are as follows (Law of Property Code, 2002):

- the right of superficies (the right to own a built structure above or beneath the land owned by a third person), and
- apartment ownership (condominium).

Since 2002 when the Law of Property Code was adopted, the right of superficies is being used to own a building above, below, or on land owned by another person (but not for all structures, such as tunnels and bridges). The right of superficies and apartment rights separate the ownership of physical objects from the land itself, and the need for 3D delimitation of real properties has become an important issue in the Slovenian LAS.

3.1. Land cadastre and building cadastre

The Slovenian LAS consists of two parts: (1) the cadastre, where spatial position, spatial extension, and physical characteristics of land and buildings are recorded, i.e., in the land cadastre and the building cadastre; and (2) the land registry, where rights and restrictions related to land are recorded. The cadastre operates under the Ministry of the Environment and Spatial Planning, with the Surveying and Mapping Authority of the Republic of Slovenia (SMA) as the central institution, while land registry, as part of Court of Justice, is organized within the Ministry of Justice.

This "dual" system, which is well known in Central Europe (the so-called "German system"), has been introduced in 1871 with the Land Registry Act (German: das Grundbuchsgesetz). However, the land cadastre is older and has its roots in the Austrian Franciscan cadastre from the first half of the 19th century, when the Slovenian territory as a part of the Habsburg monarchy was systematically surveyed and cadastral maps were provided. Originally, the land cadastre was established for taxation purposes. Land being an object of taxation and precondition for several activities in space, the state got a special interest in controlling land ownership and use. By introducing the "dual" system, registration of land RRRs gave publicity and legal protection to holders of those rights. The principles and administrative structures defined in the 19th century have not significantly changed and remained almost the same for several decades (Lisec & Navratil, 2014; Navratil & Frank, 2004).

In the early 20th century, many discussions focused on the issue of land surveying methodology and its limited precision. In the period 1887–1904, new instructions for land cadastral surveying were published (Lisec & Navratil, 2014). After the Second World War (WWII), the surveying authority decided to introduce the national geodetic reference system (Bessel 1841 ellipsoid with Gauss-Krüger Transverse Mercator projection of a meridian zone – D48/GK), which was also gradually introduced in the land cadastre. By this time, the georeferenced cadastral maps became particularly important for spatial planning and land management, when overlaid topographic, cadastral, and other thematic maps were already used. The progress in information technology (IT) and GIS, having developed since the early 1960s, importantly changed the way in which land cadastral data are structured, stored, managed, delivered, and used within digital information systems. The idea of a multipurpose cadastre began to take shape and, consequently, the workflow in the land cadastre changed in recent decades. In the 1980s, the digital land cadastre database, which contained attribute data, was introduced in Slovenia. An additional decade was needed to finish digitalization of cadastral maps for the whole Slovenian territory. Presently, the land cadastre database contains data about registered units (cadastral community, land parcel), the coordinate database of boundary points, the digital cadastral map, and historical records of land parcels connected to surveying plans and documentation as the base for entries. Since 2008, the land cadastre graphical data have to be georeferenced also in the national reference geodetic system D96/TM (a new datum realization based on the European Terrestrial Reference System of 1989, Transverse Mercator projection of a meridian zone with central meridian of 15° east of Greenwich).

The legal ground for establishing the building cadastre was the Recording of Real Estate, State Border and Spatial Units Act (2000). Before 2000, registration of an owner of an apartment or other parts of buildings was possible in the land registry based on a building and floor (apartment) sketch, but those data were just appendices to the documentation for entering records into the land registry. With the new legislation from 2000, the cadastral documentation for a cadastral entry with a georeferenced footprint of the buildings and floor plans is a precondition for registration of rights and restrictions on buildings or parts of buildings in the land registry.

If a building on a land parcel exists, the building footprint with a building identifier is already registered in the land cadastre. The building itself is described in detail in the building cadastre, which was by 2006 officially established for the whole country, based on photogrammetric stereo data acquisition with additional attribute data acquired from the publicly available data sets. These general data about buildings are updated through regular cadastral procedures, where detailed data based on field measurements and building inspections are gathered and registered in the building cadastre (the so-called buildings with a "cadastral inscription"). The data in the building cadastre consist of basic data on buildings and parts of buildings, including location in the national geodetic reference coordinate system. It is a technical base for registering legal relations on buildings and parts of buildings in the land registry – similar to the land cadastre for land parcels (Fig. 2).

