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3D Cadastres Best Practices: Legal foundations

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Key words: 3D cadastre, 3D real property, legal framework, land management, land administration

SUMMARY

The concepts of three-dimensional (3D) real property have been the subject of increased interest in land use management and research since the late '90s while literature provides various examples of extensive research towards 3D Cadastres as well as already implementing 3D cadastral systems. However, in most countries the legal aspects of 3D real property and its incorporation into 3D cadastral systems have not been so rigorously examined.

This paper compares and discusses 3D property concepts in fifteen selected countries, based on the authors' national experience, covering Europe, North and Latin America, Middle East and Australia. Each of these countries' legal system is based on different origins of Civil Law, including German, Napoleonic and Scandinavian Civil Law, which can prove useful to research in other Civil Law jurisdictions interested in introducing 3D cadastral systems. Selected countries are on different stages of introducing and implementing a 3D cadastral system; this may contribute to the detection of the main 3D real property concepts that apply as well as deficiencies and malfunctions that prohibit introduction of 3D cadastral systems, highlighting challenges that may have not yet surfaced. This paper aims to present the different legal concepts regarding 3D real property in the examined countries, focusing on the characteristic features of cadastral objects described as 3D within each country's legal and cadastral framework. The analysis of the case studies revealed that the countries are on different stages of 3D Cadastre implementation, starting from countries with operational 3D cadastral systems, to others where there is yet no interest in introducing a 3D cadastral system.

3D cadastral objects in each country are presented, as well as differences in the regulatory framework regarding definition, description and registration. The paper continues the legal workshop discussions of the 4th International Workshop on 3D Cadastres in Dubai 2014 by analysing the legal concepts of 3D cadastres in the above-mentioned countries. The outcome is an overview and discussion of existing concepts of 3D property describing their similarities and differences in use, focusing on the legal framework of 3D cadastres. The article concludes by presenting a possible way forward and identifies what further research is needed which can be used to draft national and international research proposals and form legislative amendments towards introduction of national 3D cadastral systems.

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1. INTRODUCTION

Cadastres are being recognized as the core of land administration systems. The cadastral map should be able to represent complete and comprehensive spatial information for registering land rights, restrictions and responsibilities (RRRs) on the land parcels (Kaufmann and Steudler, 1998). However, until today most of the countries around the world use 2D land parcels as the base for their land administration systems (Ho et al., 2015), regardless of the 3D characteristics implied by the relative real property legislation. Thus 2D projectional presentation of RRRs on land parcels cannot accommodate complex, overlapping real property so it needs to be extended to three-dimensional (3D) space and properties. Contrast between 3D real property implications in legislation and its 2D registration and documentation is becoming more emphasized with the increasing development of urban areas with complex structures, high-rise buildings and underground infrastructures. The rights of cadastral objects may relate to spaces above or below the Earth's surface (Stoter et al., 2011). More complex relationships in space can no longer be unambiguously mapped onto the Earth's surface in 2D. Pressure on the land use, especially in the city centres, has led to dense construction with complex structures with intertwined relationships. In general, registration of rights is possible on parts of the building. However, the spatial representation of the extension of rights often does not exist or it is possibly stratified on two-dimensional representation. In addition, an increasing number of tunnels, underground networks and infrastructure objects (e.g. water, gas, electricity, telephone, Internet and other pipe networks) under or above land are not owned by the owner of the land above or below (Roić, 2012).

The concept of three-dimensional (3D) real property has been the subject of increased interests in land use management and research during the last decade while it has been in focus for more than one and a half decade along with the discussion about how to secure rights in space (Fendel, 2002; Stoter and v. Oosterom, 2006; Ploeger, 2011; Stoter et. al., 2012; v. Oosterom, 2013; Paasch and Paulsson, 2014; Kitsakis et al., 2016). General questions such as registration of properties in strata (i.e. in layers) have been discussed. What “3D property” is depends, to a large extent, on the legal system and cultural background (Fendel, 2002). Since then, the problems of finding definitions have been addressed by e.g. Paulsson (2007) and Sherry (2009). Paulsson (2007) concludes that there does not seem to be a simple meaning to the concept of 3D property. Research has been carried out concerning the legal framework of 3D cadastres aiming at identifying the main topics concerning the legal aspects of 3D property and cadastre (see, e.g. Paasch et al., 2016).

There are several countries already implementing 3D cadastres, inter alia Sweden, Norway, Australian states of Victoria and New South Wales, in Canada Brunswick and British Columbia, as well as Chinese cities such as Shenzhen. However, in most cases the legal aspects of 3D real property and its incorporation into 3D cadastral systems have not been so rigorously examined (see e.g. Paulsson and Paasch, 2013).

This chapter provides a comparison and discussion of 3D property concepts in selected countries, which are selected based on the professional experience of the authors. Currently they are in different stages in their 3D cadastral development. In addition to that, the authors aim through this chapter to provide input to countries that are exploring or are in the midst of the process of developing a 3D cadastral system, especially from a legal perspective. Since the countries are on different stages of introducing and implementing the 3D cadastral systems this study contributes to the detection of main 3D real property concepts that apply internationally as well as deficiencies and malfunctions that prohibit introduction of 3D cadastral systems. To compare between these countries, a set of criteria was proposed to provide a systematic comparative analysis.

The remaining of this chapter is structured as follows. Section 2 presents the topics examined in each of the fifteen case study countries. In Section 3, previously examined topics are summarised in tables, while also their similarities and differences are presented and analysed, while Section 4 presents the conclusions derived through preceding comparative analysis. The chapter ends by presenting issues emerging from current study that require further research.

2. 3D LEGAL ISSUES EXEMPLIFIED BY CASE STUDIES

There are several countries already implementing 3D cadastres and literature provides numerous publications on 3D cadastres' developments (e.g. Karki et al., 2011; Mangioni et al., 2012; Stoter et al., 2012). The examples in this chapter highlight different, national concepts of 3D property, covering Europe (Austria, Bulgaria, Croatia, Czech Republic, Greece, The Netherlands, Poland and Sweden), South America (Argentina and Costa Rica), Asia (China and Jordan), Australia (State of Victoria) and Canada (Province of Quebec).

Investigation of 3D real property aspects in each of the examined countries starts by providing information on general characteristics of national real property legislation in the form of the following questions:

- What was the reason to introduce a 3D system or why would it be necessary?
- What is the current status?
- What is the legal definition of 3D objects and what are the possibilities for delimitations?
- What types of rights can be registered in 3D?

To facilitate this procedure, as well as to prevent different apprehension of national legal concepts, aspects examined were required to respond to the following fields:

- How is real property defined in law (Land Code, Civil Code, or any other legal document in each country that defines land)? Is the third dimension implied/clearly defined in the legal definition?

- What are the 3D object situations (including every situation regardless its recording in cadastre, or if it is defined by law)? - What are the 3D objects recorded in national registries and how are they recorded (e.g. 2D plans + floor number, 3D pdfs, 2D projections etc)? Which registries are used to record these objects?
- Are there any restrictions or responsibilities implying 3D aspects (or directly defined in 3D) defined by law?
- How is 3D space separated from land ownership in case of underground/above ground infrastructures (e.g. real property stratification, specific legislation, servitude establishment etc)? This requirement mostly refers to Civil Law jurisdictions, where Roman principles significantly restrict partition of 3D space.

In the following section, above mentioned aspects are presented for each country, in alphabetical order.

2.1 Argentina

2.1.1 Background information

In Argentina, property rights are fundamental rights ensured by the National Constitution. Until 2015, the Civil Code of the Nation, approved in September 25, 1869, condensed the bases of the legal order in civil matters. During this period, the property had a vertical development, and even when the owner could exercise his/her property right in different ways, there were some restrictions. The volumetric definition of the property found in that Civil Code was not evident in the National Law of Cadastre (Ley Nacional de Catastro No. 26.209/2007), which shows an inconsistency in the national regulatory framework. On August 1, 2015, a new legal framework was developed: the Civil and Commercial Code of the Nation came into force and it brought up several changes related to 3D Cadastral concepts, but its application is in transition within the provinces' legal framework.

Property rights are registered in titles or deeds, physically written and stored in the Property Registry. These documents include the name of the beneficiaries and a brief, and usually unreliable, estates description. In parallel, the parcels are registered in cadastral institutions by a paper cartographic document named "blueprint of surveying", that provides some kind of graphic and alphanumeric information about the parcel boundaries. In the most cases, cadastres do not share databases with the Property Registry; they can only exchange specific information. Some provincial cadastres have digital databases based on blueprints plus legal and economic information (basically holders, restrictions and tax valuation). Most of them have established a Geographic Information System to manage databases, but still many institutions work with paper documents (in all registry stages), even 3D legal objects.

Even when the Civil and Commercial Code of the Nation imposes all real rights and some restrictions, each province organize its Cadastre and Property Registry under its proper law. Not all of the provincial law adhered at National Law of Cadastre.

In this context, the legal framework doesn't provide 3D conceptual and legal framework to improve cadastral institutions, neither promotes transition from physical to digital databases.

2.1.2 Status of 3D objects' recording

The complex reality of cities in terms of RRR materialized through different kinds of the 3D objects started to push lightly the necessity of a 3D information system. Beside this, the new

concepts of rights written in the 2015 Civil and Commercial Code demonstrate that the 2D parcels cannot accommodate the complex overlapping of real property. Despite this reality, Argentina is not a country that is exploring a 3D cadastral system yet, particularly from the legal perspective. There are some initiatives at the discussion level in academic events, but even in jurisdictions where the cadastral norms are changing, the 2D paradigm is still present. The absolute 3D representation of buildings is not a common practice in Argentine cadastres. The 3D representation prototypes are generally generated in a GIS environment, showing the building as a function of the number of floors (the alphanumeric database indicates this value, which is multiplied by 3 meters to generate the volume). Most of the 3D objects are represented in 2D plans plus a number that normally corresponds to the floor, and a cross-section with identification of heights relative to the ground in case of buildings (Figure 1), and a topographic profile, in the case of towpath (Figure 2).

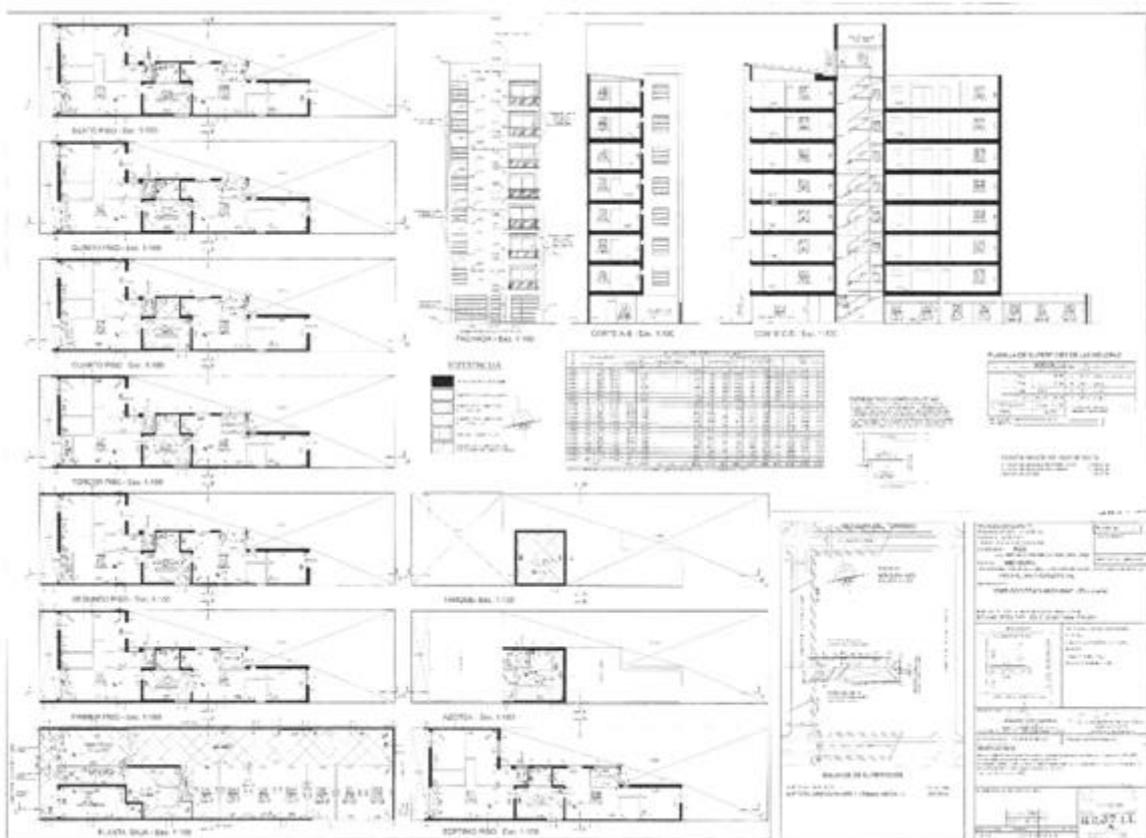


Figure 1: Survey blueprints of horizontal property

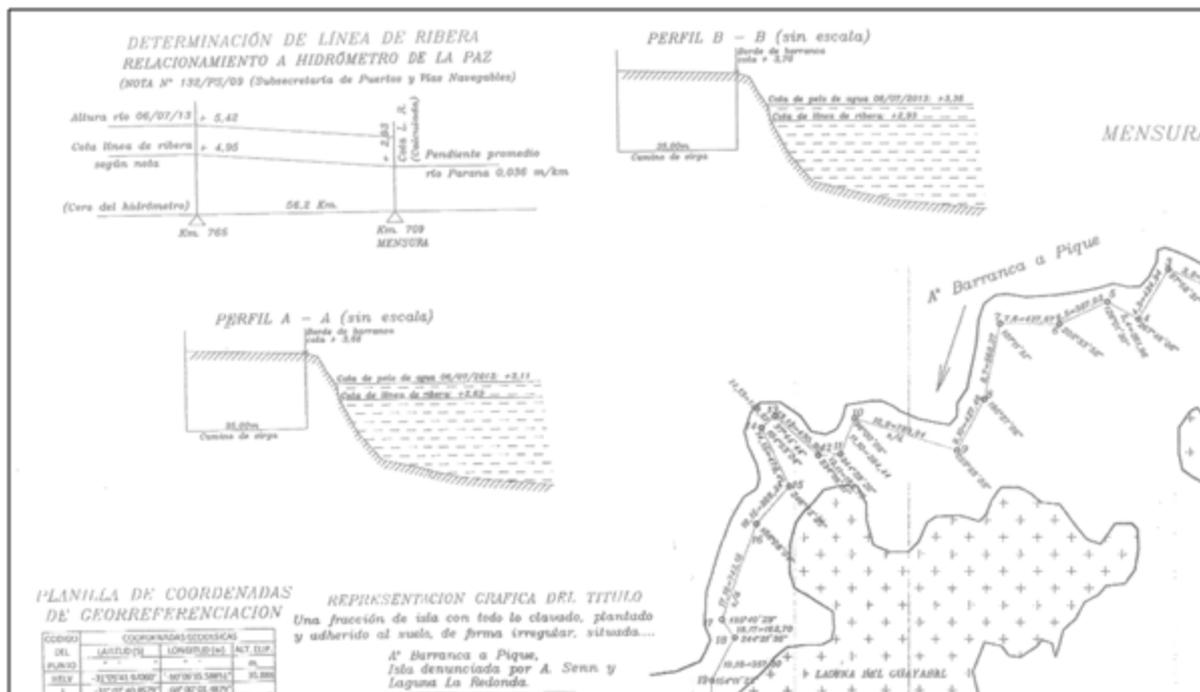


Figure 2: Survey blueprints of riparian and towpath

2.1.3 Legal definition of 3D objects

According to the Civil and Commercial Code of the Nation, there are two kinds of private properties: Properties by Nature, which is the land and other things incorporated to it by the man or under the ground but without the man intervention (Art. 225), and Properties by Accession, which are things immobilized by adhesion to the ground. In both cases, it could be said that the 3rd dimension is implicit.

The concept of 3D parcel does not exist officially in Argentina. All the parcels are defined in 2D according to the Cadastral National Law No. 26209, which says: "... a parcel is a representation of a continuous real estate territory identified by a polygonal boundary with one or more legal titles of possession, whose existence and essential elements are recorded in a cartographic document registered in the cadastral institution" (Art. 4).

The Cadastral National Law defines a "territorial object" as any portion of the territory that, by nature, is finite and homogeneous. The law defines the "legal territorial object" too as those generated by a legal cause which may be a property title (as is the case in real estate transactions), an ordinance or law (as is the case in ownership restrictions, the creation of reservation areas, or the demarcation of an urban area), or even an international treaty (such as those that establish the borders between countries). The law stipulates that all the legal objects and their public records must be managed by the provincial cadastres. Furthermore, the record of titles is responsibility of the Register of Property. The institution is separated from the provincial cadastre; however, the databases are shared. In fact, the information about ownerships stored in cadastral databases came from the Registers. At the same time, in the property titles, notaries write a brief description of the parcel's boundaries, and usually it refers to the respective blueprints. Both institutions are tightly related and they need each other to complete the RRR's record.

2.1.4 Types of rights that can be registered in 3D

Horizontal Property: right that can be exercised over a property of its own. It gives to the owner the powers of use, and material and legal disposition. It can be exercised over private parts and over common parts of a building, in accordance with what established the respective regulations of horizontal property constitution (Art. 2037 of the Civil and Commercial Code). The registration of rights into the volume of a building is perfectly possible and clear in the cadastral map of horizontal properties. The spatial representation of the extension of rights above the roof and below the lowest garage does not exist.

Surface Right: Temporary real right that is constituted on a foreign property. It grants to the owner, the faculty of use, enjoyment and material and legal right to plant, forge or build, or planted, forested or constructed in the land, the air space or underground, according to the modalities of its exercise and term of duration established in the title sufficient for its constitution and within the provisions of this Title and the special laws. The surface right does not mean a land modification, but an affectation. It can be established on the top of the building.

Rivers and lakes boundaries: the riparian line is a boundary that divides the public and private property rights, separating river (public domain) of land (private domain). It must be determined from the average ordinary maximum floods level (Art. 1960), it is a vertical surface which involves water levels. Associated with it, there is the towpath: a restriction to private ownership established in Art. 1974 of the Civil and Commercial Code, defined as a 15 m strip measured from the riparian line of water bodies, toward the interior of adjoining properties.

Active Real Estate Easements: under Title XI – Easements, Chapter 1 – General Dispositions, the Civil and Commercial Code define an easement (*servidumbre*) as a real estate right, permanent or temporary, exercised over a property owned by others. It is a restriction to the right of ownership by the property titleholder. An easement requires two real estate properties, a master and a slave, which must belong to different owners. It can be established at any elevation level (floors, terraces, etc.)

Administrative Easements of Utility Pipes (electrical conduits, gas pipes, etc.): the National Law No. 19.552/1972 for electrical conduits and the National Law No. 17.319/1967 for hydrocarbons, stipulate that administrative easements for ducts, affect ownership by imposing restrictions and limitations needed to build, maintain, repair and use a pipe or duct that is an essential component of an energy system. These administrative easements are represented graphically as areas or surfaces, with no consideration for the height (electrical conduit) or depth (gas pipe) at which they are laid.

Rights Granted under the Mining Code: Established by Decree No. 456/1997, it regulates the property of mines, and the rights of exploration and operation. Art. 7 stipulates that the mines are private assets of the Federal Government or the Provinces, depending on their location. Art. 10 stipulates that, “independently of the original ownership by the State... the private property of the mines can be established by legal grant”. This granting of mining rights can be interpreted as a mining easement to the mining company. On the other hand, Art. 12 defines mines as real estate properties. Art. 20 establishes a mining cadastre to describe the physical, legal, and other useful information about mining rights. Those rights are identified

with points that represent the vertices of the “area” defined in the requests for exploration permits, discovery manifests, etc. However, the Mining Code does not mandate in any of its articles the volumetric representation of the mineral to be explored.