Presently, the land cadastre is a parcel-based land information system (LIS), where information on approximately 5.5 million land parcels is collected. Data are available in digital form and cover the entire territory of the Republic of Slovenia. In the building cadastre, data on buildings and parts of buildings are recorded. The building cadastre is linked to the land cadastre and land registry. According to the SMA, there were

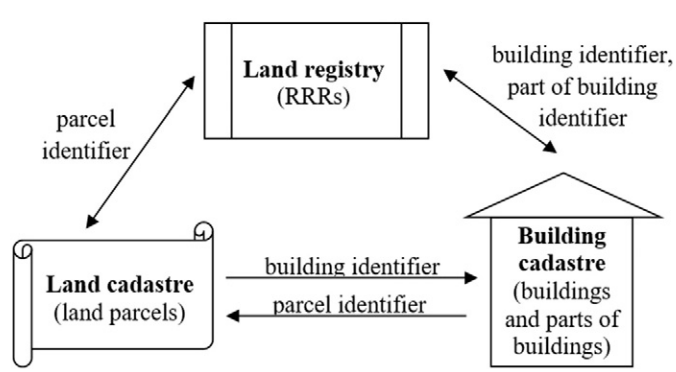

Fig. 2. Connections between the land cadastre, building cadastre, and land registry in Slovenia.

almost 7.5 million real property units registered in the cadastres at the end of 2014 (apartments, houses, garages, offices, and land parcels).

3.2. Heights of boundary points in the Slovenian land cadastre

The land cadastre is based on fixed boundaries that are usually marked with border signs. The legal spaces of a land parcel and building footprints are mostly specified by 2D coordinates in the national geodetic reference coordinate system (D48/GK and/or D96/TM). Because the land cadastre has been developed continuously from the very first beginning, there are still many land parcels and buildings that are recorded with approximate coordinates, determined by transforming the original cadastral maps provided in regional coordinate systems, based on data acquisition using the plane table, in relation to the national geodetic reference coordinate system D48/GK (see also Abart, Ernst, & Twaroch, 2011; Lego, 1967; Lisec & Navratil, 2014).

The land cadastre's spatial data are represented in two dimensions, and data on heights are not available for the observations before tachymetric measurements replaced the method of "graphical" data acquisition at the beginning of the 20th century. The first systematic attempt at introducing heights into the land cadastre in Slovenia was made after WWII, when the reference coordinate system D48/GK was introduced for the so-called cadastral-topographic measurements in the former Yugoslavia. Beside tachymetric measurements, photogrammetry had a special role, concerning the acquisition of topographic elements. In dense urban areas, new cadastral and topographic surveys were conducted after WWII, in particular, after 1974 when new cadastral legislation was introduced. The results of those new measurements were cadastral-topographic maps (see Fig. 3), where the height attribute was determined for several characteristic points (the height referred to the national reference height system – referring to the tide observations in Trieste, at Sartorio Pier).

Although not obligatory, most of the land parcel boundary points determined after 1974 possess a height attribute (local or in the national height reference system) or, at least, their height could be calculated from observation data (tachymetric observations). By introducing the parallel national geodetic reference coordinate system D96/TM in the land cadastre in 2008, height remained an important result of original measurements (tachymetric, measurements using GNSS, or combined measurements). This information is important because nowadays the land surveyor gets the crucial data for introducing the third dimension into the land cadastre through a systematic recording and modeling of 3D entities that must be defined within the formal cadastral system, where no additional costs of land surveying in the field are required. Notably, the transformations of heights between the traditional height reference system (orthometric heights above the sea level with the reference height point in Trieste) and ellipsoid heights are not always clear (see also Navratil & Unger, 2013).

3.3. Model for transition to 3D real property cadastre

In Slovenia, most complex 3D real property situations related to buildings can be registered in the land registry using the right of superficies and apartment rights. To register apartment rights or rights of superficies in the land registry, the building must be entered in the building cadastre (its footprint also must be entered into the land cadastre). The registration of rights on a building or a part of building in the land registry requires the cadastral entry:

- of the land parcel and building footprint in the land cadastre, and
- of the building and parts of the building (building units) in the building cadastre.

The land cadastre data (in American Standard Code for Information Interchange (ASCII) format) include:

- vector data in the state reference coordinate system: boundary points, links between the points, definitions of the polygons with the settled topological rules, and centroids with the unique land parcel identifier – parcel number (Fig. 4);
- attribute data (area, land use, reference to the building, etc.) linked to the land parcel identifier (centroid of the land parcel);
- archival documentation (scanned surveying documentation).

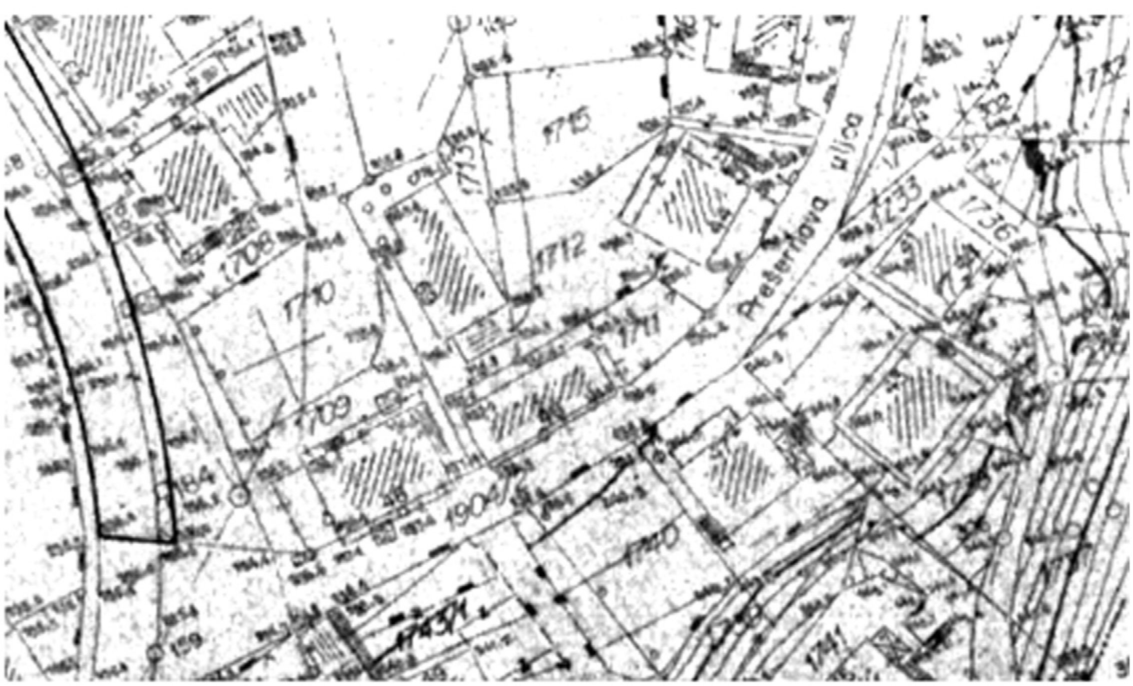

Fig. 3. An example of a cadastral-topographic map from Zagorje ob Savi.
(Source: Surveying and Mapping Authority of the Republic of Slovenia).

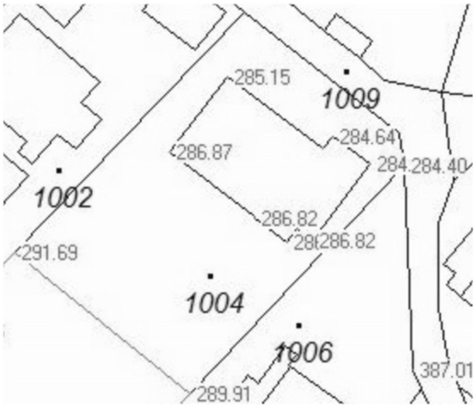

Fig. 4. Graphical representation of vector data in the land cadastre – the building's footprint on parcel l004 is linked to the building in the building cadastre.
(Source: Surveying and Mapping Authority of the Republic of Slovenia).

The building cadastre is a recent cadastral evidence. It combines technical and semantic data about buildings, for example location, height, area, building use, strata plans, cross-sections, and the number of apartments. Height information is required for the lowest and the highest point of a given building and also for one characteristic point of the terrain. Its data are saved in the XML format (Fig. 5) that includes:

- vector data on vertical projection of the building to the Earth's surface (its location in the state reference coordinate system);
- attribute data (characteristic heights of the building; identification number of a building and parts of it; and attribute data of building parts such as floor number, area, type of use, etc.) and raster data on floor plans and cross-sections;
- archival documentation (scanned surveying documentation).

In order to establish a unique cadastral database of real properties with the possibility of 3D graphical representation of cadastral data, the integration of the land cadastre and the building cadastre is an option (Fig. 6). When focusing on cadastral spatial data on real property units, for which rights and restrictions are registered in the land registry, it must be emphasized that new cadastral measurements from the past two decades (boundary points of land parcels and buildings' footprints) have coordinates in three dimensions; however, in older surveying measurements, the heights of boundary points were often attributes. As the basis (input) for the 3D real property representation, only the data on land parcel boundaries based on more recent surveying, the so-called coordinate cadastre may be used. Because of the lack of numerical data (coordinate cadastre), a problem arises when trying to introduce 3D representation of real properties recorded in the cadastre.