Restrictions under the Aeronautic Code: established by National Law No. 17.285/1967, the Aeronautic Code describes the limitations to ownership of property located close to airports. It defines the limits to obstacles in the airspace in airports and their surrounding environment, to ensure the secure landing and takeoff of aircrafts. Although these obstacles are by nature volumetric bodies, they are represented by their projections on the representation surface. Cross-sections are also enclosed to describe the height over land over which the restriction extends.

2.1.5 Concluding remarks

The idea of a 3D system that extends to three-dimensional space is still embryonic in Argentina. There are a few academic researches only. The introduction of a 3D system is not going to happen soon in the country particularly because, even not having an official explicit definition at the national legal framework, the terms "3D property" and "3D parcel" are not part of the legal terminology in the country.

The georeferencing of cadastral parcels and the territorial objects under the same system (even in 2D) is still incipient for the urban areas. It could represent the first step to establish a 3D cadastre in Argentina. Even though the provincial cadastrals are still independent, their points of contact with the municipal cadastrals could accelerate the process of creating territorial data in 3D. The public and private utilities and the organizations that control the environment and air traffic must structure their data under the same system of reference as the territorial cadastrals, representing their structures with equivalent precision.

2.2 Australia (State of Queensland)

2.2.1 Background Information

Queensland is in the north-east seaboard of Australia and is the second largest state in Australia with an area of 1.8 million square kilometres. There are more than 3 million total parcels of which around 300,000 are building units and around 4500 are volumetric parcels in the Digital Cadastral Database (DCDB). The Department of Natural Resources and Mines is the custodian of all cadastral data.

Queensland is one of the pioneering and leading jurisdictions in 3D cadastre and 3D registration. The Building Units and Group Titles Act (1980) has been registering building units and common properties in the cadastral system for the last 37 years and 3D volumetric parcels for the last 20 years since 1997. Currently there are two very important projects underway in Queensland; one is a cadastral and geodetic systems review project with an aim to consolidate all cadastral and geodetic databases as well as to include 4D in the database, and the second is 3D QLD initiative which aims to provide 3D indoor navigation and 3D augmented reality through cadastral database (<http://3dql.org/>).

2.2.2 Status of 3D object's recording

In Queensland all titles are registered and maintained by the Titles Registry Office (Karki, 2013). For the purposes of registration of titles, all 2D and 3D titles are treated the same and

registered similarly (Karki, Thompson, & McDougall, 2013). The Land Title Act (1994) and the Land Act (1994) are the main acts for registration of freehold and non-freehold lands respectively. Building units are registered under Building Units and Group Titles Act (1980) and Body Corporate and Community Management Act (1997). Almost all freehold land is surveyed by private licensed cadastral surveyors. The Surveying and Mapping Infrastructure Act (2003) guides surveyors and assists in maintaining survey infrastructure, the Surveyors Act (2009) guides the activities of surveyors and provide protection for the landowners. The Sustainable Planning Act (2009) administered by the local governments guides surveyors by managing development zones. In addition there are several directives for surveyors and land practitioners; the Land Practice Manual, the Cadastral Survey Requirements (CSR) and the Registrar of Titles Directions for Preparation of Plan (RTDPP). All these legislation and directives have provided a robust legal framework for the registration of 3D titles which is assured by the state through the Torrens titles registration system.

2.2.3 Legal definition of 3D objects

Section 10.2 and 10.5.1 of the RTDPP allows any kind of 3D object to be registered as long as they can be defined mathematically. There is a separation between the 2D plans (called Standard Format Plan), 3D building unit plans (called Building Format Plan (BFP)) and 3D volumetric plans (called Volumetric Format Plans (VFP)). While separate legislation exists for building units, volumes are dealt under the directives of the RTDPP.

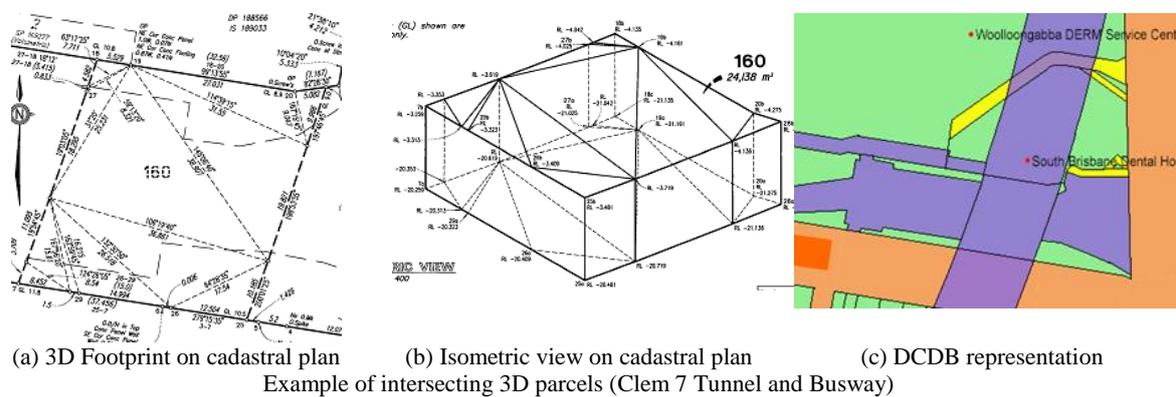
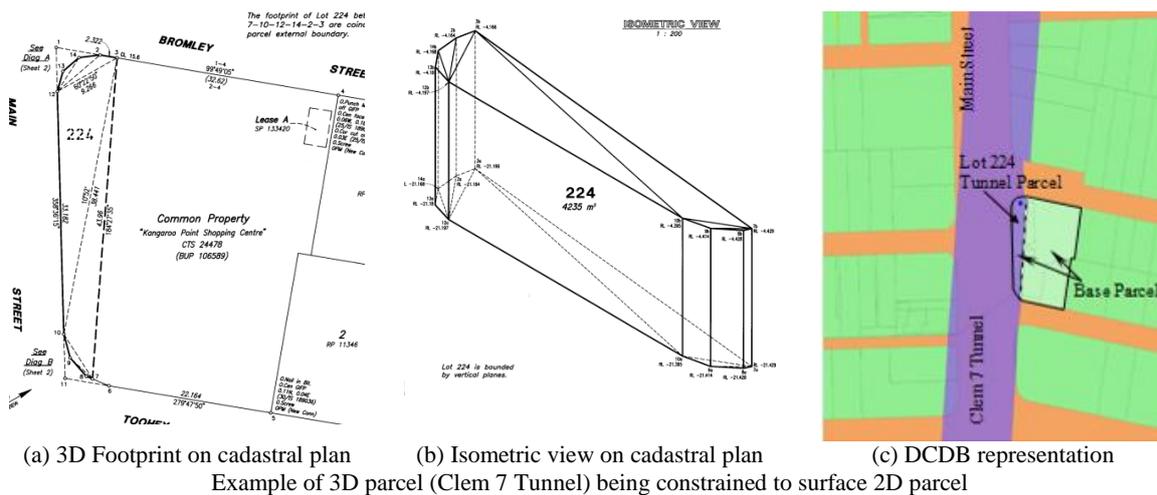
The 3D cadastral plans (BFP and VFP) show 2D footprints on 2D base lot with 3D Isometric views that are part of the cadastral plan. 3D objects have different lot numbering systems to distinguish themselves from a 2D lot number. 3D Volumetric plans show connection to elevation geodetic control point and dimension and bearings of objects. Distinction is made between the terminology lot and parcel. Lot is the surface or the base parcel whereas parcel is contained within a lot and is the various units/apartments, common property, volumes etc. within the bounds of a surface parcel. Where the lot does not have any other parcel, such as in the case of a 2D lot, the lot and parcel are often used interchangeably and is understood from the context.

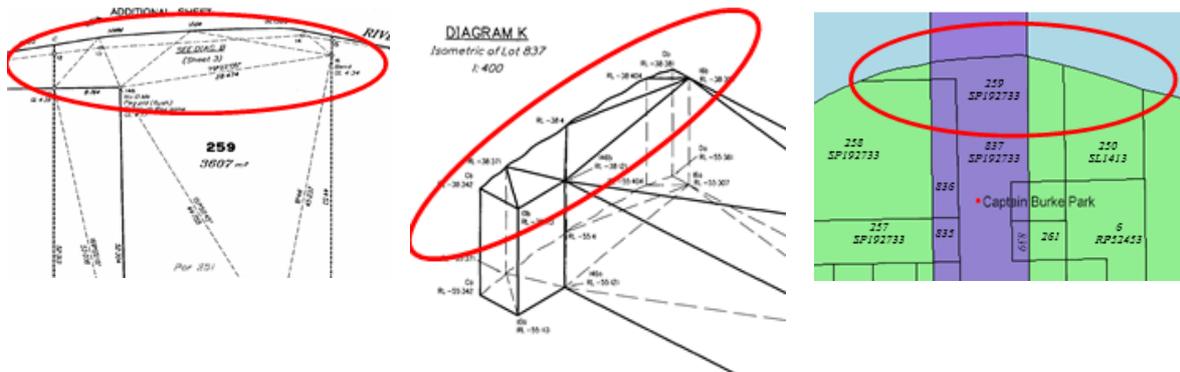
The land registration process has evolved through Common Law. Torrens titles system is used for titles registration and paper titles are not provided to owners but rather stored in a Titles database. This information can be purchased for a small fee and is frequently accessed by banks, real estate agents, solicitors and conveyancers etc. but is protected by privacy acts. The point of truth for title is the Titles Registry Office record, and for parcel dimensions is the paper cadastral plan. Private cadastral surveyors survey the land and are legally responsible for the accuracy of plan data while the State is responsible for the title. There are differences in the representation of the paper cadastral plan in the Digital Cadastral Database (DCDB). The cadastral plans have a great deal of detail regarding the survey such as dimensions, reference marks, geodetic control points, encroachment information, details of past surveys, isometric views, leases, covenants etc. The DCDB does not display this additional information and simply shows the parcel polygon and other attributes such as tenure type, ownership details including all other RRR. Thus the paper plan is the point of truth for cadastral data, not the DCDB which is just a representation of the information from the cadastral plan and the Titles office. The digital cadastral database is a representation only and not the point of truth. Both the Titles Office and Directorate of Survey is within Department of Natural Resources and Mines, but are

separate entities. All cadastral representation, including valuation, topographic data, imagery etc. are open source and is disseminated free of charge.

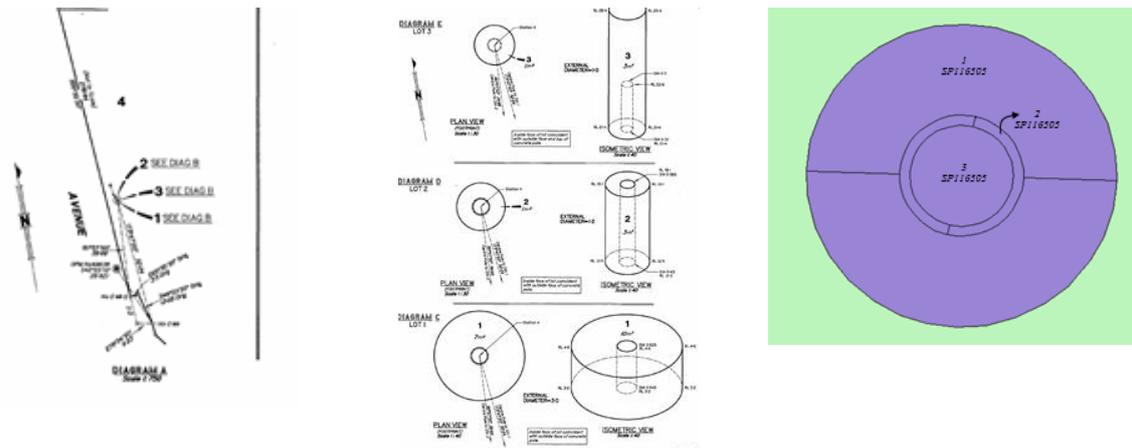
2.2.4 Types of rights that can be registered in 3D

All RRR on 3D are registered and any RRR that is possible to be registered on 2D is also possible to be registered on 3D parcels. Figure 3 shows some examples of 3D parcels registered in Queensland. The 3D parcel is truncated and separate 3D lots are created for each volume at the intersection of the extent of the 2D lot at the surface or with the intersection with another volumetric parcel. The 3D objects registered in Queensland are 3D Easements, Leases, Covenants; 3D Roads; Air spaces; 3D Ambulatory boundaries; Water Spaces; Underground space (with or without construction); Restriction easements (e.g. so others cannot obstruct view); Mining rights; Limitations (above or below a certain height); Apartments and Common Property; Tunnels, Utilities (network and individual infrastructure); Carbon abatement zones; Commercial spaces; Car parks (including the incline plane); Bridges (pylons and bridge spaces); Sports spaces (stadium, locker spaces) etc.

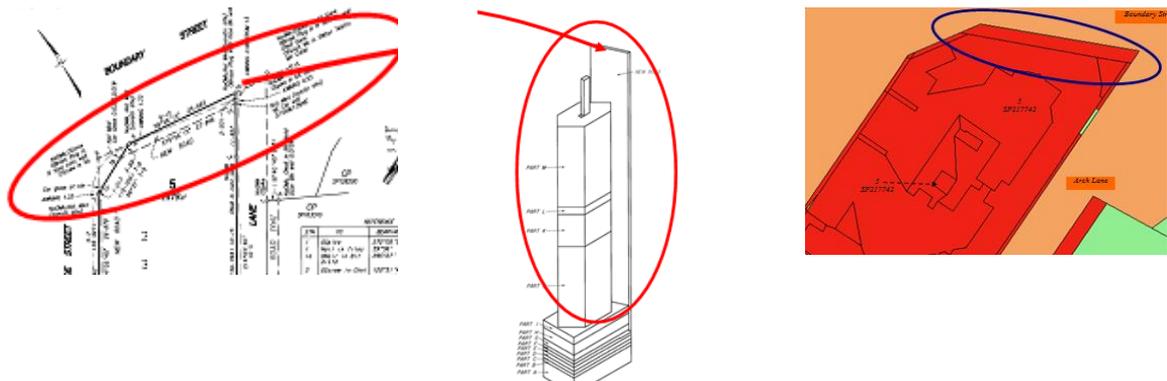




(a) 3D Footprint on cadastral plan (b) Isometric view on cadastral plan (c) DCDB representation
 Example of 3D ambulatory boundary (Clem 7 Tunnel and Brisbane River)



(a) 3D Footprint on cadastral plan (b) Isometric view on cadastral plan (c) DCDB representation
 Example of registered 3D airspace for utility network infrastructure



(a) 3D Footprint on cadastral plan (b) Isometric view on cadastral plan (c) DCDB representation
 Example of reserved airspace for 3D road parcel

Figure 3: Examples of 3D volumetric parcels registered in Queensland (Karki, 2013)

2.2.5 Concluding remarks

Queensland has a long history of legislative support for registering 3D cadastral objects. Since the registration of 3D is treated similar to 2D and the Title is supported by the state, the owners, developers, surveyors, mortgagers etc. have no issue in creating, maintaining, registering, transferring, and mortgaging 3D parcels. Also, since the digital cadastral database is not

considered the point of truth, the lack of recording of 3D in a database is not seen as a hindrance in the development of 3D parcels. Queensland is further investing in the development of a 3D capable database as well as enhanced functionalities such as 3D indoor navigation and 3D augmented reality using data from a 3D cadastre.

2.3 Australia (State of Victoria)

2.3.1 Background information

The State of Victoria is located in the south-eastern corner of Australia. It is the geographically smallest mainland state, but the most densely populated and urbanised. Victoria is the second most populous Australian state with an estimated population of 6,100,900 as at June 2016 and a total land area of 227,420 Km² (ABS 2016). The Victorian land administration system is called Land Use Victoria which is the principal agency for land administration, property data and helping with better use of government-owned land.

2.3.2 Status of 3D objects' recording

Legislation has evolved in Victoria over an extended period to meet the demands for recording rights, restrictions and responsibilities (RRRs) related to the ownership of the 3rd dimension of space. The evolution has been driven by the requirements of developers, owners, lending and financial institutions, mortgagees and planners. The current legislation governing the registration of land RRRs including 3D RRRs is the subdivision Act 1988 (Aien et al. 2013). The land registration involves issuing a certificate of title that is complemented by a graphical representation of the spatial extent of the RRRs associated with the land known as the subdivision plan. Victoria's current legislation allows for registration of 3D land RRRs; however, the techniques for graphically depicting them in subdivision plans rely on 2D representation such as 2D cross-section and floor plan.

2.3.3 Legal definition of 3D objects

In legally defining 3D RRRs, two fundamental pieces of information is used; one is the type of 3D RRRs and second is the boundaries by which the spatial extent of the RRRs is defined. In practice the RRRs that are registered in Victoria include lot (private interest), common property (communal interest), roads (public interest), reserve (park and green spaces in public interest), crown land (land in interest of government) easement (utility network interest), restriction (limitation on the use of land), depth limitation, and airspace (above the ground/ external building interest). The types of boundaries that are used in legally defining the 3D RRRs include structural, ambulatory and projected. Structural boundaries are defined based on building parts e.g. walls. Projected boundaries are used to define invisible boundaries e.g. balconies. Ambulatory boundaries are based on dynamic natural features e.g. river borders (Atazadeh et al 2017).

2.3.4 Types of rights that can be registered in 3D

In most cases, roads, easements, reserves, crown lands and restrictions are 2D RRRs. But 3D lots, common property, depth limitation and airspace are common 3D RRRs and registered in different ways and methods.

Apartment units are registered as lots. An apartment unit may include accessory parts such as parking space and storage space. Apartments and its accessory parts are registered under one title. Common property is another type of 3D RRRs that is registered as communal legal spaces (such as corridors and lobbies) and physical structures (such as walls and ceilings). 2D cross-section and floor plan views of only apartments and communal legal spaces are represented, and communal physical structures are only described in the subdivision plans. Depth limitation and airspace are registered as 3D RRRs. They described but are not delineated in subdivision plans (Atazadeh et. al. 2016).

2.3.5 Concluding remarks

Victorian regulations have a longstanding track record in facilitating registration of 3D RRRs. The laws and regulations in Victoria have evolved such that it is one of the lead jurisdiction in 3D cadastres. While the registration of 3D RRRs is for many years, 3D presentation of them is not functional yet. Land Use Victoria in conjunction with the University of Melbourne leads the way to establish and realise Victorian 3D digital cadastral system (figure. 4) (Shojaei et. al. 2016).

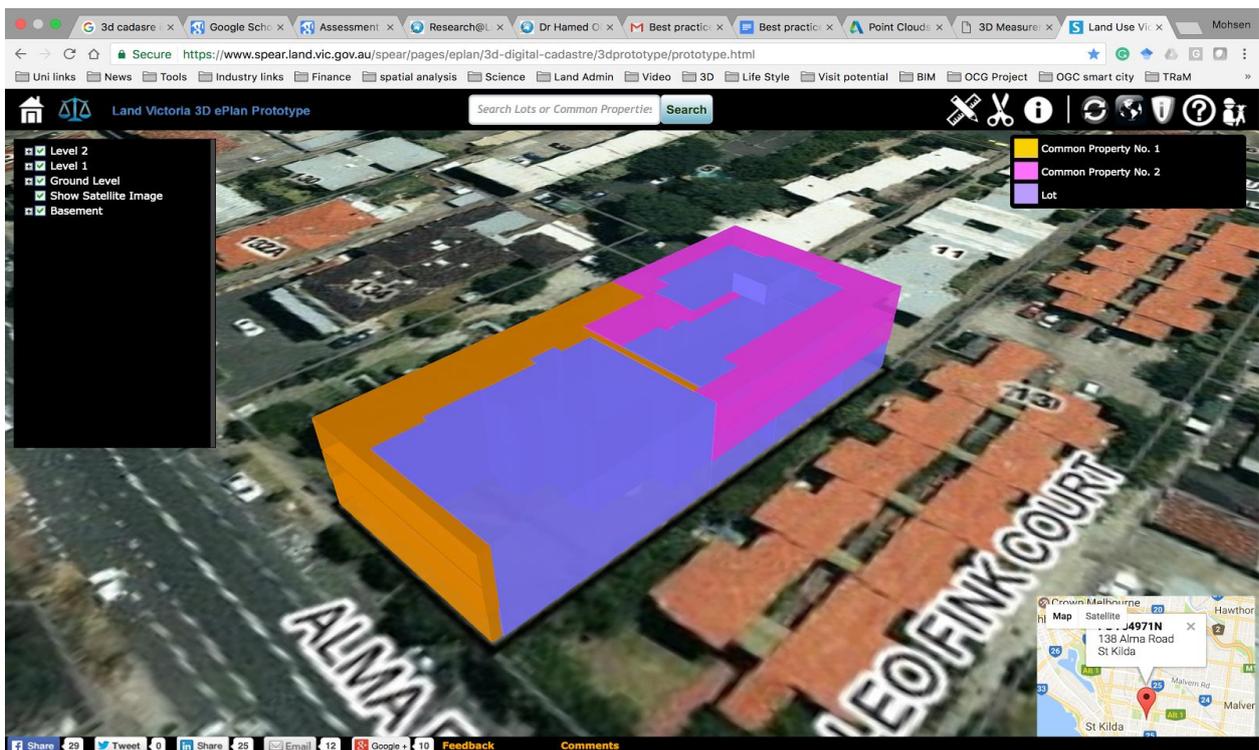


Figure 4: A prototype 3D cadastre system developed by Land Use Victoria accessed <https://www.spear.land.vic.gov.au/spear/pages/eplan/3d-digital-cadastre/3dprototype/prototype.html>

2.4 Austria

2.4.1 Background information

The Austrian cadastral system has a long tradition. The current system was initiated in 1817 and developed since that time (for details see Liseč and Navrátil, 2014). Currently, the focus of

the cadastral authority is on digitizing the survey archive, a project that shall be finished in 2024 (Lichtenberger et al. 2015). Since this effort requires significant resources, other endeavours, like the realization of a 3D cadastre, have to be postponed. The ownership of land is defined in the Civil Law code. Theoretically the vertical extent is not restricted, i.e., ownership ranges from the centre of the earth to infinity. In practice, however, the ownership right ends where other public rights restrict private ownership, e.g., international airspace or mining rights. The system adopts title registration and thus data on ownership and other rights can be trusted.

2.4.2 Status of 3D objects' recording

In 2007 the question, whether Austria needs a 3D cadastre or not, was raised (Navratil and Hackl, 2007). The paper discussed the principles of the Austrian cadastral system and shows that it is possible to register rights on parts of a parcel. A right of way, for example, can be restricted to a specific path. However, the spatial restriction can only be defined in 2D.

Several types of real 3D objects are registered in the Austrian cadastre: tunnels, condominiums, and traditional wine cellars. Tunnels are not shown on the cadastral maps but they can be registered as restrictions on the land register. The wine cellars are connected to a small building with the winepress and there a tunnel starts where the barrels are situated. The cadastral map shows the small building and a dashed boundary line where the tunnel starts. The actual geometry, the length, and the depth of the tunnel are unknown. The legal construction of condominium is quite elaborate. Figure 5 shows an example of the documentation. Each owner of an apartment is shared owner of the land (compare Fig. 4c: “Ingeborg” and “Heinz Ing.”) and has an exclusive use right of his apartment (specified in the purchase contract). The share is determined by the size of his apartment in relation to the total area of all apartments on the parcel. A document, the “Parifizierungsplan”, registered in the land registry, describes the geometry of the whole construction and shows all apartments and stipulates the utility value for each apartment (shown in Fig. 4b). The cadastral map, however, does show neither the apartment structure nor the spatial distribution of use rights. Since the “Parifizierungsplan” contains all building floors, it could be used as a starting point for a 3D representation of condominium. However, analysis of this matter is still ongoing.

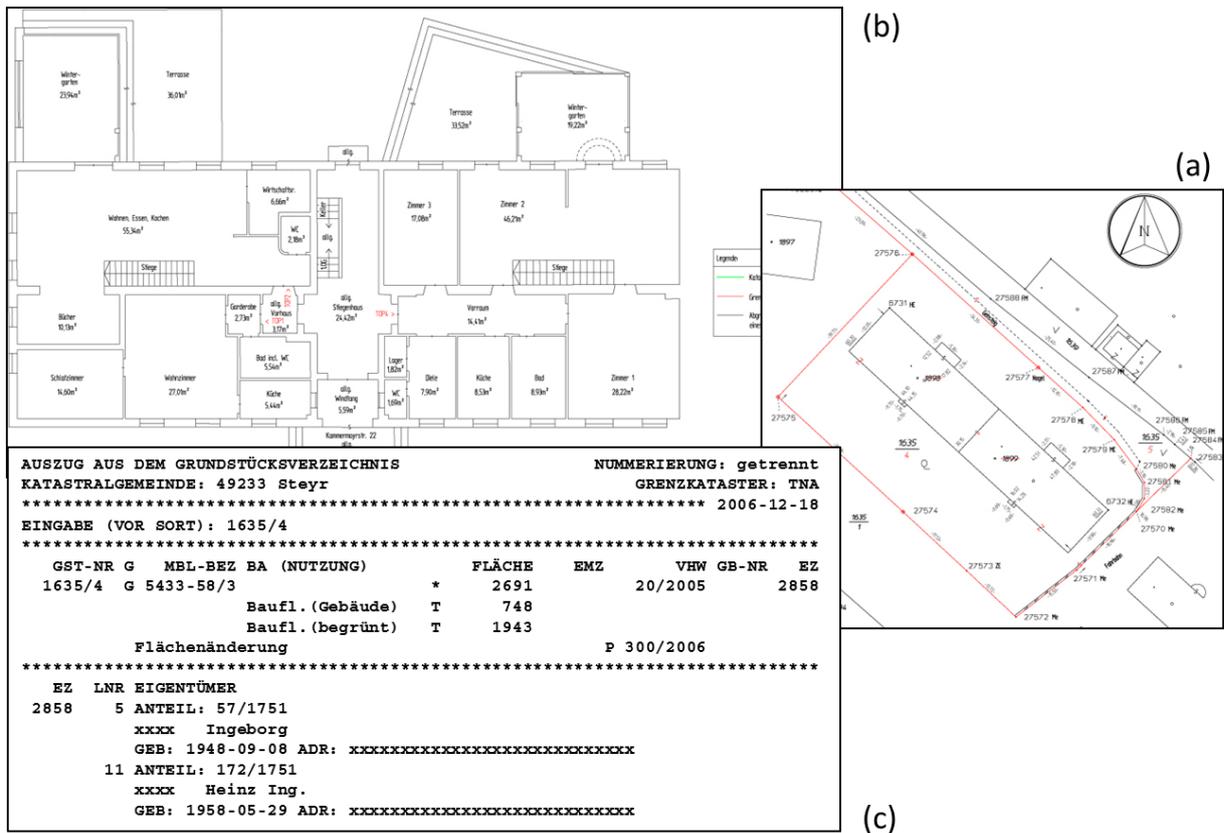


Figure 5: Representation of condominium in Austria (Source: Vermessungsbüro DI Mayrhofer)

2.4.3 Concluding remarks

The surveying authority in Austria, the Federal Office of Metrology and Surveying (BEV), is carefully observing the international trends. However, the current budget does not allow implementing multiple large projects simultaneously and the current digitizing process of the survey archive requires significant resources. Thus, Austria, although quite interested in the topic of 3D cadastres, will have to postpone implementation and restrict to research in the next years.

2.5 Bulgaria

2.5.1 Background information

In the second half of 20th century when Bulgaria was under the totalitarian regime the deed registration system was adopted in 1910 following Belgium model. The New Bulgarian civil law was built on the foundations laid by the Roman legal system, enshrined in the French Civil Code of 1804, the Italian Civil Code of 1865, but it has also borrowed from other countries' legal systems. The legal records were kept by central and local agencies. Cadastral mapping was only for mapping purposes primarily in the urban areas. In 1990 in Bulgaria private rights and liberalized land markets were restored by law. Nearly 90% of the territory of the country was restituted. The development of the digital cadastral system and property register in Bulgaria started in early 90s. The change was initiated with acceptance of the Law of ownership and use of land (Penev, 2016). Cadastre and property register act (CPRA) has been established in 2000

and it arranges new principles for the organization, funding, creation, administration and use of the cadastre and the property register. It is intended to serve as a basis for reform in the registration and transfer from personal to property registration. The Act provides for the introduction of information systems for land registers, which are designed to store, maintain and provide cadastral data and property rights. Nowadays in the capital Sofia and some more big cities in the country everything is in digital form and an analogue archive is carefully kept. However digitization and database creation in the smaller ones is still in process.

2.5.2 Status of 3D objects' recording

Currently only 20% of the country has efficiently working digital 2D Cadastral systems. Since the efforts are mainly focused to cover the complete country first with 2D digital cadastre, the third dimension is still considered as not of primary importance. However, in the urban environment, mainly in the capital Sofia, undoubtedly there are situations where 3D Cadastre is definitely needed. Most common examples in Bulgaria for situations wrongly registered in the 2D cadastre system are underpasses which are shopping areas. Another example is shown on Figure 6, where according to the cadastral law the bridges are not included in the cadastral map. Only the beginning and the end of such constructions on the ground should be included in the map. However on the figure in red are presented the parcels which are under the bridge. However, for their correct association of rights, restrictions and responsibilities the vertical extent of real property rights should be properly defined.

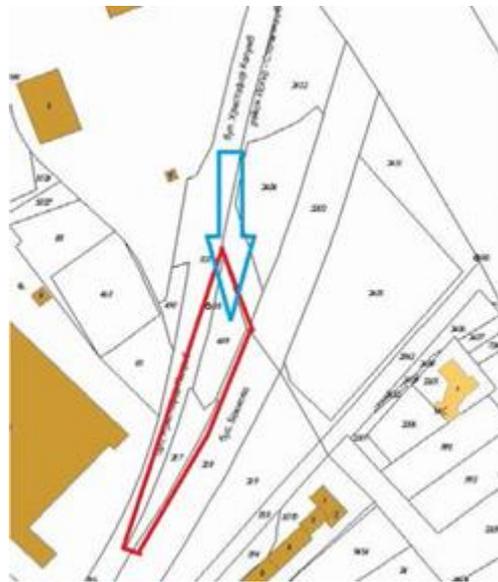


Figure 6: Digital cadastral extract in Bulgaria. (Source: GCCA)

There is no digital 3D registration of underground utilities in Bulgaria. From an institutional and organizational point of view Geodesy, Cartography and Cadastre Agency (GCCA) is an executive agency established in 2001 with main functions pursuant to the Cadastre and property register act. The Agency is a legal entity, having its seat in Sofia and operating through its 28 regional units – Geodesy, Cartography and Cadastre Offices (GCCO), located in the administrative centres of the regions. The cadastre is created, maintained and stored in 2D form by the GCCA and the property register is kept and stored by the Registry Agency. The new Bulgarian system remained deed registration system. The transfer of real rights takes place with

architectural plans and 3D models such as BIMs, which are daily accepted in Municipalities. However, in the current system they are considered as supplementary material or additional source of information due to the fact that in the law third dimension is not mentioned. However, with their help easily a hybrid version of a 3D Cadastre as defined by Stoter and Salzmann (2003) can be easily applied if allowed in the law.

2.6 Canada (Province of Quebec)

2.6.1 Background information

The province of Quebec (Qc) is one out of 10 provinces in Canada. Its population is about 8.2 million people for an area of 1.7 million of square km (making it the largest Canadian's province). Common law prevails everywhere in Canada, except in Quebec, where civil law predominates (Roman Law and Customs of Paris). A first Civil Code of Lower Canada has been adopted in 1866, then introducing legal provisions on land property, ownership, land right transfer, and land registration. A major revision resulted in 1994 (after a few decades of work) with the new Civil Code of Quebec (CCQ). The CCQ contains more than 3000 articles, with some of them referring to the concept of property of things and land (Book IV) and the publication (by registration) of rights (Book IX). For example, Book IV comprises rules about the kinds of property and its appropriation, the ownership, the modalities of ownership, the dismemberments of the right of ownership (i.e. easements), the restrictions on the free disposition of certain property, the patrimonies by appropriation, the administration of the property of others. Several laws are supporting the application of the CCQ, like the Act respecting Land Survey, the Cadastre Act, the Act respecting Land Use Planning and Development, the Territorial Division Act, the Act respecting Registry Offices, and the Act to promote the Reform of the Cadastre in Quebec, since they all refer to some aspects of land property management.

The Quebec Land Registry System is not a Torrens system, where each title is guaranteed by the State. Instead, the security of land title depends upon a Deeds Registration System, that indexes and archives legal documents related to rights in land. To constitute the legal title of property of one owner to a piece of land, "a chain of titles" from the original grant of the land by the State to the current individual owner need to be established. Land registry offices were established in Quebec in 1840. It consisted at that time of a mere Index of names, in which legal documents were files according to the name of the contracting parties, without a direct connexion to a specific piece of land. That structure was not fully effective to secure land rights. To resolve the problem, a cadastre was legally created in 1860: since then, all legal documents can be filed according to each land lot number, and registered in a land book. For more than a century, the cadastral map became gradually obsolete because of a weak update procedure: new parcels were not systematically represented graphically and identified with an individual lot number. In 1994, in accordance with the Civil code of Québec, an important cadastral reform was launched, aiming at renewing all cadastral plans and producing one accurate, digital, online, and up-to-date cadastre and registration system.

The official authority responsible to manage the land registration system is the Ministry of Energy and Natural Resources (MERN). Composed either by the land book and the cadastral map, the land registry is accessible online[1] where all cadastral plans, land books and legal

documents are available, and updated each day. In 2017, more than 4.0 million of private land parcels were recorded in the renewed Quebec cadastral system (3.48 million of land parcel and 549 000 of vertical lot). This one can also be defined as multi-purpose, because it is also used as the basis for fiscal and land use regulations purposes, such as those proposed by local municipalities. Cadastral data also assist in the establishment of land administrative boundaries (as territorial subdivision). Otherwise, it is mainly used by notaries, lawyers and land-surveyors.

2.6.2 Status of 3D objects’ recording

In CCQ’s sections 2972.1 and 2972.2, two mechanisms for registering property rights can be identified. The first one, namely the Land Registry System, corresponds to land books and cadastral plans used to record and publish property information related to land parcels, condominium apartments (vertical cadastre), or any immovable objects located in a 3D space that the owner wants to register. The cadastral map contains the official legal unit number (i.e. lot number), its relative position, dimensions, and area. Easements are not represented on the cadastral map. If a vertical cadastral representation is necessary to identify the co-ownership of condominium apartments, then a specific protocol (technical specifications) to spatially represent these objects is compulsory. It consists of producing supplementary plans (*plan complémentaire-PC* in French) for which subdivision plans and vertical profiles of each distinct lot (whether they are common or individual properties), and showing 3D characteristics (altitude, height and volume information). Figures 8 and 9 show an excerpt of the cadastral map and its corresponding PC plan (Pouliot et al., 2011). The declaration of co-ownership signed by the owners’ corporation of the condominium units will then refer to those PC-plans.

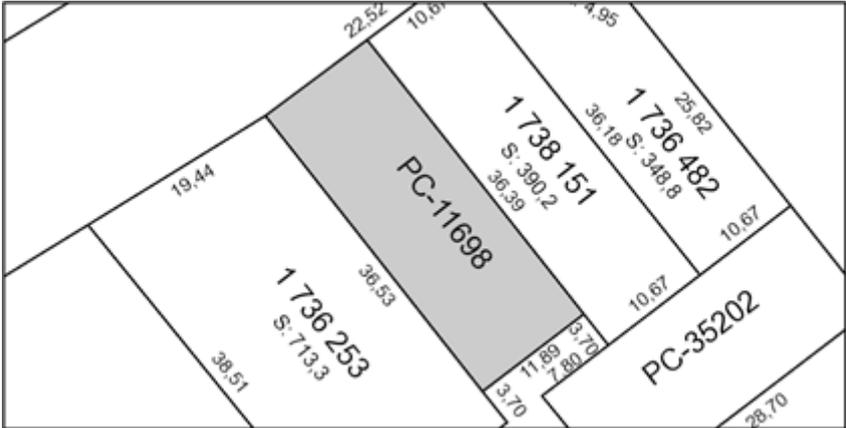


Figure 8: Cadastral plan of overlapping properties marked as PC-11698

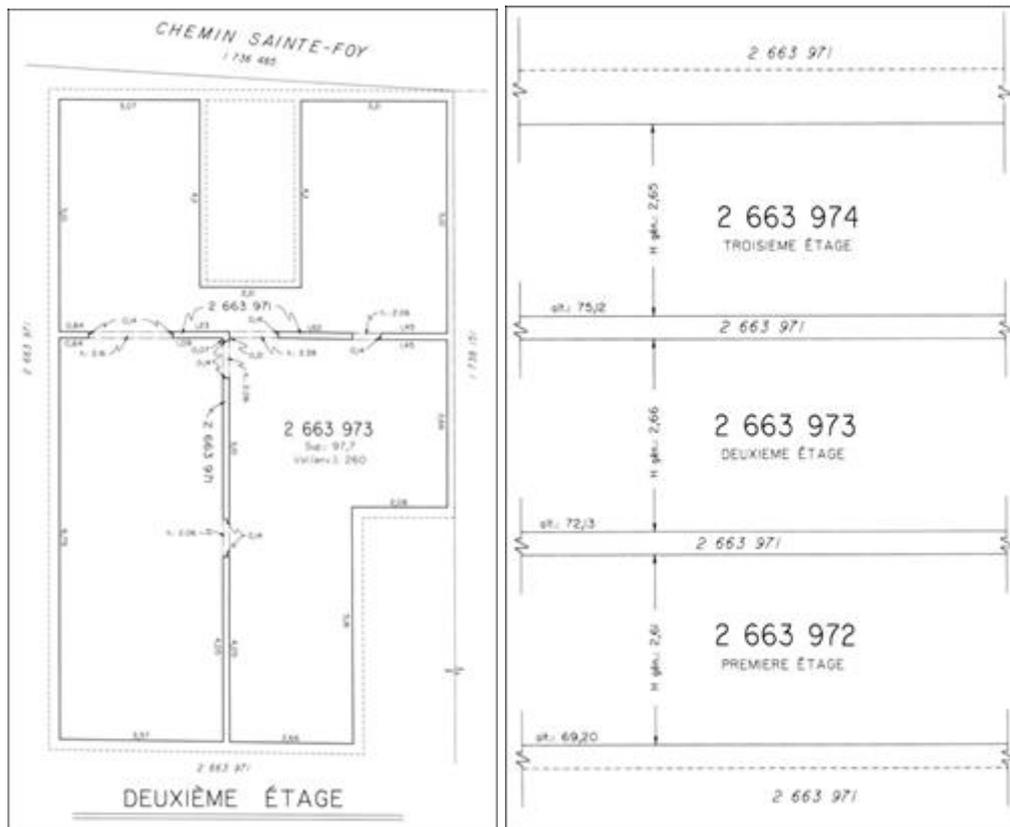


Figure 9: Supplementary plan of PC-11698. (Left: subdivision plan of the second floor. Right: Vertical profile)

The second mechanism refers to property objects that are not distinctly matriculated, like state resources and private utilities networks. This registration system is based on land files that are kept under an ordered number (and not the lot number) and is commonly called FITNO (*Fiches Immobilières Tenues sous un Numéro d'Ordre*). FITNO system proposes two registers as the register of real rights of the State resources and the register of public service networks and immovable objects located in a non-cadastral surveyed territory. These registers maintain a list of real estate transactions (e.g. deed, easement, sale) associated to the legal objects, the name of the holder, the name of regional administration and an ordered number to record the file. In most case, FITNO registration system does not propose spatial representation equivalent to a cadastral plan (Pouliot et al., 2015); there is no mandatory link between FITNO registers and cadastre register.