A special challenge is related to buildings and their parts. Parts of buildings, condominiums, etc., are presently only attributes and graphically represented as images, which does not allow for graphical representation and reuse of data in the 3D environment. Although not strictly 3D, a drawing of each vertical layer (floors) is provided for the building cadastre, together with other characteristic vertical sections and characteristic heights. It is not required to send these drawings in vector format to the SMA, and a simple image is sufficient. Vector data from the cadastral procedure, provided by the appointed private land surveyor, are definitely a largely unused treasure when thinking about 3D graphical models of cadastral data in Slovenia. In addition, the projection of the building to the ground (horizontal extension of the building) in the state geodetic reference coordinate system is included – these data are recorded in vector format in the building cadastre.

4. Case studies with proposed solutions

In the continuation, three different generalized cadastral situations are presented to show the current cadastral registration in Slovenia and to discuss spatial data requirements for the implementation of 3D representations. The discussion includes (1) a group of single-family houses with traffic and utility infrastructure; (2) apartment ownership in the urban area; (3) and a tunnel and a viaduct. In addition, remarks are given how the collected data might be used for graphical representation of real properties in a 3D environment and what kind of data are missing for this purpose. In the conclusion, an example of a building from the official records is used to illustrate the idea of transition from 2D to 3D cadastre in Slovenia.

4.1. A group of single-family houses with traffic and utility infrastructure

In the first case, there is a group of single-family houses with traffic and utility infrastructure (Fig. 7). Only land parcels and building footprints are registered in the current cadastral registration in the national spatial reference coordinate system (Fig. 7, left). If the user needs information on the houses, floor plans and cross-sections should be checked in the building cadastre. The existence of traffic and utility infrastructure on properties can be found in the land registry as easements, but


```
<KS_XML>
…
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<gml:featureMember>
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</gml:LinearRing>
</gml:outerBoundaryIs>
</gml:Polygon>
</gurs:GEOMETRY>
</gurs:GU_REPSTAVBE.API_STAVBE_WFS.TLORIS_ETRS>
</gml:featureMember>
</TLORISI_ETRS_GML>
….
</KLS_XML>
</gml:Stavbe>
</KS_XML>
```


Fig. 5. Part of XML file from the building cadastre.
(Source: Surveying and Mapping Authority of the Republic of Slovenia).