2.6.3 Legal definition of 3D objects

The Quebec legislation does not refer specifically to the concept of 3D objects. Nevertheless, 3D objects exist and their registration is done through the process previously explained (cadastre system or FITNO). The CCQ is referring to land property object, but no indication is provided about the third dimension. CCQ's section 3026 identifies relative position, the length of boundaries and the unit area. Boundaries are mapped using X and Y coordinates, but these ones have no legal significance. Beyond legal and descriptive information as name or title, only measurements as length, perimeter and volume have official geometric meaning. PC plans also supply altitude-Z, height and volume of buildings or infrastructures. Consequently, 3D objects can be identified and located according to PC plan documentation. That 3D information is

available for cadastral object registration, not for FITNO object registration (except when engineering plans are available, but this is still rare).

2.6.4 Types of rights that can be registered in 3D

The Quebec Land Registry System offers:

- Horizontal ownership (this right is 2D)
- Vertical ownership (mainly co-ownership)
- Easement
- Right of long lease
- Right of superficies
- Mining right

2.6.5 Concluding remarks

Co-ownership was introduced in 1969 in the Civil Code as a new modality of land property tenure. Since that moment, it was possible to identify on supplementary cadastral plans overlapping properties with 3D characteristics. Then, Quebec cadastral system honestly manages 3D situation when overlapping properties exist with 2D map and vertical profiles available on PC plans. Unless a need might be identified, Quebec authority is not currently exploring the introduction of full volumetric representations for cadastral data.

Pouliot et al. (2011; 2015) and Pouliot and Girard (2016) investigated the possibility of having volumetric representation for condominium units, and the requirement of having normalised spatial representation for the registration of underground networks or FITNO registers. They highlighted some weaknesses of the current Quebec cadastral system as the challenges for understanding the spatial arrangements of cadastral units when many PC plans are existing, the loosely coupling of PC plans with the cadastral database, not having spatial representation for FITNO registration, not able to know which land parcels is crossing underground network and thus no link with the cadastral system, no guideline for the description of the network (neither semantic or geometric) and the complexity for finding a specific underground network in the current registration system. For instance, Pouliot and Girard (2016) support the mandatory registration and mapping of underground utility networks; accessible by all concerned (the owners, the public administration, the land lawyer, the notary, the land surveyor, etc.). New federal Canadian legislation (BILL S-229, an Act enacting the Underground Infrastructure Safety Enhancement) is under preparation which may be foreseen as a step in this direction, although yet it is devoted to safety enhancements and not necessarily the protection of ownership rights. Besides, MERN is questioning the migration of FITNO records to cadastral unit registration and the value of mapping easements on the cadastre plans.

2.7 China

2.7.1 Background information

China is located on a vast territory of 9.6 million square kilometers. In general, mountain, plateau, and hill occupy almost 69% of Chinese land while and flat land is only 31%. Rural land is 94.7% with its population 53.4% (CBS 2012). The rest is urban land. Although the rural land covers the greatest land percentage, the percentage of arable land is merely 10.4% which is 1.432 billion Mu. The relation between land and people is controversial. On the one hand, people need arable land to supply food. However, the protection of arable land is not sufficient

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Dimitrios Kitsakis, Jesper Paasch, Jenny Paulsson, Gerhard Navratil, Nikola Vučić, Marcin Karabin, Mohamed El-Mekawy, Mila Koeva, Karel Janečka, Diego Erba, Ramiro Alberdi, Mohsen Kalantari, Zhixuan Yang, Jacynthe Pouliot, Francis Roy, Monica Montero, Adrian Alvarado, Sudarshan Karki

as the quick change of landscape due to urbanization leads to encroachment of farmland as well as farmland's misuse. Land boundaries, as well as land registration, are not updated with the quick change of land rights. Meanwhile, the urban land exemplifies diverse use types comparing to rural land. The typical characteristic is high density and mixed land use, which requires updated land registration system as well as accurate property rights for high-rise development.

There has been a trend of cadastre unification regarding the urban and rural cadastral systems, particularly regarding the emphasis of rural cadastral registration promoted by Opinions on the Registration and Verification of Rural Collective Land (2011). The emerging trend also can be observed in the process of legislation in the regard of housing and land registration. For example, the registration acts, Housing Registration Act (2008) and Land Registration Act (2008), have gradually merged to Real estate registration regulation (2015), which confirms the trend of integration of spatial dimension of housing and the land parcel in the cadastral system. Meanwhile, urban cadastre improves in the tandem of high-rise development, which is incredibly promoted by the Property Law (2007), particularly in the regard of independent registration of 3D parcel.

Current research in 3D cadastre in China involves 3D cadastre modelling and data processing, spatial data model and modelling method, topology building algorithm, the design of the 3D cadastral system and its local application such as in Shanghai, Shenzhen, and Xiamen. Conducted research projected the technological development of 3D Cadastre in China and the practical need of 3D cadastre in local practice.

However, research also reflected that it is difficult for 3D cadastre model to apply in China due to several reasons. Firstly, complex land use types, as well as mixture of rural land and urban land problems, as it is hard to establish unified 3D cadastre information system for the whole country. Secondly, undergoing 3D cadastre implementation is in urban China, such as pilot projects in Shenzhen, Wuhan, and Shanghai. The demand for high-quality cadastre information for property registration and transaction has been on the agenda since high-rise real property boom in cities. But barriers regarding the implementation of 3D cadastre exist mainly due to the uneven land administration structure. The two issues mentioned above increase the difficulties regarding the unified cadastre system as well as the improvement of 3D cadastre in China.

2.7.2 Status of 3D objects' recording

Recent progress towards 3D cadastre development in practice is especially prominent in several cities in China. Shenzhen Planning and Land Development Research Centre led a research project on "key technology and normative research of land space and use right management." The research centre designed a unified model of two/three-dimensional map management, verified the necessary and sufficient conditions for the automatic construction of three-dimensional topological relations, and proposed a search algorithm for 3D topological relations. The problem realizes the dynamic maintenance of three-dimensional topological relations. By solving the technical problem, the project designed the three-dimensional property body coding scheme and the three-dimensional property right certificate scheme, and formulated the "three-dimensional property body surveying and mapping specifications".

The research and demonstration of 3D cadastre have been up to a certain level. Guo et al. (2013) proposed the 3D representation of property by establishing the sheer land volume and building model inside, applied to a case of underground parking space of Nanshan district in Shenzhen.

In 2011, Shenzhen auctioned a piece of underground land for parking cars. The surface land is planned as urban green for public use, while another two-storey underground parking space covering 16,000 m² is designed. The land department listed underground land for auction using the 3D representation model. Meanwhile, the model was recorded and archived as a 3D digital version for underground land administration (Guo, et al. 2013).

Furthermore, Ji (2007) designed 3D cadastral objects registration model (3DCORM) in ArcScene by using cases of Songbai high-rise building and Lujiang underground car park in Xiamen (Ji 2007). Liao (2014) proposed two 3D cadastre models that are closed spatial land parcel and open spatial land parcel and emphasized the importance of 3D land planning and approval process for the implementation of 3D cadastre in Shanghai (Liao 2014).

2.7.3 Legal definition of 3D objects

Cadastre referred to the state for a certain purpose, record of land ownership, boundary, quantity, quality and use of the core situation of the registration book. It has been through a long process regarding the cognition of cadastre in 2D. Even in recent publications, scholars recognized cadastre as a record of land ownership, boundary, quality, quantity and use of the core situation of 2D registration document (Genshen Su, 2011).

The concept of 2D data cadastre was given in Cadastral Investigation Procedure. “Cadastre refers to the record of land ownership, location, quantity, quality, value, use and other essential conditions of the registry book and data”. The cadastre has been recognized as 2D for a long time. The most substantial progress regarding legislation of 3D land and property rights is the issue of the Property Law in 2007.

The Property Law (2007) confirms the dual land ownership regarding the State and Collective (Article 47, Article 48). It also mentions the real property registration authority as well as the register as the key legal-proof document for land and property rights (Article 16). Importantly, the Property Law for the first time establishes the legal status of superficies and easements (Article 156), which contributes to the development of potential 3D cadastre and land registry. At the same time, the Property Law defines the property rights on buildings involving differentiated ownership that includes exclusive right referring to the private apartment, common rights referring to common property and common management right relating to membership and voting right (Article 70-83). The article demarcates the differentiated properties in 3D. Particularly, it subdivides the common property from the exclusive property, which founds the basis of 3D cadastre in building level (figure 10). Besides, the article 136 allows the independent registration of 3D parcel concerning the right to use land for constructions. And the article 138 specifies that in a contract concerning the right to use land for construction, the content should include the detailed demarcation of the space.

Since the registration authority separated to land and housing due to individual executive land administration and housing management, land registration and housing registration disaggregated each other and operated independently. The historical separation resulted in cadastre referring to land parcel and boundary for land administration. The information sharing and communication between land and housing authorities will facilitate housing registration regarding housing rights registration. The absence of 3D cadastre reflected administrative segregation in a sense. With the high-rise development in urban China, the protection of private property raised the demand on 3D land and property rights registration. Under such background, the definition of the spatial registration object was officially defined by the definition of real property unit in Real Property Registration Operational Specification (2016). Real property

registration should be registered as a basic unit of real property. Real property units are spaces where the ownership boundary is closed and has an independent use value. The space for independent use should be sufficient for the proper use and can be utilized independently (figure 11).

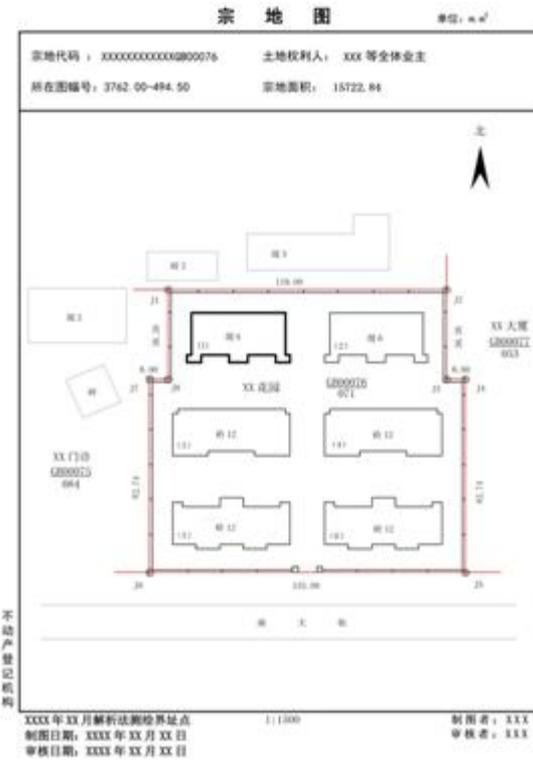


Figure 10: Land and building integration in 3D cadastre (Source: Real property rights survey technical program, 2015)

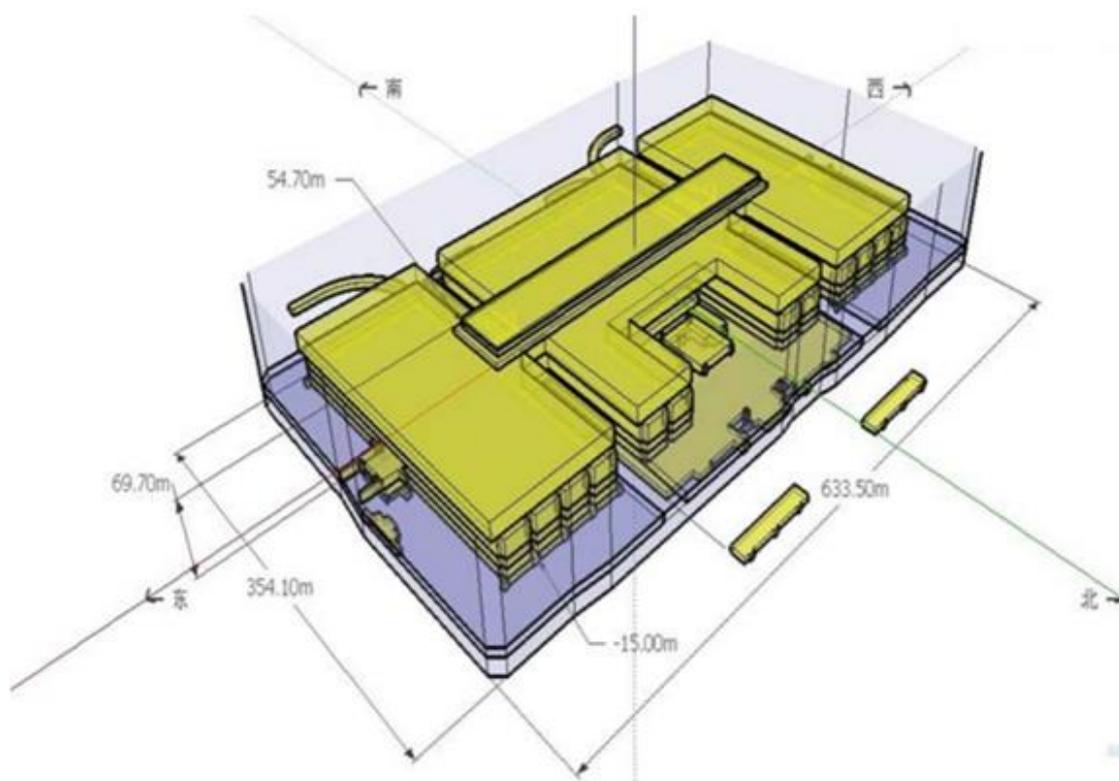


Figure 11: 3D representation in the registration file (Source: Guo et al. 2012)

2.7.4 Types of rights that can be registered in 3D

Provisional Regulations on Real Property Registration (2015) provide that the following real property rights should be registered. (1) Ownership of collective land; (2) ownership of buildings and structures, such as houses; (3) forest ownership; (4) cultivated land, woodland, grassland (5) use rights of construction land; (6) use rights of homestead land (8) easements; (9) mortgage rights and etc (Article 5). And the electronic medium is regarded as the real property register medium (Article 9). The register of real estate shall be kept by the real estate registration institution permanently (Article 13). The competent department of land and resources under the State Council shall in conjunction with the relevant departments establish a unified platform for the registration of information on real estate registration (Article 23).

Furthermore, Real Property Registration Operational Specification (2016) clarifies the record type and method, including registration of collective land ownership, state-owned construction land use right and housing ownership registration, homestead land use rights and housing ownership registration, and collective construction land use rights and buildings, structures ownership registration.

It also defines the registration unit regarding real property registration (Article 1.3.1). The real property should be registered as a basic unit in the registration. Real property units are spaces where the ownership boundary is closed and has an independent use value. The space for independent use should be sufficient for the proper use and can be employed independently.

2.7.5 Concluding remarks

The development of 3D cadastre is a long process in China, which requires addressing two main difficulties. One is the unified land registration system regarding rural and urban land

administration. The second one is the inclusive and clarified land administration structure from the central government to local authority regarding vertical organizations as well as horizontal collaborations. However, precise definition of the 3D object is legitimized by regulations in China, which is referred to 3D real property unit. The real property unit is legally bonded by Property Law, which confirms that land right is a bunch of spatial rights, including underground, ground and above ground land use rights, and the land and property conveyance should be bonded as a 3D object in any circumstances. There are also practices of 3D cadastre visualization and monitoring administration in Shenzhen, Wuhan, and Shanghai. Technical progress is leading the way of 3D Cadastre implementation. However, there are still technical difficulties which need to be resolved. Firstly, insufficient land information, particularly the missing underground information leads to difficulties to collect detailed information for 3D modelling. Secondly, the vertical information of land title regarding elevation, height, and depth is incomplete. Thirdly, cadastral measurements' content and requirements are required to be expanded in 3D.

In the long run, the 3D cadastre implementation needs further input of technical solutions for data acquisition and modelling process. Moreover, further-advanced legalization of 3D cadastre and social integration are also crucial for the widespread use of 3D cadastre.

2.8 Costa Rica

2.8.1 Background information

In Costa Rica, the right to property is a fundamental right protected at the Constitutional level. Its legal structure is delimited by the Civil Code of 1886, the Laws of Urban Planning, Real Property Tax, National Cadastre and additional special regulations. The Civil Code (CC) refers to the concept of property saying: "The property right is not limited to the surface of the earth, but extends by accession to what is on the surface and to what is below. Subject to the exceptions established by law or convention, the owner can make all the constructions or plantations that fit him above, and make underneath all the constructions he deems fit and remove from the excavations all the products that may be given him." (Art. 505)

In this context, there are two essential points related to 3D property, since the Art. 505 explicitly defines that property is not limited to the surface, but extends vertically.

CC recognizes that ownership is not an absolute right, establishing the possibility to constitute limitations and restrictions to the property. In this sense, Art. 292 of the CC states that it is permissible to establish limitations on the property, but they will not be valid for more than ten years, except in the case of beneficiaries under age, in which this term can be extended until the beneficiary turns twenty-five years of age.

This power to limit or restrict the right to property is ratified in art. 383 of the CC, according to which: "Private property on real estate is subject to certain charges or obligations imposed by law in favour of neighbouring properties, or for reasons of public utility." Despite the development of vertical growth, the volumetric definition of property in the Cadastre Law is not evident, still being represented in 2D cadastral maps.

2.8.2 Status of 3D objects' recording

The development of real estate law in Costa Rica happened through different stages, but the main task has been to have a title that reflects the reality in an adequate way. There is a complexity associated with the different types of property developed in the Costa Rican legal

system, and in front of this complexity, the 3D property identification system could make a difference.

The ownership in condominium, co-ownership, variants of these or other types of rights, as well as the various limitations or possibilities established in the Costa Rican Civil Code, make limited the current description of the property in Costa Rica. It generated several conflicts at the registry level because there are differences between the reality and the literal description of the property in the title. In this context, 3D identification system of properties could help, however, even when a 3D identification system already exists in some digital cadastres along the country, it is only as an experimental project.

2.8.3 Legal definition of 3D objects

In Costa Rica, there is no legal concept of 3D property. All parcels are defined in 2D in accordance with National Cadastre Law No. 6545, which states: "property is the portion of land registered as a legal unit in the Public Registry or susceptible of being registered, by a number that individualizes it" (Art. 8). Cadastre is defined as: "the representation and graphic and numerical, literal and statistical description of all lands included in the national territory ... (Art. 2)."

The Civil Code establishes the extension of the property right, stating: "it is not limited to the surface of the earth, but extends through the surface and below. With exceptions established by law or convention, the owner can make all the constructions or plantations that consider convenient, and build underground all the necessary constructions... "In cases of condominium ownership, the above shall only apply with the limitations established in the specific law (Art. 505)."

Costa Rican legislation stipulates that the execution and maintenance of the Cadastre is a function of the State and its realization is the exclusive power of the National Cadastre (Art. 2 Law No. 6545).

2.8.4 Types of rights that can be registered in 3D

Horizontal Property: Defined at the Art. 265 of the Civil Code and regulated in the Property Regulatory Law No. 7933/1999. According to this law framework, each owner shall be the exclusive owner of his or her house, apartment, office, parking lot among others. There are parts that will be considered in co-ownership, parts assigned as common use which belong to all individual owners. Both different figures can be combined.

The operations of buildings or departments subject to the horizontal property regime, are registered in a special section of cadastre, it is a double registration between the mother parcel and the horizontal property parcels, properly related.

The registration of rights in the volume of a building is perfectly possible and clear in the cadastral map of the horizontal properties. The spatial representation of the extension of rights above the roof and below the lower garage does not exist.

Protected Areas: These are the environmental restrictions on private property established in Art. 33 of Forestry Law No. 7174. They are defined as: a) a radius of 100 meters measured horizontally, in the areas bordering permanent springs, b) a strip of 15 meters in a rural area and 10 meters in an urban area, measured horizontally on both sides, on the banks of rivers, streams or streams, if the ground is flat, and 50 meters horizontal if the terrain is broken, and c) an area of 50 meters measured horizontally on the banks of lakes and natural reservoirs and in

lakes or artificial reservoirs built by the State and its institutions (except for private artificial lakes and reservoirs). These protected areas prohibit the cutting or removal of trees in the protected areas described, except for declared projects of national convenience (Article 34).

Reservation of public domain in favour of the Nation: Regulated in Art. 31 of Law No. 276 of Water, it comprises the lands that surround the sites of abstraction or outlets of drinking water, in a perimeter of not less than 200 meters' radius and forest areas that protect or must protect the set of lands in which the infiltration of drinking water occurs, as well as those that give rise to watersheds and reservoir margins, springs or permanent course of the same waters. In these areas, the legal regime of public and unavailable goods by the subjects of private law applies.

Easements: Regulated to the Construction Law defines "the restriction of the domain of a property which is established for public benefit or another property" (Art. 1.3). Easements cannot be imposed on or in the name of a person, but only in favour of a fund (Art. 370 Civil Code), it is characterized by being inseparable from the fund to which they actively or passively belong (Art. 372 CC) and its indivisibility (Art. 373 CC). The types, lengths and special characteristics are regulated in the Regulation for the National Control of Splits and Urbanizations, No. 3391.

Easements for the use of public waters: Stipulated at Art. 99 et seq. of Water Law No. 276 for the construction of works of public interest in private property.

Easements of high voltage airlines: Costa Rican Institute of Electricity has the power to expropriate and impose forced easement on private property, for reasons of public utility (Art. 2).

Aeronautical Easement Zones: The General Law of Civil Aviation No. 5150 defines the requirements and procedures for conducting aeronautical studies of height restrictions, applicable to the construction and installation of telecommunications infrastructure to be located in the area of influence of an aerodrome, which is defined as the area of land or water (including all buildings, installations and equipment) to be used for for the arrival, departure and surface movement of civil aircrafts.

2.8.5 Concluding remarks

The Cadastre and the Property Registry are under the same institution (National Registry) that simplifies the connection of the legal and physical data.

The Civil Code (CC) refers to the concept of property saying: "The property right is not limited to the surface of the earth, but extends by accession to what is on the surface and to what is below. Subject to the exceptions established by law or convention, the owner can make all the constructions or plantations that fit him above, and make underneath all the constructions he deems fit and remove from the excavations all the products that may be given him." (Art. 505). In this context, there is an essential point related to 3D property: the property is not limited to the surface, but extends vertically.

The CC recognizes that ownership is not an absolute right, establishing the possibility to constitute limitations and restrictions to the property. In this sense, Art. 292 states that it is

permissible to establish limitations on the property, but they will not be valid for more than ten years, except in the case of beneficiaries under age, in which this term can be extended until the beneficiary turns twenty-five years of age.

At the level of the cadastral maps, as documents that graphically identify the property in Costa Rica, there is no description of 3D elements. The map registered as a graphic element of the property description contains elements that identify the parcel only at 2D level, however the 3D boundaries in apartments are the structure elements, the exterior walls are common property, and the boundary is the inside of the wall and ceiling (Figure 12).

The development of projects oriented to 3D implementation is moving forward and probably they will be effective soon. Figure 13 shows an example, developed in Escazu city.

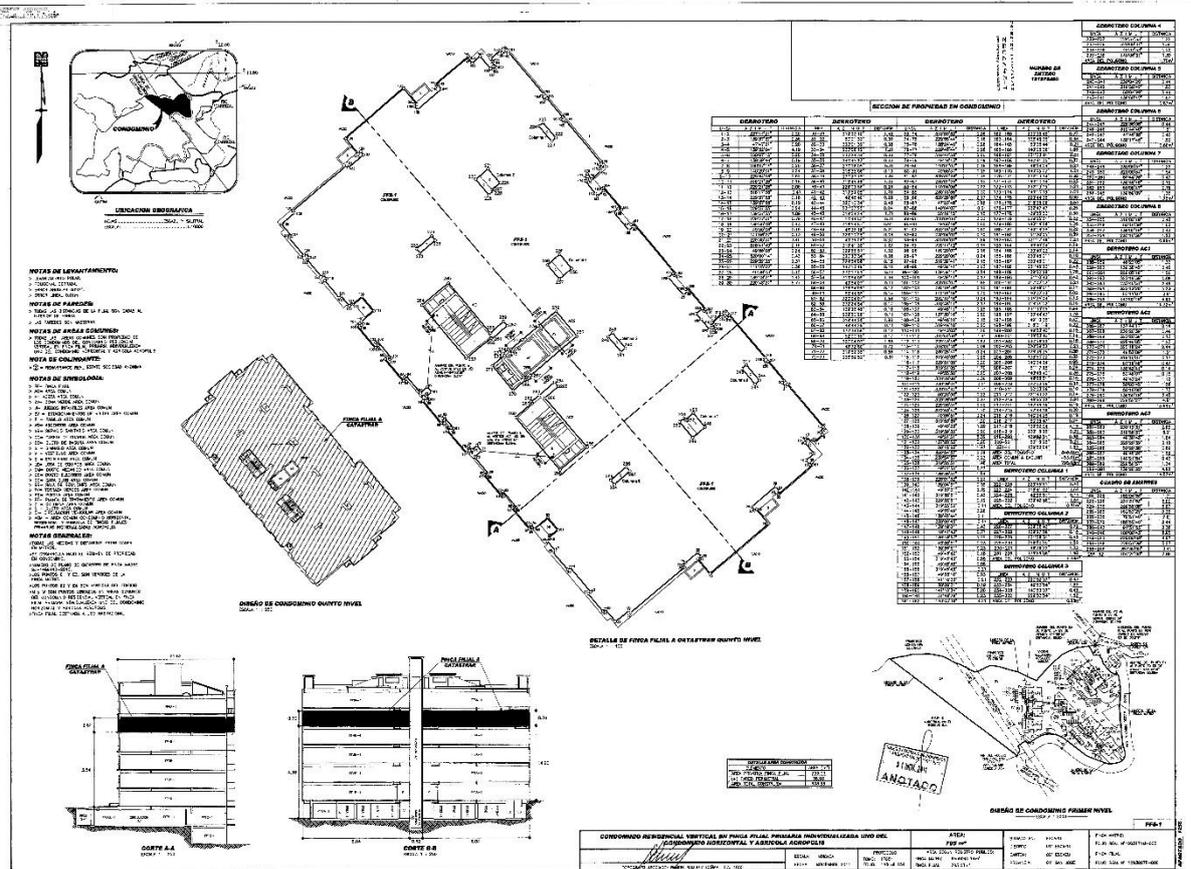


Figure 12: Survey blueprints of horizontal property A



Figure 13: 3D perspective of Escazu - Costa Rica.

2.9 Croatia

2.9.1 Background information

Real property in Croatian real property law is, according to the “superficies solo cedit” principle, a land surface parcel to include everything permanently associated with this parcel on or below the land surface (primarily buildings, houses, etc). A real property, in legal terms, may consist of more land parcels registered in the land book in the same property sheet, as they are hence legally combined in a single body (registered land unit). Grass, trees, fruits and all valuable commodities the land provides on the surface are parts of this real property until this land is divided. What is on the Earth’s surface, built on or below the ground with intention to remain there permanently or is built in, added to or on top of the real property, or associated permanently in any other way, is a part of this real property until partitioned. However, parts of the land of a building and other land associated features with a temporary purpose are not.

2.9.2 Status of 3D objects’ recording

Buildings are registered in the cadastre at obligatory request of a party. A geodetic report prepared by the authorized survey company must be supplied with this request. Responsible cadastral office must prior review and certify the report. Buildings are registered in the cadastre with the following attributes: area, intended building use, building name, and house number. On the cadastral map building are shown in planar view. Condition of registration in the cadastre is currently reduced to 2D entry per floor, so it is technically possible to register in cadastre all owners of each part of the building, but only in the alphanumeric part of cadastral record. Currently cadastre is able to accept analogue and digital graphical data about every floor, but it is not an obligation by law. Only the land book has an obligation to accept elaborate on partition of real property. The cadastre has systematic data entry while in the land register entries are in free field form so the apartments and office spaces can be described in more detail (number of rooms and size of the apartment or office space in square meters). Registration of apartments and office spaces in Croatia has been separately operated since 1958. Registration of apartments and office spaces in Croatia has been continuously operated since 1991. It is a

kind of 3D registration. Cadastral offices also archived construction documents as a part of geodetic reports.

2.9.3 Legal definition of 3D objects

Rights referring to the use of a limited space will be registered as 2D parcel registered in the cadastre. However, the right registered might refer to a construction or space on several 2D parcels. Basic spatial unit of the real property cadastre is a cadastral parcel. One cadastral parcel is a unit of a cadastral municipality or cadastral region at sea determined by a parcel number and its boundaries. Unique identifier of the cadastral parcel consists of an identification number of the cadastral municipality or cadastral region at sea and the parcel number. Boundaries of the cadastral parcel may be borders or other boundaries defined by legal relations on the land surface.

2.9.4 Types of rights that can be registered in 3D

Types of rights that can be registered in 3D are any type of rights, which can be registered in 2D. According to the Ordinance on Surveying Design (Official Gazette 2014) the integral part of surveying design is a document called Geodetic Situational Draft. A situational draft is made to display position and elevation data on all visible natural and built features of the land surface in the construction area (e.g. buildings and other structures, utility lines with associated facilities, traffic infrastructure, vegetation, water and related objects, relief etc.). Croatian Land Administration System also registering 3D cadastral objects related to constructions (buildings, pipelines, tunnels). Infrastructure objects also registering in 3D (public utility infrastructure). Right of construction in legal terms is equal to the definition of real property.

2.9.5 Concluding remarks

3D descriptions of land features currently are poor in Croatia. Particular parts of real property are registered in 2D plans (Figure. 14) with indication of the floor where they are located. One could consider this as a 2.5D approach. This approach temporarily enables registration of rights in strata, but it does not support changes. Hence, it is necessary to develop the spatial representation component in registration of 3D objects of law. The best solution would be to add 3D data in cadastral plans (Vučić et al., 2011). This would facilitate registration and better description of particular structures such as bridges, tunnels, viaducts, overpasses, underpasses, underground structures, etc.

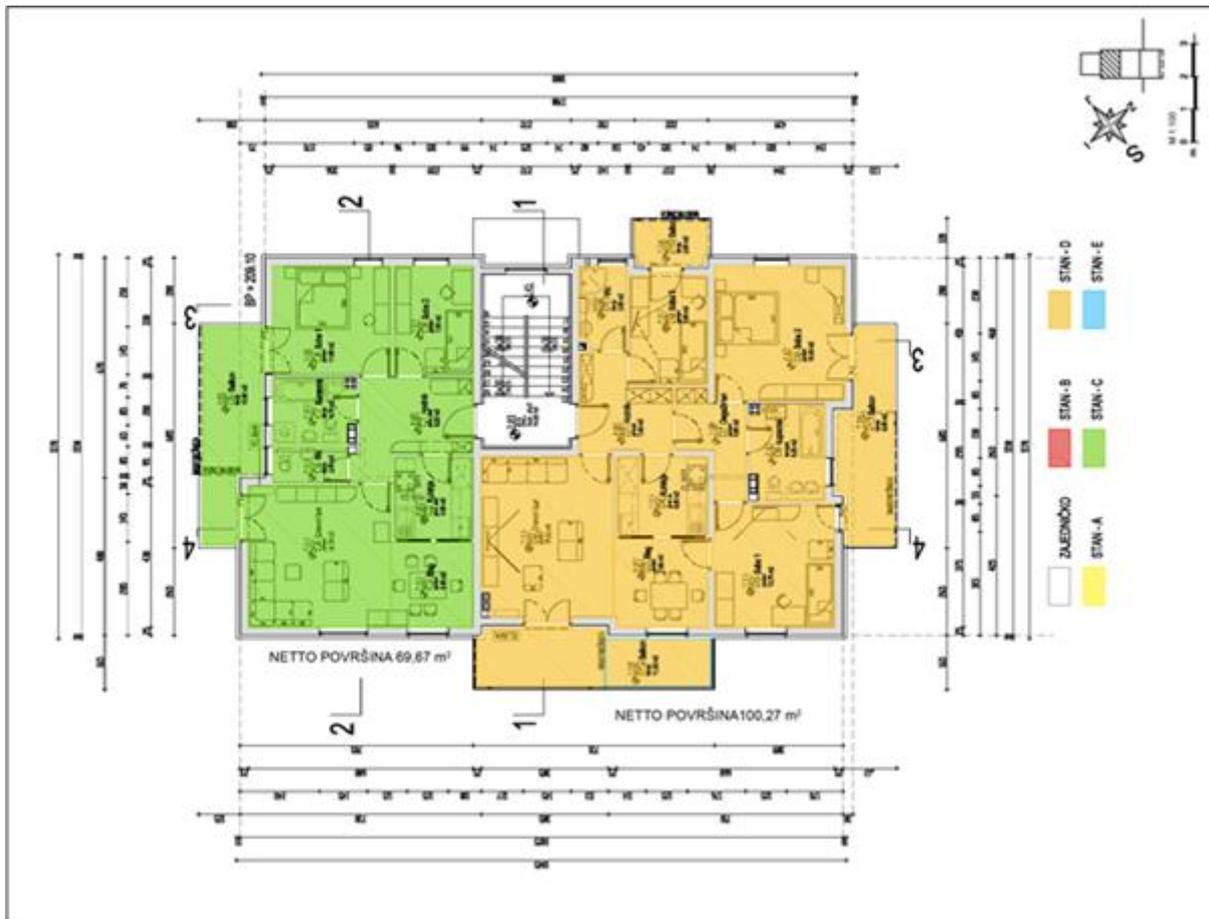


Figure 14: Report on Partition of Real Property (source: URL 1)

In Croatia at this moment there are no official records that can provide complete information about all buildings as spatial objects. Cadastre and Land Book are the only official and systematically maintained registers which contain data on real property, which also includes buildings. Condition, integrity and structure of data collected on buildings and maintained in these registers does not allow insight into the state and basic characteristics of certain buildings and overall condition of buildings in the entire country. Therefore, one of the strategic objectives of the State Geodetic Administration is establishment of multipurpose cadastre of buildings to provide such data and information. Implementation study of the cadastre of buildings should answer how to establish institutional, legislative and financial framework and propose the structure of the data model and technical standard for the information system of such cadastre. Also, this study should provide short-term and long-term strategic guidelines regarding system architecture, data model, specific needs of stakeholders, required legislation, the benefits delivered by such system and financial resources needed for its establishment and maintenance. The study should define implementation phases of the cadastre of buildings based on experiences from EU countries which have already introduced similar systems into daily operations. The study so far, among other activities, questioned the needs of the following future key users: Ministry of Construction and Physical Planning, Tax Administration, Ministry of Justice. It is also in progress questioning the needs these key users: Ministry of the Interior, Croatian Chamber of Economy, National Protection and Rescue Directorate, Croatian Bureau

of Statistics, Croatian Office for the State Property Management, and the representative sample of Croatian cities and municipalities. All of this is conducted to involve public into project and consider the needs of users which will be, after the establishment of the unified multi-purpose register of buildings, an added value to more regular spatial planning, property tax collection, overall development of cities and municipalities, and the overall benefit of the state institutions and society (URL 2).

The plan of the Croatian Government is to create a modern building cadastre that will suit the needs of society and the community.

2.10 Czech Republic

2.10.1 Background information

The Czech cadastral system is based on the compulsory title registration. The cadastre of real estate is the set of data about real estates in the Czech Republic, including their inventory and description and their geometric specification and position. Parts of it are records of property and other material rights and other legally stipulated rights on these real estates. Cadastre of real estate contains many important data about parcels and selected buildings and their owners and is administered as the information system about the territory of the Czech Republic mainly by the computer means, where cadastral unit is the basic territorial unit. Cadastral documentation comprises mainly from the file of geodetic information encompassing the 2D cadastral map (including its digital representation in given cadastral units) and the file of descriptive information including the data about cadastral units, parcels, buildings, flats and non-residential premises, about owners and other justified persons, about legal relations and rights and other facts given by the law. Civil Code defines a real property to be extending to the space above and below the surface parcel, comprising all buildings and constructions permanently attached to it. The real property extent is delimited to the extent that the owner has no reasonable cause in opposing against it or it is subject to laws. The new Civil Code explicitly considers the 3D space above and below the land as a part of the land without any limitation on the maximal height or depth above/below the land. In practise, this can cause a trouble. For example, during the construction of tunnels as such constructions affect the space below the land (and this space is a part of the land to “unlimited” depth). Another paragraph of the Civil Code provides that the owner cannot object to activities performed by a third party at a height or depth without justification for preventing such use.

2.10.2 Status of 3D objects’ recording

The following types of 3D objects are registered in the Czech cadastre: buildings, residential and non-residential units. The digital cadastral map contains only 2D outlines of buildings and there is no graphical information about the flats in the map. Furthermore, there are 3D objects not registered in the cadastre but schematically displayed on the 2D cadastral map like selected hydraulic structures (dams, weirs and hydroelectric power station) and culverts and bridges. It is possible to register rights on a part of parcel. However, the spatial restriction can only be defined and displayed in 2D.

The underground constructions are not registered in the Czech cadastre and therefore are not displayed in any form on cadastral map. In case that the underground construction is a building with assigned building number, then such underground building can be registered in the Basic

Register of Territorial Identification, Addresses and Real Estates (RTIARE). 2D geometries of such underground buildings are available in RTIARE. This basic register is the central information source for information systems of public authorities (Čada and Janečka, 2016). The examples of such buildings not registered in the cadastre (because they do not have any part above the ground) but registered in the RTIARE can be low energy buildings completely situated below the surface with the roof covered with grass or wine cellars with business premises. The special cases are the underground buildings which are at least partially located above the ground. These buildings are registered in the cadastre and displayed (only outlines of the parts which are located above the ground) on the cadastral map.

2.10.3 Legal definition of 3D objects

The parcels are identified in the cadastre by the number of cadastral territory and parcel number based on an orthogonal projection. The real property could also be the “layers” above or below the ground. Such horizontal division of real property is allowed in a case when particular layers serve for different purposes and are subjects to different legal regime. For example, this is a case of mineral resources, which are owned by the Czech Republic no matter who the owner of the parcel is. On the map, there is no graphical information about these resources and no easements are established.