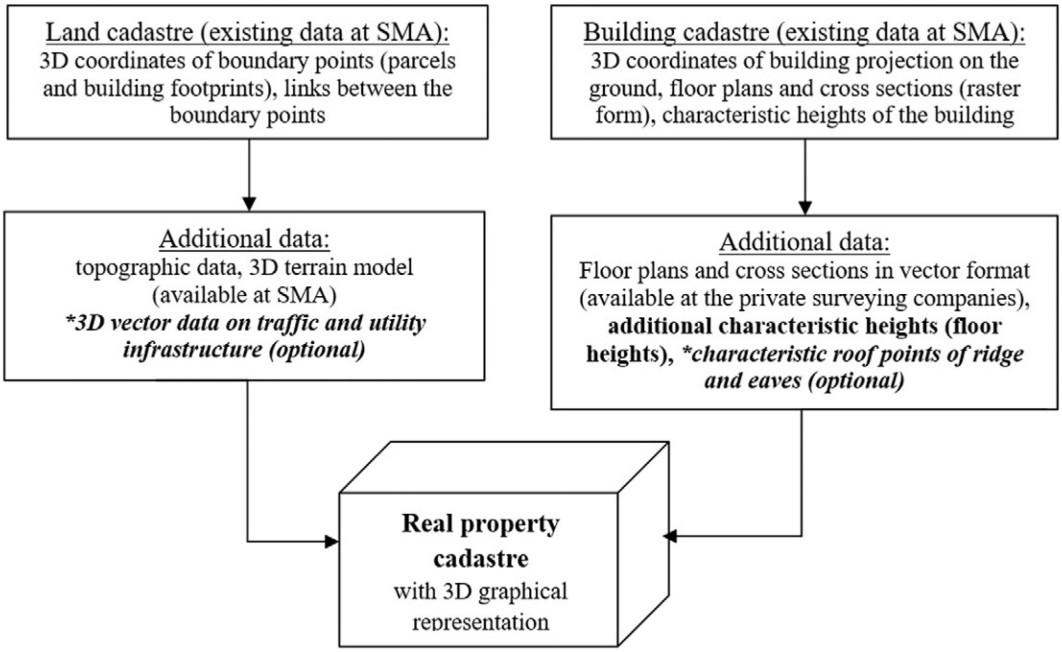

Fig. 6. Transition to a 3D real property cadastre in Slovenia by merging the land cadastre and the building cadastre – additional data required to establish the 3D cadastre with data representation in a 3D environment are outlined (data that are currently not available at the SMA or collected during the cadastral procedure are shown bold).

without any graphical representation and positional information. The graphical presentation of traffic and utility infrastructure is available in the Cadastre of public infrastructure (axes of line infrastructure), but connection with either the land cadastre or the building cadastre has not been seen; the spatial reference coordinate system is the same, but due to the limited positional precision of data, in particular, in the land cadastre and in the Cadastre of public infrastructure, another data harmonization concept has to be applied (not a simple overlay of spatial data). The proposed 3D cadastral solution represents each property as one property unit, which consists of one or more spatial units (e.g., a land parcel, objects of public infrastructure with graphical presentation of easements, and a building – Fig. 7, right).

Existing data acquired and recorded in the current cadastral process (Fig. 7, left):

- Land cadastre: boundary points (with height attributes), building footprints (with height attributes) in the national geodetic reference coordinate system, and polygons with settled topology in vector format;
- Building cadastre: horizontal extension of the building (only 2D) in the national geodetic reference coordinate system; polygons with settled topology in vector format; drawing of floors and characteristic vertical sections (not in the national geodetic reference coordinate system; in raster format); and characteristic building heights (minimum, maximum, and terrain);
- Cadastre of public infrastructure: cables and pipelines (axis in the national geodetic reference coordinate system, height attribute is optional) – the database is not a part of LAS.

Missing data for the proposed 3D cadastre solution (Fig. 7, right):

- Buildings: external façade (if different from the building footprint), characteristic roof points of the ridge and eaves; drawing of floors and characteristic vertical sections in the national geodetic reference coordinate system in vector format;
- Infrastructure: traffic and utility infrastructure spatial extension;
- Other topographic objects: road embankment.

The data acquired during the cadastral surveying could be included in the 3D cadastral model of real properties and their graphical representation. Height attributes of parcel boundary points are to be used for presentation of terrain slope (if needed), the same implemented for the characteristic point of house footprints. Roofs of houses are represented in a way that roof type can be recognized. The inclusion of topographic elements, including objects of public infrastructure, into the land cadastre was recognized as an important element in Slovenia already in the era of cadastral-topographic measurements after WWII –

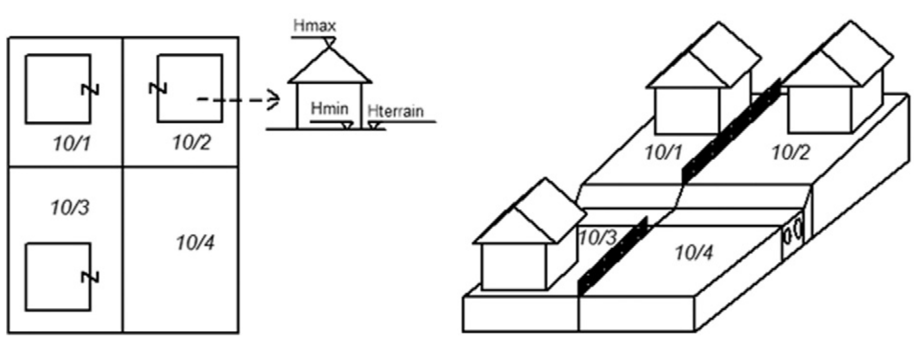

Fig. 7. The first case study: the current cadastral representation in the land cadastre and building cadastre (left), and the proposed 3D cadastre solution (right).

beside for the registration of real property rights in the land registry, valuation, and taxation of real properties, the model provides information for other public uses such as spatial planning, land and building management, utilities and energy services, etc.

4.2. Apartment ownership in the urban area

The second case study is concerned with apartment ownership in the urban area (Fig. 8). In the land cadastre, such a building is represented with two footprints only (Fig. 8, left), where the polygon is georeferenced in the national geodetic reference coordinate system and boundary points usually have height attributes. In the building cadastre, users can find floor plans and cross-sections, and the land registry contains information on ownership and other RRRs. In the proposed 3D cadastral solution, the whole building is registered, including below and above ground levels (Fig. 8, right).