In case of flats, cadastre does not require volumetric or height data. Only a schematic drawing illustrating the floor plans and textual description of flats is required. Each owner of a flat is also shared owner of common parts of the building. The size of share is determined by the size of his flat in relation to the total area of all flats. The parcel(s) on which the building stands is included in the common parts of the building. The digital cadastral map does not display neither the flat structure nor the spatial distribution of use rights.

2.10.4 Types of rights that can be registered in 3D

Flats: The new Civil Code also regulates the ownership of building units, which was previously contained in a separate act. A building unit remains a separate piece of real estate and does not form part of the land. The owner of the building unit automatically also owns a share of common parts of the building.

The digital cadastral map does not show the apartments and their structure nor the spatial distribution of use rights.

Buildings: After 1 January 2014, a person who owned a building and the land on which it stands, that building became part of the land (the Czech real estate law returned to the principle that structures are part of the land on which they are built - a “superficies solo cedit” principle). Buildings established on land (except for temporary buildings, utility lines and some other exemptions) are no longer be objects of law and only form a part of the land.

If the land owner and the building owner were two different persons during this time, the building remained as real estate, but the land owner holds a pre-emptive right to the building and the building owner holds a pre-emptive right to the land. The building will then become part of the land when the building and the land first meet in the hands of the same owner. The building will not become part of the land if the building or the land is encumbered by a right in

rem (i.e. right associated with a property, not based on any personal relationship). The digital cadastral map contains only 2D outlines of buildings.

Before the newly built apartment building and rights are registered to the cadastre, one must provide Cadastral Office with the owner of the building declaration on the limitation of housing units (flat or non-residential premises). A part of this declaration is a schematic drawing illustrating the floor plans and textual description of flats.

Underground constructions: The Civil Code declares that utility constructions, especially water pipelines, sewerage networks or power lines are not a part of land. It is understood that the related constructions and technical facilities are part of utility constructions. To detach the space from land ownership in case of utility constructions the easement is used. The (2D) scope of such easement is then graphically displayed in the digital cadastral map. Underground constructions with separate special-purpose use (e.g. metro, collectors, wine cellars...) are considered as real estates. If an underground construction is not a real estate, then it is a part of the land, even if it affects (lays below) the other land. However, in practice, most of underground constructions are not registered in the cadastre. The special case are the underground buildings which are at least partially located above the ground. These buildings are registered in the cadastre and displayed on the cadastral map, see figures 15 and 16.



Figure 15: (Left) Visualization of the underground construction - the archaeological park in Pavlov, Czech Republic (Olivová, 2016); (Right) Entrance to the archaeological park in Pavlov, Czech Republic (photo: Institute of Archaeology of the CAS, Brno).

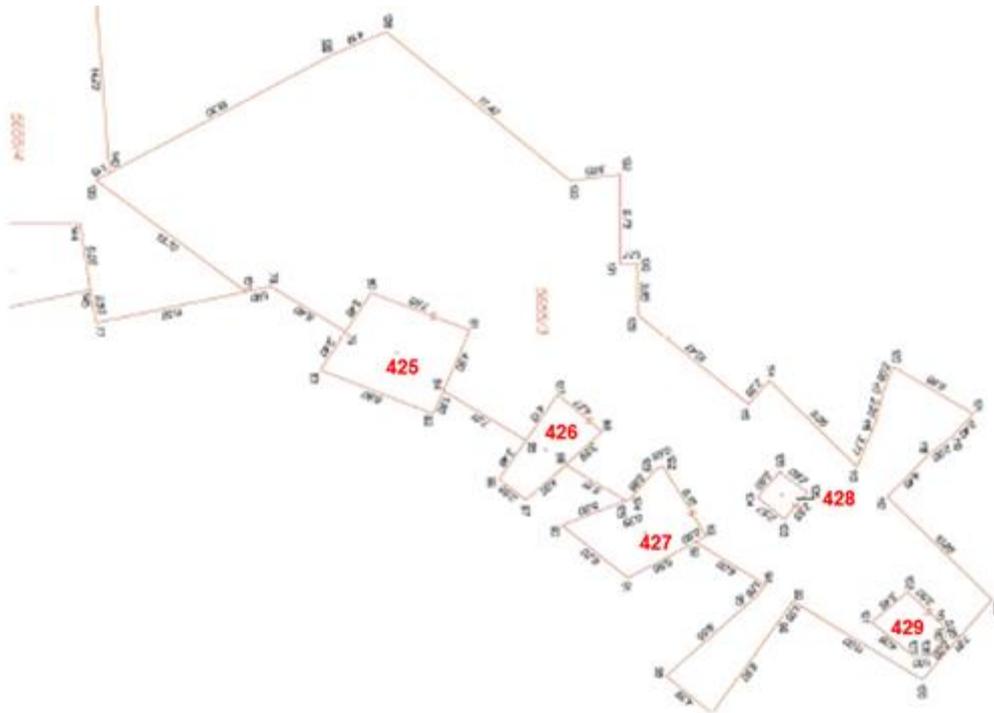


Figure 16: Visualization (in 2D map) of the boundary of the underground construction – the archaeological park in Pavlov. Every part of the construction above the ground must lay on a separate building parcel (here total 5 building parcels with bold red number) (Olivová, (2016).

GeoInfoStrategy and 3D objects: There is a strong emphasis on the creation of National Set of Spatial Objects (NSSO) within the GeoInfoStrategy. NSSO is defined as the source of guaranteed and reference 3D geographic data at the highest possible level of detail for selected objects of the real world, covering the whole territory of the Czech Republic. A part of NSSO should be for example 3D buildings. Within the framework of the GeoInfoStrategy the register of technical infrastructure of public administration containing the utility constructions as 3D objects should be established.

2.10.5 Concluding remarks

The 2D digital cadastral map which covers the whole territory of the Czech Republic is going to be finalized in 2017. In the Czech Republic, the 3D Cadastre is currently mostly academic research which is forced by the needs of professional end-users and the problems they meet in their day-to-day work. On the other side, there is the governmental initiative GeoInfoStrategy (the Strategy for the Development of the Infrastructure for Spatial Information in the Czech Republic to 2020 approved by the Czech government in October 2014) dealing with 3D spatial data and referring also to ISO 19152.

2.11 Greece

2.11.1 Background information

Greece has no established 3D Cadastre legislation and currently there is no indication of introducing so. The country is under cadastral survey due to the ongoing Hellenic Cadastre project in transition from deed registration to title registration system, and further amending of

cadastral survey requirements to include more spatial data would increase the project's cost as well as delay its completion (Rokos, 2001). However, there is a significant number of real property objects that can be described as 3D and specific regulations apply. According to Greek legislation immovable property comprises land and its constituent parts (Civil Code, Art. 948). Constituent parts are considered objects that have been steadily attached to the ground, especially buildings [...] groundwater [...] (Civil Code, Art. 954). Real property ownership extends, if not provided otherwise by law, to the space above and below the earth's surface. However, the owner cannot forbid activities in height or depth that has no interest in opposing against them (Civil Code, Art. 1001), except cases of horizontal ownership (apartment ownership), vertical ownership, mines and regulations imposed by neighbourhood law. Technical requirements of cadastral survey define real property as an "independent and uniform ownership object which is owned in its entirety by one or more co-owners. Real property comprises land parcels, horizontal, vertical and composite vertical ownership, mines and SRPO which have been established in specific regions under customary law."

2.11.2 Status of 3D objects' recording

Although real property objects with 3D characteristics are registered to the Hellenic Cadastre, such as horizontal and vertical ownership, mines, easements and Special Real Property Objects (SRPO), registration is limited on 2D land parcel. In case of underground antiquities or infrastructures, thematic cadastres have been established, e.g. the ongoing Archaeological Cadastre, or data is recorded by the agencies responsible for each utility. Regardless the case, registration and mapping of such objects involves their projection on 2D surface parcels, e.g. utility easements, or identification through tags, e.g. SRPO. On regions where Hellenic Cadastre is operating, registered survey plans include height information, while utilities' operating agencies maintain cross section diagrams, which are also required for granting rights of passage through state, municipal, private or public space.

2.11.3 Legal definition of 3D objects

Apartment ownership in Greece is called horizontal ownership. Law 3741 "about ownership per floors" establishes ownership of a floor or part of a floor, along with an indivisible share on common property. Cadastral registration does not require submission of volumetric or height data, although building's floor plans and cross sections are planned to be incorporated to the Hellenic Cadastre after completion of the project. Exact location of real property within a building cannot be directly accessed as only buildings' footprints are presented on the cadastral maps.

Vertical ownership allows for separate ownership of a building or buildings within a co-owned land parcel; vertical ownership concept does not imply separate building and land ownership. In case that horizontal property is established within a vertical ownership, this constitutes a composite vertical ownership. Similarly to horizontal ownership, the boundaries of vertical or composite vertical ownership are not shown on the cadastral maps.

According to Greek Mineral Code, mineral exploration and extraction licenses are granted by the State that requires areas where mineral activities take place to be defined on survey drawings using geographical coordinates in national datum. Article 30 allows for mineral exploration activities on the surface parcel and below in unlimited depth. Mineral activities are registered in Mortgage Register Offices and operating Cadastral Offices under responsibility of the State

(Article 86). Mines' boundaries are maintained on a separate layer to be separated from overlying land parcels.

Similarly, underground pipelines are considered to be of public benefit and are established through servitudes of passage. The law provides for further restrictions on building structures and plantation along pipeline's centre line recorded to local Mortgage Register Offices or operating Cadastral Offices under Ministerial Decrees.

Recording of archaeological sites in Greece is under responsibility of the, currently under construction, 2D "Archaeological Cadastre". However, restrictions and responsibilities of land parcels that fall within regulations of Archaeological legislation are not recorded during this stage of the project.

Other types of 3D property units traced in Greece are SRPO, deriving from Customary Law including "anogeia" (constructions built over another parcel), "katogeia" (constructions built below ground level), "yposkafa" (constructions built below another parcel, usually dug into the earth), "symmata" (constructions built on the seashore to draw boats during winter), arches (property objects extending over a road), wells and tanks. Registration of SRPO requires data regarding all involved parcels. Tags are used to identify such objects with reference to the unique cadastral identifiers of related parcels. A separate layer is used to present SRPO to the cadastral map either as polygons or as points, as presented in Figure 17.

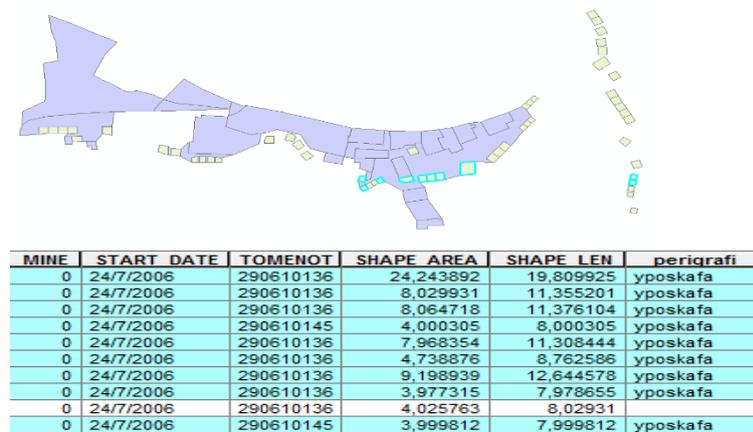


Figure 17: Presentation of "yposkafa" on cadastral map (highlighted in blue) and tags on descriptive database. (Source: NCMA S.A. National Cadastre and Mapping Agency)

2.11.4 Concluding remarks

Although a significant number of 3D real property situations can be traced in Greece, there has been no progress towards the establishment of 3D Cadastre legislation. Stratification of real property is currently accommodated within 2D legal and cadastral framework, while the effect of the right of superficies is under evaluation due to its recent establishment and limited application field (state owned real property). Current legal and administrative framework can merely address complex situations of real property stratification. Systematic research is conducted on academic level, (Papaefthymiou et al., 2004; Tsiliakou and Dimopoulou, 2011; Dimopoulou and Elia, 2012; Kitsakis and Dimopoulou, 2014, Kitsakis and Dimopoulou, 2016) on the aspects and implementation of a 3D cadastral concept in Greece. Completion of the Hellenic Cadastre project is anticipated to allow for concentration on legal and administrative reforms to accommodate 3D cadastral issues.

2.12 Jordan

2.12.1 Background information

Jordan has about 1.6 million real properties. The majority of real properties are located in urban areas in the western part of the country, as the eastern part of the country mainly consists of desert. The Jordanian cadastral and land registration system has its roots in the Ottoman cadastre, which was introduced in the middle of the 19th century. The number of real property services and transactions are constantly increasing (an average of one million different transactions annually) and in recent years the value of land has increased dramatically. A property can be owned by one or more persons or legal entities in either single or joint ownership. A property consists of one piece of land (parcel). In addition to parcel ownership the Jordanian legislation allows apartment ownership, i.e. ownership of 3D units to serve as apartments/flats, commercial units, etc. This type of property has gained public interest due to increased pressure on land and rising land values, especially in the capital, Amman, and other urban centres.

2.12.2 Status of 3D objects' recording

The total number of physical buildings containing registered ownership apartments is more than 70,000, and the total number of apartments is more than 480,000. Apartment registration is part of the property registration procedure. The registration of apartments is done by registering the apartment drawing(s) in the national real property register. In order to register an apartment a survey of the apartment's physical boundaries is required. The physical boundaries are required to be surveyed by a private surveyor and a drawing to be submitted together with the application for registration. One of the required documents is a detailed map of the apartment footprint containing measurements of new or updated apartment building (figure 18). Measurements locating the apartment within the parcel boundaries are also provided on the map (figure 19).

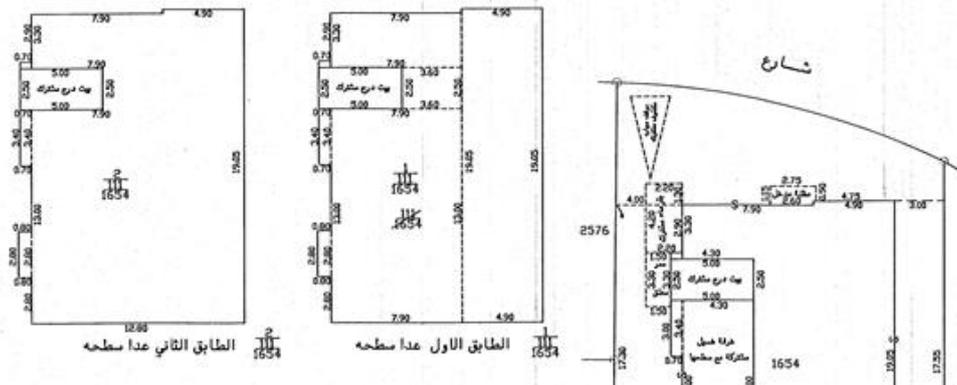


Figure 18: Part of building footprint with detailed apartment measurements. (Courtesy of the Department of Lands and Survey, Amman, Jordan)

Since 2016 private surveyors are instructed to supply apartment drawings in digital form as part of the registration procedure. This is done by sending all information about the transaction including a digital file with building data via the Land Registration Directorate to the Department of Lands and Survey. The apartment building footprints are after verification registered in the cadastral map at the Department of Lands and Survey. A unique building identifier based on the parcel identifier is attached to each apartment. It is planned to register

existing 3D units digitally and including them in the cadastral index map by for example scanning the apartment drawings.



Figure 19: Example from the cadastral map database with a new building footprint (yellow polygon) and the Department of Lands and Survey building coordinate (yellow dot). Aerial photo is used as background. (Courtesy of the Department of Lands and Survey, Amman, Jordan)

2.12.3 Legal definition of 3D objects

An apartment is defined as a separate registered object. Each owner has the right to register each apartment built on the parcel as an independent property. The parcel and the parts of the building designated for common use are considered as common ownership for all apartment owners. The land and building parts designated for common use are common for all apartment owners (Law of Ownership of Floors and Apartments of 1968. Law no. 25. With later amendments).

Each apartment has shares in the parcel it is located within. The total number of shares is divided between the apartment owners. If an apartment changes owner it is required that the shares in the parcel follow with the transaction of ownership.

2.12.4 Types of rights that can be registered in 3D

The apartment ownership right is registered in the cadastre. Other rights, restrictions and responsibilities, such as easements and usufructs, are not registered as 3D units.

2.12.5 Concluding remarks

3D property (apartments) is an important component in the Jordanian real property system. The registration of apartments is based on detailed drawings submitted as part of the registration procedures. In addition to this, 2D digital footprints of apartment buildings with a unique identifier for each apartment are also submitted to the registration authorities. The legislation and governmental ordinances for creation and registration of this type of real property has worked well as an instrument to secure ownership for an increasing number of 3D units.

2.13 The Netherlands

2.13.1 Background information

The Netherlands has a proven track record of developing land registry systems which are efficient and widely applicable while also managing to cater to a wide variety of interests. ISO 19152, the Land Administration Domain Model, is an example of this. ISO 19152 and its documentation is written in English however, many documents describing what is happening in the Netherlands are not. The legal base of the Netherlands is the Civil Code (originally from 1838, modernized in 1992). The law system is based on the French Civil Code; however there is an influence from the Roman Law and Dutch customary law. In terms of building and land ownership, like in most legal system in other countries, Dutch law adopts the rule taken from Roman law. The most refined system of land registration is title registration where the owner of a certain property will be immediately seen. A deed, drawn by notary in many cases, is the form saying who is giving up rights and who is gaining them and this as for many other countries is presented to the registrar. One of the advantages of deed registration is that the procedure is very quick. In the Netherlands the system consists of three information collections: (1) archive of deeds “public registers”, (2) parcel-based property register “cadastral register”, and (3) an index map “cadastral map”. All of them are carefully maintained in paper based and nowadays in digital form in the Agency for Cadastre and Public Registers ”Cadastre”. The property rights transfer requires notarial deed which has to be registered in the public registers. Each property is identified by a unique parcel number referring to the one in the cadastral map. In the Netherlands according to the law, the ownership of the building and other constructions are included in the ownership of the land. The transfer of ownership takes place after the deed has been registered, and a parcel-based index (cadastral ledger, kadastrale legger) was introduced in the 19th century which has grown into a title register, which fulfills an important role in actual conveyance, but has no special legal status (Zevenbergen, 1996). However, according to the Dutch law it is not possible to divide the ownership of the land into 3D volumes and to convey a building without the land. Using the apartment rights or so called “condominium rights” multi-level properties can still be created. In order to describe the 3D boundaries of properties, the requirements only exist for deeds which establish apartment rights. It is required by the law separate registration per floor in the land registers. Multi-level property rights such as the right of long lease or the right of superficies exist in Netherlands before the start of the Dutch Cadastre (in 1832). In the Netherlands the public registers are kept in an analogue form, however the notaries and Kadaster are working in a digital form. The cadastral register has been kept digitally since 1990s. The digitization of the cadastral maps was finished in 1997 and the technical infrastructure has been created in order to allow the notaries to submit the deeds of transfer electronically (Zevenbergen, 2002).

2.13.2 Status of 3D objects recording

The Netherlands is still working on registration of mapping in 3D Legal spaces. The efforts of Kadaster are focused on maintenance and updating of the Large Scale Topographic Map (Basisregistratie Grootchalige Topografie - BGT) which basically includes buildings, roads, water bodies, railways and vegetation. This map is a result of the cooperative work of different organizations such as Municipalities, private companies, Ministry of Industry and Trade, Ministry of Defence and organizations which administer railroads and infrastructure.

Current legal system supports the idea that the owner of a property is the owner of the space above and below, however the boundaries are neither visualized nor fixed. The Map of Legal Spaces (Kadastrale Kaart) is a clear example where 3D should be visualised but in reality is still in 2D. For some situations currently, to be efficiently represented 3D ownership situations are projected on a 2D parcel maps. In case that all involved stakeholders agree on multi-level registration in 3D Cadastre the registration will be possible. However challenges can be faced in case of future transfers of multi-level property rights. To address such issues, the Netherlands Kadaster was focused in analysis in order to improve the registration process (Stoter et al. 2012). Therefore two phases for improvement were suggested. The first one, which started in 2012 and finished with a real registration of a 3D situation in 2016, was focused in how to establish rights on 3D volumes for decades and not only to make them visible. These efforts lead to accepting the 3D pdf format as a part of the deed (Figure 20). The second phase which is still in progress deals with 3D data management and dissemination.

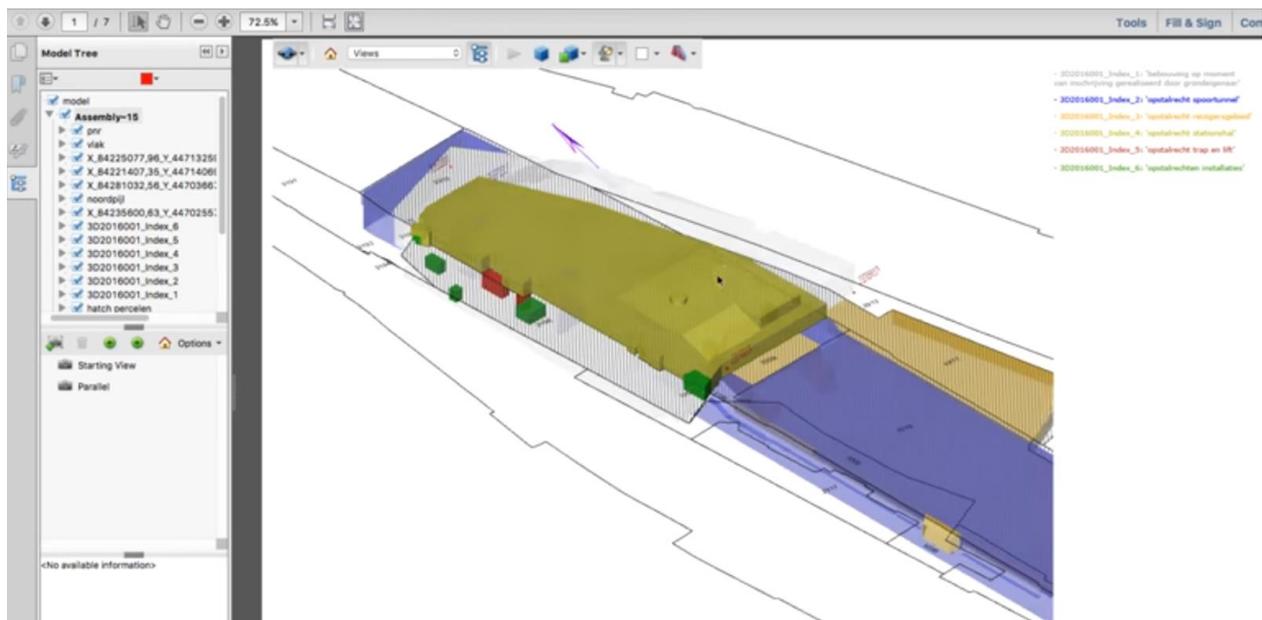


Figure 20: 3D PDF, official document that visualises rights of multi-level ownership in 3D. It concerns the combined city hall and railway station in Delft. (Source: <https://www.youtube.com/embed/vFMoH-2r7xo>)

3D representation of the rights into PDF which was included into the deed was a big achievement reported from Stoter et al. (2016). This deed was also recorded in the Land Register.

2.13.3 Legal definition of 3D objects

It was proved that computer-based model is valid and suitable representation of the real object. With CAD (Computer Aided Design) systems it was found by many researchers in the field that 3D objects can be easily constructed and maintained (v. Oosterom et al., 2005). However for 3D cadastre it's of great importance to consider the difference between 3D objects and 3D parcels. The parcels are not real-world objects. As defined by v. Oosterom et al. (2011) 3D parcels can be considered the legal volumes formed with real rights and that can overlap with several ground parcels.

2.13.4 Concluding remarks

There is no legislation and no legal framework for 3D descriptions of parcels in The Netherlands yet. Netherlands have a lot of official university level research project in cooperation with government bodies and Netherlands is mature for implementation of 3D cadastre legislation. Ideally including 3D in the land registry system definitely is a great step forward. However, it is important to start with initial registration of 3D legal spaces rather than improving the 2D ones. If interactive topological models are created and stored in advance in a spatial 3D database, this would allow better data registration, validation, visualisation and dissemination. Current research is focused on how to lay the groundwork on the legal framework. Stoter et al. (2016) describe how a 3D pdf was registered in the Dutch Kadaster with rights, restrictions and responsibilities in 3D. As described by her this procedure took two years, due to the fact that initially it was registered in 2D and later on upgraded with 3D information. Further development is planned in the direction of 3D registration in Netherlands with a proper modification and adaptation in the regulatory framework.

2.14 Poland

2.14.1 Background information

In Poland, the 2D cadastral system is using 2D parcels in order to register rights to the land. According to the cadastral law in the Polish cadastral system there are registered three types of cadastral objects: land parcels, buildings and apartments.

Ownership of apartments in Poland is a kind of 3D registration. Although apartments have 3D characteristics, registration is still based on 2D parcels. Modelling in 3D is not implemented.

Premises registered in the cadastre should be considered as premises defines as (§2 the Cadastral Law) independent dwelling premises or premises of other destination, as understood by the Act of June 24, 1994 on property of premises.

According to the above Act (Article 2), independent dwelling premises is a single room or groups of rooms delineated by permanent walls within a building, which are used for permanent stay of humans, and which – together with auxiliary rooms – are used for meeting dwelling demands of people. This refers, respectively, to independent premises utilised in accordance to their destination, which is other than dwelling needs.

As said in Karabin (2011a), apartments, together with accessory rooms, are marked on projections of appropriate storeys of buildings; in case when accessory rooms are located outside a dwelling building, they are also marked on a copy of cadastral map. The above documents become an annex to an act which establishes a separate ownership of apartment. Those documents are stored in a land book and in a cadastre in analogue form.

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) – underground tunnels, the subway tunnels and other devices of the underground infrastructure like water, gas pipes etc are the objects of the GESUT database and they are presented on base maps only. So information concerning those objects may be found on the base maps (scales in towns usually amounts from 1:500 to 1:1000) and in the complete surveying documents concerning those objects in the archive. As said in Karabin (2011b), the content of the base map is sufficient to identify the spatial extension of those objects in the x,y plane and for the technical infrastructure installations in the vertical plane as well, since heights of particular

elements of that infrastructure (conduits, manholes etc.) are also specified. The technical documentation of subway is stored also in Warsaw's Subway Ltd. company.

2.14.2 Status of 3D objects' recording

There is no 3D cadastre in Poland. Only some proposals from academic centres exist. Complex model for Poland was worked out by Karabin (2013; 2014). For Poland Karabin (2013; 2014) proposed new cadastral objects, i.e. 2D and 3D parcels, as a result of the proposed registration of the minimum (Z-) and maximum (Z+) levels, which define the vertical extent of property in a metric system. It allows the implementation of a "layer" approach to the rights and restrictions in the cadastre. This idea of a "layer" approach has been presented, among others, by Dimopoulou and Elia (2012) (Figure 21 left).

2.14.3 Legal definition of 3D objects

In mentioned above proposal performed by Karabin (2013; 2014) there are described new 3D cadastral objects for Poland. Karabin (2013) assumed that space should be subdivided into layers: the space accessible by the owner and the space, which will be reserved for the State Treasury - required for security of the aircraft traffic, the space where natural resources occur, below the depth accessible by the private owner. Dimopoulou and Elia (2012) proposed the following division:

- Potential building/constructing space right owned by the State or the Local Authority,
- Potential building/constructing space right owned by the parcel owner/s,
- Existing building owned by the parcel owner/s,
- Parcel owned by one or more private parties,
- Land space under the parcel owned by the State or the Local Authority.



Figure 21: (left) The "layer" approach to the 3D cadastre (Source: Dimopoulou and Elia, 2012), (right) The structures visible in blue - the legal space of the 3D cadastral parcel. Space of construction in the form of a 3D city model (inside the legal space). Source: Ying et al. (2012)

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, space where natural resources occur, below the depth accessible by the private entity). According to that idea Karabin (2013) proposed new cadastral objects: 2D cadastral parcel and 3D cadastral parcel.

2.14.4 Concluding remarks

First of all, it is necessary to introduce in Poland the division of space of a property. Second necessary step is to register in the cadastre the minimum (Z-) and maximum (Z+) levels, which

define the vertical extent of property. It is also important to distinguish between legal space of the 3D cadastral parcel and space of construction. This idea was presented by Ying et al., (2012): “we design two types of cadastral geospace: 3D land space and 3D housing/building space. 3D land space is a certain vertical extension of the 2D parcel according to planning or demands of architecture, and 3D housing/building space is the physical space or its approximation”, Figure 21 (right).

Above guidelines allow to make a first step for introduction of a 3D cadastral system in Poland. Complex model approaches of 3D Cadastre for Poland exists (e.g. Karabin, 2013).

2.15 Sweden

2.15.1 Background information

Sweden is in relation to its size a scarcely populated country. The majority of the population is centred in or in a close distance of the major city centres (Source: Statistics Sweden). This may create complex situations of ownership and other rights, restrictions and responsibilities associated with land (and water and air). One solution to efficiently manage these situations has been the introduction of the concept of 3D property.

All land and, in principle, all water areas are divided into property units or joint property units, which are recorded in the Swedish cadastre, consisting of a textual and a spatial part. The property unit is registered with a unique registration identification number. The physical 2D footprint of a 3D property unit is registered by x and y coordinates in the spatial part of the cadastre, whereas the extension in height can be described in different ways; by z coordinates, by adding a textual description of the legal boundaries in the cadastre (e.g. that they follow the outside of a wall or roof), and the number of the floor level the 3D unit is located on. See examples of 3D registration in Figures 22-24.

Läge, karta (09)				
Område	N, E (SWEREF 99 TM)		N, E (SWEREF 99 18 00)	
1	6582728.4	671911.8	6581457.7	151337.1
2 3D-utrymme	6582787.6	672177.9	6581504.8	151605.6
Ändamål: Byggnad				
Storlek: Utrymmet i horisontalplan är ca 75 kvm.				
Höjd: Höjdläget är mellan CA+31,2 meter och CA+55 meter i RH00.				
Urholkan: Solna Haga 4:20, Solna Haga 4:26				
3 3D-utrymme	6582888.3	672049.6	6581611.2	151481.9
Ändamål: Byggnad				
Storlek: Utrymmet i horisontalplan är ca 6 kvm.				
Höjd: Höjdläget är mellan CA+26,3 meter och CA+58,5 meter i RH00.				
Urholkar: Solna Haga 4:20				
Urholkas av				
3D-utrymme: Solna Haga 6:1 område 1				

Figure 22: Textual 3D information (in Swedish) in the land register (3D-utrymme = 3D space, i.e. 3D property unit or 3D property space (El-Mekawy et al., 2014).

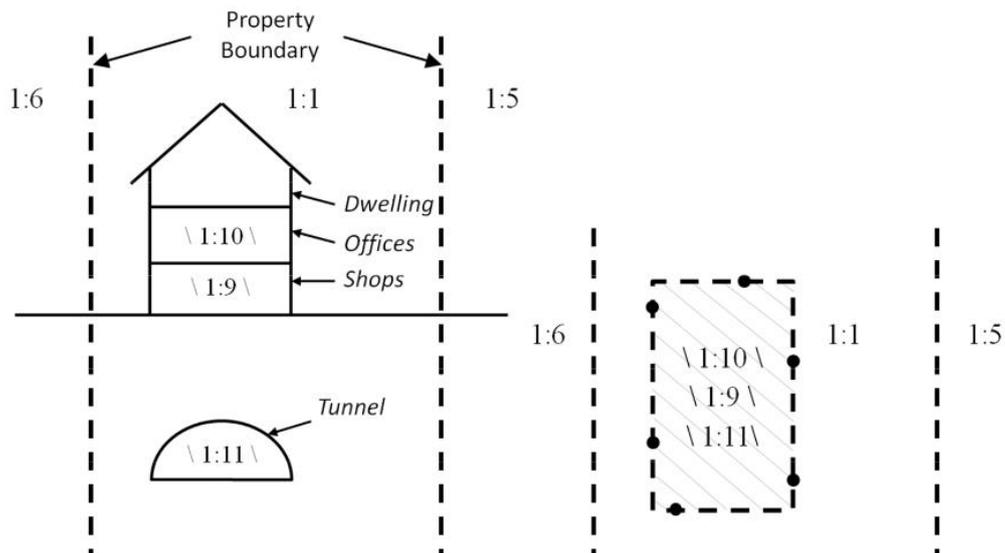


Figure 23: Examples of Swedish 3D property shown in cross section (left) and the visualization on the cadastral index map (right). Based on Lantmäteriet (2004).

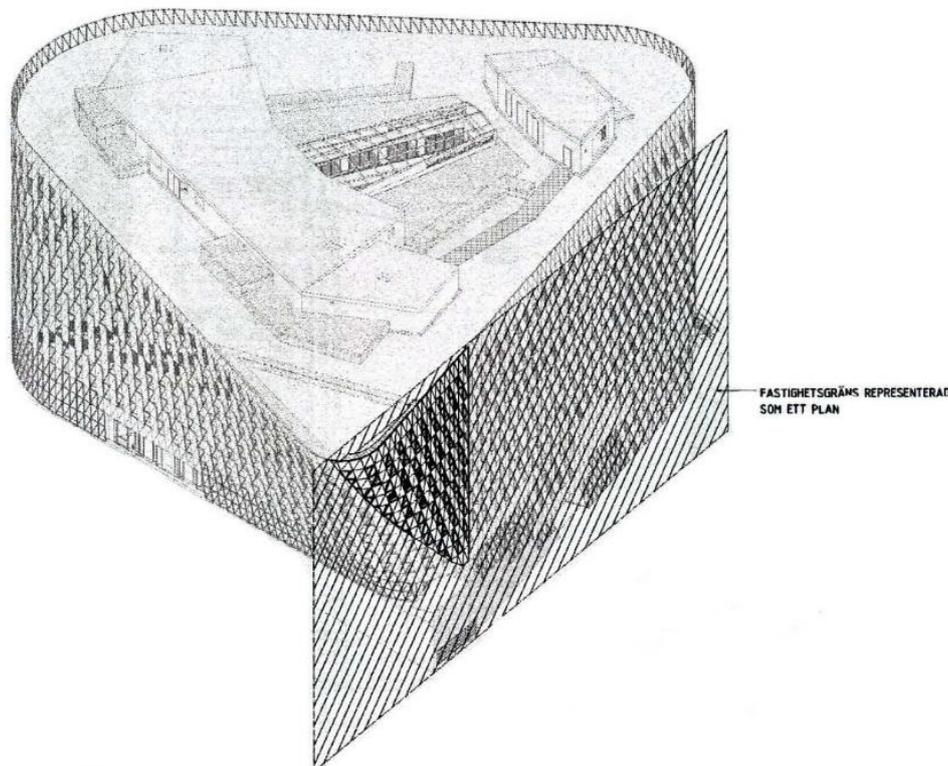


Figure 24: 3D boundary shown as a vertical plane cutting through a building on a 3D construction drawing, being enclosed in the legal survey documents. Based on Lantmäteriet (2014).

2.15.2 Status of 3D objects recording

The concept of 3D property was introduced into the Swedish legislation in 2004 and expanded in 2009 by the addition of condominium (apartment) ownership. The condominium is a special form of 3D property intended for ownership of a residential apartment. For political reasons, it

was separated from the initial 3D property legislation and was introduced later. 3D property is, however, still a new instrument for land management. There has been an increase in interest for 3D property and ownership apartments in later years, although the demand has failed to meet the expectations prior to the implementation of the 3D property and condominium legislation (Paasch et al., 2016; El-Mekawy et al., 2014).

2.15.3 Legal definition of 3D objects

3D property is defined as a property unit, which in its entirety is delimited both horizontally and vertically (Swedish Land Code, Chap. 1, Section 1a). It can separate and contain different functions such as units consisting of several apartments or offices, commercial premises, etc. It also often consists of infrastructure objects, e.g. tunnels or other large underground facilities. The 3D unit must relate to a (whole or part of a) built construction or other physical facility (Figure. 22). A Swedish 3D property may extend under or over one or more ground parcels. It is therefore not bound to be located within the boundaries of a 2D property. Condominium apartments are solely created for residential purposes and special conditions and restrictions apply concerning the formation of 3D property (Paulsson, 2012).

2.15.4 Types of rights that can be registered in 3D

There are no limitations on the range of rights related to 3D units. Neither are there any limitations on the range of restrictions or responsibilities related to 3D units. The range of rights to be formed on a 3D property does not differ from those created on 2D property, e.g. ownership, easement/servitude and different types of access and use rights (Paasch et al., 2016, El-Mekawy et al., 2014).

2.15.5 Concluding remarks

Taking into consideration that 3D property formation only has been possible for a little more than a decade the number of 3D properties today is still limited, but the legislation and use of this type of property has worked well and there seems to be an increase in interest to use 3D property formation as an instrument to solve complex ownership and use right issues in urban environments.

3. DISCUSSION AND COMPARISON

The long-term aim of this article was set to contribute to the knowledge base on understanding and developing 3D cadastral systems. Therefore, a short-term objective was targeted to compare and discuss 3D property concepts in selected fifteen countries (or provinces/states) among those which have witnessed some developments in this field in recent years.

To discuss the findings of this article, it is important first to reflect on the definition of the ‘3D property’ concept. It has been found from the compared case studies that there is still inconsistency in the way ‘3D property’ is defined. This conforms to the findings of recent literature reviewed in section 1 that legal aspects in these countries are not yet as developed as the technical aspects (e.g. spatial data infrastructure (SDI), data modelling, database management, and geometrical representation) and the organizational/registration aspects (e.g. management and capacity-building issues, registration of 3D property in land administration systems, such as the content, storage, structure).

The case studies can be summarized as in the tables below.

Table 1: Summary of national case studies.