Existing data acquired and recorded in the current cadastral process (Fig. 8, left):

- Land cadastre: boundary points (with height attributes), building footprints (with height attributes) in the national geodetic reference coordinate system, and polygons with settled topology in vector format;
- Building cadastre: horizontal extension of the building (only 2D) in the national geodetic reference coordinate system; polygons with settled topology in vector format – drawing of floors with parts of the building (apartments) and characteristic vertical sections (not in the national geodetic reference coordinate system; in raster format); and characteristic building heights (minimum, maximum, and terrain).

Missing data for the proposed 3D cadastre solution (Fig. 8, in the middle):

- Buildings: external façade (if different from the building footprint), characteristic roof points of the ridge and eaves; drawing of floors and characteristic vertical sections in vector format.

For 3D representation of a real property (building and parts of building), the data acquired during the current cadastral surveying could be used. Height attributes are already available for parcel boundary points and for characteristic points of building footprints. When using data from the official databases of the land cadastre and the building cadastre for generating a 3D real property model, it must be emphasized (as in the previous case) that most of the missing data are already acquired during the current cadastral registration, but the SMA does not collect these crucial data in an appropriate form. This is particularly important for the floor sketches prepared in vector format, based on an internal on-site inspection of the building, but raster images are being collected in the building cadastre. The only missing data are inner heights of floors, which can be added after the internal inspection of the buildings. Depending on the level of detail of a building model, some additional characteristic roof points might be acquired.

4.3. A tunnel and a viaduct

The third case study is concerned with a tunnel and a viaduct on the highway. In the land cadastre, the viaduct on the highway is recorded as a land parcel as it was located on the land surface, and the tunnel is not recorded or represented at all (Fig. 9, left). Major transport infrastructures such as tunnels and viaducts are not treated as buildings and are therefore not recorded in the building cadastre. As a consequence, registration of ownership and other rights to those 3D objects is currently not possible, except when the structures have the same legal status as the land. Otherwise, rights on infrastructure installations can be registered in the land registry as an easement on the land parcel.

Existing data acquired and recorded in the current cadastral process (Fig. 9, right):

- Land cadastre: boundary points (with height attributes) in the national geodetic reference coordinate system and polygons with settled topology in vector format;
- Cadastre of public infrastructure (not linked to the cadastres and land registry): axis of the highway in the national geodetic reference coordinate system, the height attribute is optional.

Missing data for the proposed 3D cadastre solution (Fig. 9, right):

- Tunnel: boundary points of 3D property object in the national geodetic reference coordinate system;
- Viaduct: boundary points of 3D property object (height attribute added to boundary points from the land cadastre);
- Other topographic objects: road embankment, viaduct pillars, and terrain model.

The proposed 3D cadastral solution represents the highway as one spatial object (see also Paulsson, 2013) onto which it is possible to attach all RRRs. The 3D representation of the relief and highway must provide information that the real property object is a viaduct and a tunnel. In this solution, land properties under the viaduct can also be owned by other persons, but legal regulation is needed here. The land use of the property object is traffic infrastructure, but this does not affect the land use on the land surface. For 3D graphical representation of real property objects in the case study, some available data (digital terrain model, data from the Cadastre of public infrastructure) can be used, while the data on the spatial extension of a real property object have

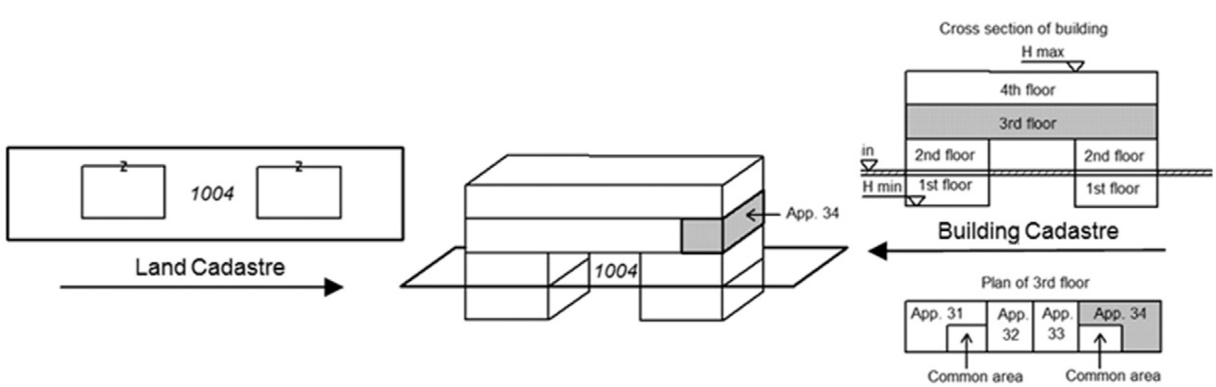

Fig. 8. The second case study: land parcel boundaries and footprints of the building in the land cadastre (left), the proposed 3D representation of real property (in the middle), and data recorded in the building cadastre (left).

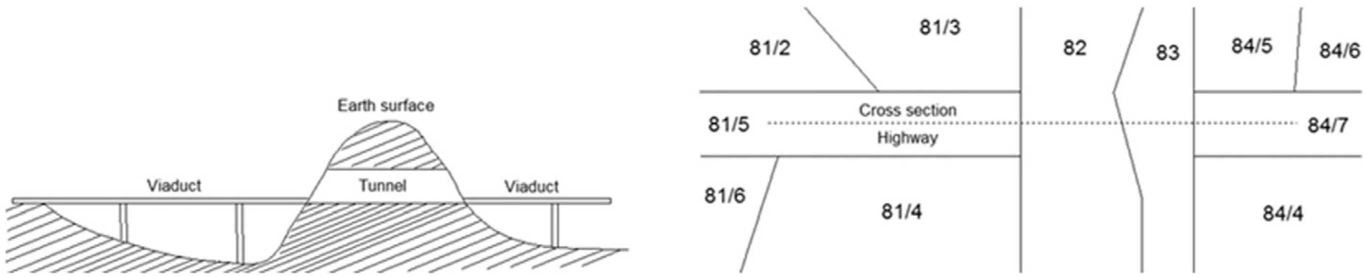

Fig. 9. The third case study: real situation – proposed 3D model (left); current cadastral representation (right).

to be acquired additionally (horizontal and vertical extension of objects, heights of characteristic points).

4.4. Case study — a multistorey building

For this case study, a building with apartment ownership was taken from the official records (Fig. 10). In the land cadastre, the building is represented with the georeferenced footprint in the national reference coordinate system together with the land parcel. In the building cadastre, there are vector data of the projection of the building to the ground as well as raster floor plans and cross-sections.

To design a 3D model of the selected building (Fig. 11), the data were acquired from the land cadastre at the SMA (parcel boundary, footprint of the building), while the data from the building cadastre at the SMA were not in appropriate form (in raster form). Hence, we followed the procedure for the preparation of the cadastral documentation for building entry into the building cadastre and provided vector data (floor plans). For the purpose of 3D modeling, the heights of the floors had to be measured in addition to already required data within the current cadastral procedure. Depending on the level of detail of a model, some additional data (characteristic roof points and external façade) might be required.

4.5. Discussion

The need for the introduction of the 3D real property cadastre with graphical representation of georeferenced cadastral units in a 3D environment is evident in Slovenia. In particular, built environment is becoming increasingly complex and current cadastral data models are not sufficient even for the main cadastral functions – real property registration and taxation purposes (Lisec et al., 2015). The introduction of 3D cadastral data models would also contribute to the idea of multipurpose cadastre if the data are available for use in different GIS and other applications.

The main aim of our research was to prove that the current graphical cadastral subsystem (2D) in Slovenia can be upgraded into a 3D real property cadastre with 3D cadastral graphical representation. The requirements for additional data needed for cadastral data representation in 3D environment are dependent on the level of details of 3D models. However, from the case studies, we have proved that the introduction of the third dimension in the existing cadastre is possible and that 3D

Fig. 10. A land cadastre map with land parcels and buildings' footprints on orthophoto (upper left corner), and graphical representation of the selected building in the building cadastre (the projection of the building to the ground, vertical section with characteristic heights, and floor plans).

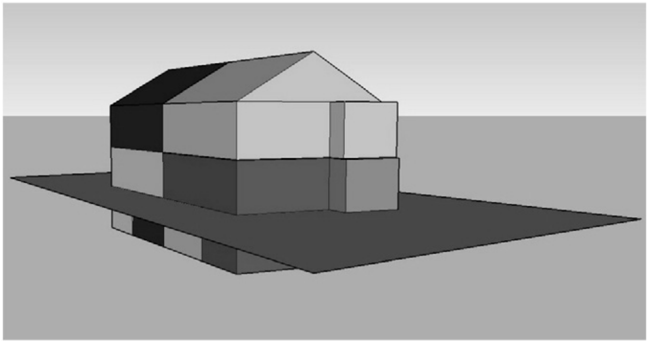

Fig. 11. 3D model of the selected building based on cadastral and additionally acquired data (floor heights).

graphical representation of cadastral objects is possible based on the data that could be gathered in the modified current cadastral procedures.

From the legal point of view, Slovenian LAS is quite clear in providing the possibilities to create 3D real properties, but the cadastre is complex, and, in fact, in some cases the registration of 3D objects is impossible. The law allows the creation of 3D real properties in cases of rights of superficies or condominiums; therefore, the 3D real property units have to relate to buildings. As a consequence, 3D real property units do not cover all 3D situations (for example, construction works that are not buildings).

A particularity of the Slovenian real property cadastre is that it consists of two databases: the land cadastre and the building cadastre. They are linked, but separate, although they both represent the same space. As the building cadastre is relatively new, i.e., it was established at the beginning of the millennium based on the photogrammetric data acquisition, the number of the so-called “cadastral inscriptions” with building details is very low. The land cadastre with buildings' footprints is not harmonized with the building cadastre in the cases where buildings are not registered in the cadastres with a cadastral inscription (according to the new cadastral procedure).

Currently, the cadastral system requires coordinates of land parcel boundary points and building footprints in the national geodetic reference coordinate system (with height attributes) with topologically settled polygons in vector format. The building cadastre, linked to the land cadastre, provides data on spatial extension of the buildings in the national reference coordinate system (building outline and characteristics heights), use, size of the building (net floor area and floor area in use), floor plans, and apartment plans in raster format. However, the current cadastral registration of buildings is not adjusted to the requirements of cadastral data representation in the 3D environment, because its graphical representation is limited to land parcels and strata plan drawings with apartment units in raster format. In order to support 3D representation of real properties, the cadastral registration can be improved already by setting up regulations to prepare data in an appropriate format and to acquire the minimum set of additional data needed to design 3D models (see also Fig. 6).

An additional challenge refers to 3D construction works that are not buildings (tunnels, bridges, etc.); registration of ownership and other rights directly to those 3D objects is currently not possible, except when objects have the same legal status as the land on which those objects are located (the object follows the legal fate of the land). Infrastructure installations and facilities are most commonly registered descriptively in the land registry, as an easement on the entire parcel area. Notably, the database was established for utility infrastructure (cadastre of public infrastructure), but this is a database, rather than a cadastre, without legal status.

5. Conclusions

Over the last decade, the demand for 3D real property cadastre has increased significantly worldwide. The physical and legal complexities of the built and natural environment prompt new concepts and definitions of real property units in order to meet the demands of today's society and to balance private and public spatial interests. Particularly in urban areas, there is a tendency to use space above and below the Earth's surface. Complex 3D real property objects cannot be defined and registered as cadastral objects in the traditional 2D land cadastre; furthermore, 2D cadastral data do not support graphical representation and reuse of cadastral data in different 3D environments. Particularly in complex urban areas, we have to consider the development of a 3D real property cadastre in which proprietary rights acquire appropriate 3D space both above and below the ground level.

This paper discusses the possibilities to upgrade the traditional land parcel-based cadastre into a multipurpose 3D real property cadastre, for the Slovenian case, with an emphasis on data needed for cadastral data representation in the 3D environment. In Slovenia, most complex 3D real property situations related to buildings can be registered using the right of superficies and apartment rights. However, from the juridical point of view, the current cadastral system is not sufficient for all 3D situations. Registration of ownership and other rights directly concerning 3D construction works that are not buildings (tunnels, bridges, etc.) is currently not possible, except when the structures have the same legal status as the land (the structure follows the legal fate of the land). Infrastructures are most commonly registered descriptively in the land registry, as an easement on the entire parcel area.

Registration of rights and restrictions in the land registry requires a cadastral survey and cadastral records in the land cadastre and in the building cadastre, respectively. As in many countries with the traditional parcel-oriented land cadastre and 2D graphical representations of cadastral data, the existing cadastral system in Slovenia cannot provide a proper registration and representation of all real property situations in 3D environment. The data available in the current cadastre system can be used for 3D real property cadastre and its graphical representation in the 3D environment; nevertheless, some additional data are needed. The minimum data required could be provided already through the current cadastral procedures. These changes have to be implemented by setting up regulations to prepare data in an appropriate form. Furthermore, some technical aspects of 3D cadastral registration must be resolved; e.g., how to incorporate 3D information as part of the cadastral geographical data set.

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