Country	Background information	Status of 3D objects' recording	Legal definition of 3D objects	Rights that can be registered in 3D
Argentina	<ul style="list-style-type: none"> -Civil law jurisdiction (National and Provincial, hierarchically). - Provincial cadastral system. -Transition from Deeds to Titles in Provincial real property registration system -Land register and cadastre map exist in some cases -Digital form in certain provinces, paper form in others. 	<ul style="list-style-type: none"> -2D models with tags (high, levels) -2D registration -Under and above ground utilities are maintained by each Service Company. -Unified real property cadastre in 2D database and thematic cadastre in some cases. 	<ul style="list-style-type: none"> 2D (orthogonal projection) and different kind of levels (floor, roof, terrace, subsoil, basement, etc.) 	<ul style="list-style-type: none"> No rights registered in 3D.
Australia (State of Queensland)	<ul style="list-style-type: none"> -Common Law -Torrens Title registration system -Paper title not provided to owners -Point of truth for title is Titles Office record, and for dimensions is the paper cadastral plan -Digital cadastral database (DCDB) is a representation only and not the point of truth -Private cadastral surveyors survey land and are legally responsible for accuracy of plan data, State liable for Title -Both Titles Office and Directorate of Survey is within Department of 	<ul style="list-style-type: none"> -Building units have been registered under Building Units and Group Titles Act (1980) and Body Corporate and Community Management Act (1997) -2D and 3D Title registered under Land Title Act (1994) for freehold land and Land Act (1994) for crown and non-freehold land, the Surveying and Mapping Infrastructure Act (2003) guides surveyors and geodetic infrastructure, the Surveyors Act (2009) safeguards the public by 	<ul style="list-style-type: none"> - Separation between 3D Building Format Plan and 3D Volumetric Format plan - Any 3D object can be registered if it can be mathematically defined - Separate legislation exists for 3D Buildings - 3D Volume covered under directives 	<ul style="list-style-type: none"> All rights on 3D are registered, any RRR on 2D is possible to be registered in 3D

	<p>Natural Resources and Mines, but separate offices</p> <ul style="list-style-type: none"> -DCDB holds 2D with footprint of 3D, currently a project is underway to modify the cadastral databases to accommodate 3D parcels -All cadastral representation, including valuation, topographic data, imagery etc. are open source and is disseminated free of charge 	<p>guiding the surveyors</p> <ul style="list-style-type: none"> -Directives such as Land Practice Manual, Cadastral Survey Requirements (CSR), and Registrar of Titles Directions for Preparation of Plans (RTDPP) further guide land practitioners 		
Australia (State of Victoria)	<ul style="list-style-type: none"> -Common law, -Torrens land registration system -Parcel register and index “digital cadastral mapbase” exist -Title register is digital but copies of title are printed in hard copy 	<ul style="list-style-type: none"> -Various 3D (objects) RRRs are registered. -Utility networks are not included in the register -Land Use Victoria is responsible for the title (including cadastral plans) registration, and maintenance of index “digital cadastral mapbase” 	Is defined by the type of 3D RRRs and the boundaries that delineate the RRRs	Various 3D RRRs are registered but are represented in 2D diagrams
Austria	<ul style="list-style-type: none"> -Civil law jurisdiction -National cadastre system - Digital cadastral map and land register - Geometrical basis for condominium stored in land register but not connected to cadastral maps 	<ul style="list-style-type: none"> - 2D registration only - Condominium registration as shared ownership of land - Easements are usually not represented geometrically 	N/A (Does not apply)	No rights registered in 3D.
Bulgaria	<ul style="list-style-type: none"> -Civil law jurisdiction -Deed registration system -The 2D cadastre is maintained by the GCCA and the 	<ul style="list-style-type: none"> -2D Cadastre with use of 3D visualisation only for certain objects - under/above ground utilities' 	N/A (Does not apply)	No rights registered in 3D.

	<p>property register is stored by the Registry Agency. Integrated information system for cadastre and property register (IISCPR) was designed. Cadastre and Land registers are public.</p> <p>- Digital form in the big cities. 20% of the country has digital 2D cadastre.</p>	<p>recording to Cadastre (YES)</p> <p>-No 3D cadastre legislation</p> <p>-Cadastre is maintained by GCCA and the property register is stored by the Registry Agency.</p>		
Canada (Province of Quebec)	<p>-Civil code jurisdiction</p> <p>-Deeds registration</p> <p>- land register and cadastre map exist</p> <p>-Cadastre reform proposes updated, complete, accurate, digital and online land register and cadastre map.</p>	<p>-Mainly 2D land parcels.</p> <p>-Overlapping properties distinctly indicated on the 2D cadastre plan (with tags) and then refer to subdivision plans, mainly for condominium units.</p> <p>-Registration does not include 3D information but PC plans are available and altitude, height and volume are provided.</p> <p>-Easements are not represented on the 2D cadastral plan.</p> <p>-State resources and distribution networks recorded in distinct registers (not cadastre), no map is available.</p> <p>-Real property cadastre managed by Government.</p>	<p>The concept of 3D legal object does not exist in the documentation even though it is possible to register 3D objects (see PC-plans)</p>	<p>Co-ownership rights (private and common parts) are described by altitude and height information in the PC-Plans.</p>
China	<p>-Civil law jurisdiction</p> <p>-Dual cadastre system</p> <p>-Real property title registration system</p> <p>-Land register and cadastre map exist</p>	<p>-2D registration</p> <p>-under/above ground utilities' recording to Cadastre not fulfilled</p> <p>-Not unified registries</p>	<p>Real property unit</p>	<p>3D cadastre in pilot projects</p>

	<ul style="list-style-type: none"> -Digital form in certain cities -Unified cadastre registration under construction, the initial operational status will be achieved by 2018 	<ul style="list-style-type: none"> -Each registry is maintained by responsible institution 		
Costa Rica	<ul style="list-style-type: none"> -Civil Law jurisdiction - Unified national Registry and cadastral system 	<ul style="list-style-type: none"> -2D models with tags (high, levels) -Under and above ground utilities are maintained by each Service Company. -Unified real property cadastre in 2D database and thematic cadastres in some cases. 	2D (orthogonal projection) and different kind of levels.	3D cadastre in pilot project
Croatia	<ul style="list-style-type: none"> - Civil Law jurisdiction - Title, based registration system - Cadastre maps exist in digital form 	<ul style="list-style-type: none"> - use of 3D models in 3D objects' registration (2D models with tags - 2.5D) - under/above ground utilities' recording to Cadastre - Real property cadastre and thematic utility cadastre are maintained by State Geodetic Administration - Land book maintained by local courts (Ministry of Justice) 	Rights referring to use of limited space will be registered in land book on a 2D parcel registered in the cadastre and in the land book.	Various 3D RRRs are registered but are represented in 2D diagrams.
Czech Republic	<ul style="list-style-type: none"> -Civil Law jurisdiction -No 3D cadastre legislation, long established cadastral system based on 2D parcels. -The Czech cadastral system is based on the compulsory title registration -1993 integration of former Land 	<ul style="list-style-type: none"> -2D registration only -No graphical information about the flats in the map -The underground constructions are not registered in the Czech cadastre and therefore are not displayed in any form on cadastral map. -It is possible to register rights on a 	N/A (Does not apply)	No rights registered in 3D.

	Registry Book and Cadastre of Land into one register -Since 2014 superficies solo cedit principle. -Digital cadastral map for most of the territory of the Czech Republic	part of parcel. The spatial restriction can only be defined and displayed in 2D. -Czech Office for Surveying, Mapping and Cadastre (national mapping agency)		
Greece	-Civil Law jurisdiction -Transition from Deeds to Titles registration system - unified land registry and cadastral map (after completion of Hellenic Cadastre project) - Digital (in regions where Hellenic Cadastre is completed)	-2D representation of 3D objects to cadastral map using tags and separate thematic layers -projections of servitudes on surface parcels registered -Hellenic Cadastre and thematic cadastres exist -NCMA, agencies responsible for utilities or thematic objects	N/A (Does not apply)	No rights registered in 3D.
Jordan	-Civil Law jurisdiction. -Cadastral legislation has its roots in the Ottoman cadastre. -Digital land registry and cadastral map. -3D cadastral legislation for apartment registration.	-2D registration of 3D objects. -National, digital cadastre and building register exist. -Apartment buildings and 2D layout of apartments are registered as part of the cadastral procedure.	Ownership apartments are defined as separate entities	No rights registered in 3D.
The Netherlands	-Civil Law jurisdiction -Deed registration system -Archive of deeds, parcel-property register and index “cadastral map” are maintained from the Agency for Cadastre and Public Registers -The public registers are kept in an analogue form,	-2D registration with the first one fully 3D registration in 2016. No legal framework for 3D descriptions of parcels -2D registration under/above ground utilities’ recording to cadastre - Agency for Cadastre and	3D parcels can be considered the legal volumes formed with real rights and that can overlap with several ground parcels. (v. Oosterom et al., 2011)	Accepted 3D pdf format as a part of the deed - 2016

	notaries and Kadaster are working in a digital form.	Public Registers "Cadastré" are responsible for the maintenance of the archive of deeds, parcel-property register and index "cadastral map"		
Poland	<ul style="list-style-type: none"> -Civil Law jurisdiction -Title registration system -Dual cadastral system (both land register and real estate cadastre exist) -Land register fully digitalized with one central database Real estate cadastre also in digital form but there is no central database, also divided into two components (cadastral maps and descriptive part of cadastre) -Apartments, together with accessory rooms, are marked on projections of appropriate storeys of buildings and are stored in a land book and in a cadastre in analogue form (not connected to cadastral maps) 	<ul style="list-style-type: none"> -2D registration only. -Apartment ownership is a kind of 3D registration. Apartments are defined as separate cadastral objects. -Underground tunnels, the subway tunnels and other devices of the underground infrastructure like water, gas pipes etc are the objects of the GESUT database (under creation) and they are presented on base maps only (base maps already exists). -Owners of each utility networks have their own databases. -"layers" approach was proposed for Polish 3D Cadastre by academic society 	N/A (Does not apply)	No rights registered in 3D
Sweden	<ul style="list-style-type: none"> -Civil Law jurisdiction -Titles registration system - unified land registry and cadastral map - Digital - Complex RRRs on real property 	<ul style="list-style-type: none"> -3D Cadastre legislation since 2004 - Condominium legislation established since 2009 - 2D representation of 3D objects to cadastral map - 2D registration 	3D property is defined as a property unit which in its entirety is delimited both horizontally and vertically (Swedish Land Code, Chap. 1, Section 1a).	No difference with 2D real property – No limitations in 3D RRRs

		- under/above ground utilities' recording to cadastre		
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Table 1 summarises the results of the examined case studies. Despite their Civil Law origins, except for Common Law based state of Victoria in Australia, each country is based on a different background reflecting both conceptional differences in real property registration along with different levels of cadastral infrastructure. This includes long lasting cadastral systems, e.g. Austria, to the ongoing Hellenic Cadastre project, and centralised systems that are managed at municipal level. However, all of the examined countries share a number of, different in each case, 3D real property objects that can be efficiently managed by establishing 3D cadastre legislation.

Background: Background research among the examined case studies, presents significant differentiations between each case, which result in differentiations to the focus of each national legal framework and cadastral system as well as its “level of preparation” to accommodate 3D objects’ establishment and registration.

Austrian, Czech and Bulgarian Cadastre currently focus on completing digitisation of their archive and establishment of digital cadastral maps, while in Greece cadastral survey towards the establishment of digital Hellenic Cadastre is still ongoing. In other countries, administrative difficulties such as provincial cadastres or unified registration systems of urban and rural land, e.g. Argentina and China respectively, can be traced, inhibiting progress towards 3D cadastral systems.

On the other hand, the states of Victoria and Queensland in Australia show significant interest within 3D Cadastre field with long-standing legislation for 3D real property combined with research towards the establishment of full 3D cadastral systems, e.g. research towards Victorian 3D digital Cadastre system and initiatives towards 4D registration and 3D indoor navigation and augmented reality in Queensland.

Status: There are highlighted differences in the status. Analysis of examined case studies presents the following types of approaches, although each of these is implemented based on national specifications. Such approaches include:

- Addressing of 3D objects within existing (2D based) legal framework, which is implemented by most of the examined countries (Argentina, Austria, Bulgaria, Czech Republic, Costa Rica, Greece, Poland, Quebec and The Netherlands). However, differentiations ranging from registration of 3D pdf documents, e.g. The Netherlands, or registration of underground structures partially located above ground, e.g. Czech Republic, may apply. Similarly, registration of Greek SRPO under “3D tag” approach constitutes one of the variations within this concept.
- Fully operating 3D cadastral systems as presented in, above mentioned, specific Chinese cities, allowing for 3D partition, registration, representation and management of land (parts of China).
- Addressing of 3D objects within 3D cadastre legislation. This case involves Swedish, Queensland’s and Victorian legislation providing for 3D RRRs. On the other hand, legislative initiative on 3D real property management does not establish mapping of such units in 3D, which results in partial accommodation of 3D objects’ management.

- Registration of immovable objects in 3D space as provided in the province of Quebec, using complementary plans to present buildings' 3D characteristics. Although this concept does not constitute a complete method of establishing and recording 3D property, since it operates within the, strict under means of real property partition and extent, concept of Civil Law, it allows for a type of 3D partition of space. Even so, it is a concept that is of optional character, while it involves registration of lots' vertical profiles and 2D cadastral plans. Therefore, it can only be used as a first step towards a 3D cadastral concept. A similar concept, although not optional and focusing on building units, applies to Argentina using 2D plans along with buildings' cross sections.

It is noted that buildings, and especially apartments, constitute the most common 3D object registered in national Cadastres. Despite their 3D character, such objects are either presented in cadastral maps through their 2D footprint, e.g. buildings, or are not presented at all, while legal documentation on the establishment of apartment units' ownership involves only reference on each unit's floor number.

Legal definition of 3D objects: Conforming to literature findings, it is found in the examined case countries that the lack of clear legislation is shown to have a clear impact on legal definition of 3D objects as well as the registered rights in most of the compared countries. In Sweden, a precise 3D real property definition is used including also residence-purpose-based condominium, while Victoria's legislation also provides for registration of 3D RRRs. The same applies to Queensland, where detailed legislation regulates definition, management and surveying of a wide range of 3D spatial units. On the other hand, legal definitions of spatial units do not apply the 3D terminology in all other countries. In practice, although not established through statutory 3D legal procedure, 3D objects are legally created and managed through layer concepts, based on real property's vertical extent restrictions on Civil Codes, through establishment of servitudes or rights of superficies. Real property objects are registered in 2D as projections to cadastral parcels. 3D characteristics are simplified in 2D restrictions' registration or may even not be presented to the cadastral maps, e.g. Austria, while exceptions such as Chinese 3D cadastral volumes or 3D and volumetric information in Quebec's PC plans along with introduction of 3D drawings in the Netherlands indicate the need of recording, not statutorily established, 3D property. Themed cadastres may also be used, focusing on specific objects' recording, although lacking 3D recording of affected real property units, e.g. Archaeological Cadastre in Greece.

Rights that can be registered in 3D: This includes all the possible information with their needed drawing, notes or clarifications on rights, restrictions and responsibilities (RRRs) for each land parcel/s. Within this field, each country employs different implementations of 3D RRRs' recording due to the lack, in most of the examined countries, of 3D Cadastre legislation. Preceding case studies present similar 3D objects, except of nationally distinct special real property objects, including apartment/horizontal ownership, vertical ownership, servitudes of varying types, rights of superficies and mining rights. To these, 3D property units and RRRs can be added, applying to Queensland, Victoria and Sweden, while, Latin American countries distinct by recording restrictions based on Aeronautical Code, protected areas and reserved public areas. Regardless the case, cadastral recording of each of the considered as 3D objects in each country, does not involve 3D representation and recording within a full 3D object model.

Submission of cross sections partially addresses the issue, given that legislation is based on 2D surface parcels. However, the fact that 3D registration is not provided even in countries where 3D cadastre legislation applies, presents that public and professionals are not familiar with 3D real property concepts in order to exploit real property stratification benefits in full scale.

Table 2: 3D property objects, presentation on cadastral maps and cadastral parcel types per case study.

Country	Existing 3D objects (registered or not)	3D cadastral objects (registered)	Presentation of 3D objects to cadastral map	Type of cadastral parcel (2D/3D)
Argentina	-Horizontal property -Easement -Subsoil occupation -Air space occupation -Surface right -Rivers and Lakes -Mines	Horizontal property	2D (orthogonal projection)	2D
Australia (State of Queensland)	- 3D Easements, Leases, Covenants - 3D Roads - Air spaces - 3D Ambulatory boundaries - Water Spaces - Underground space (with or without construction) - Restriction easements (so others cannot obstruct view) - Mining rights - Limitations (above or below a certain height) - Apartments and Common Property - Tunnels, Utilities (network and individual infrastructure) - Carbon abatement zones - Commercial spaces - Car parks	- 3D Easements, Leases, Covenants - 3D Roads - Air spaces - 3D Ambulatory boundaries - Water Spaces - Underground space (with or without construction) - Restriction easements (so others cannot obstruct view) - Mining rights - Limitations (above or below a certain height) - Apartments and Common Property - Tunnels, Utilities (network and individual infrastructure) - Carbon abatement zones - Commercial spaces - Car parks	- 2D Footprint with 3D Isometric View - Different plan types for 2D, 3D Buildings, and 3D Volumes - Different lot numbering system for 3D - 3D Volumetric plans required to show connection to elevation geodetic control point - Any type of 3D geometry permitted if it can be mathematically defined	3D

	- Bridges (pylons and bridge spaces) - Sports spaces (stadium, locker spaces)	- Bridges (pylons and bridge spaces) - Sports spaces (stadium, locker spaces)		
Australia (State of Victoria)	-Apartment unit and their accessories, -common property, -depth limitation and airspace	-Apartment unit and their accessories, -common property, -depth limitation and airspace	2D	3D
Austria	-Tunnels -Condominiums -Wine cellars	-Tunnels ¹ -Condominiums -Wine cellars	2D	2D
Bulgaria	-Apartments offices -commercial buildings.	Commercial buildings	2D	2D
Canada (Province of Quebec)	-Apartments and commercial buildings, -Underground infrastructure objects as tunnels, subways, -Utility networks -Mining objects	Mandatory: -Apartments and commercial buildings, -Underground infrastructure objects as tunnels, subways -Mining objects Not Mandatory -Utility networks	2D plan with text that refer to complementary PC-plans. PC-plans show vertical profiles and subdivision plans each floor. Altitude, height and volume are indicated on the PC-plans.	2D
China	-Apartment - Commercial buildings - Underground facilities	-Apartment -Commercial buildings	2D	2D
Costa Rica	-Horizontal property -Easement -Subsoil occupation -Air space occupation	Horizontal property	2D (orthogonal projection)	2D
Croatia	-Apartments -Office spaces buildings and other structures -utility lines with associated facilities -traffic infrastructure -water and related objects	-Apartments -Office spaces	2.5D	2D
Czech Republic	-Residential and non-residential premises, -Buildings,	-Residential and non-residential premises, -Buildings	2D	2D

	-Underground constructions (e.g. tunnels, metro, wine cellars), -Real properties given by the other law (e.g. dams, weirs, hydroelectric power station), -Culverts and bridges			
Greece	-Horizontal ownership/ condominium -Vertical ownership -Mines -SRPO -Infrastructures/ utilities	-Horizontal ownership/ condominium -Vertical ownership -Mines -SRPO -Utility servitudes	2D ²	2D
Jordan	Apartment ownership	Apartments	2D	2D
The Netherlands	-Apartments -offices -commercial buildings, -infrastructure objects -tunnels -bridges	Complex building in Delft	2D (some 3D)	2D
Poland	-Tunnels (railway, subway etc) -apartments	-Land parcels -Buildings -apartments	2D	2D
Sweden	-Apartments -offices -commercial premises, etc. -infrastructure objects, e.g. tunnels or other large underground facilities, etc.	No limitation on registrable rights	2D ³	3D (3D property unit)

1 not shown on the cadastral maps but can be registered as restrictions on the land registry

2 special layer for mines and SRPO used

3 special symbology of 3D property units

Existing 3D objects:

Examination of existing 3D objects presents that there is a variety of 3D objects nationally which, apart from specific cases, are of similar nature, e.g. apartment units or underground facilities. However, compared to the list of statutory cadastral objects, only a small number of them is required to be registered to national cadastres. From the presented case studies, it is shown that there are ongoing trends for solving representing and registering 3D cadastral objects both above and underground. For the aboveground objects, it seems that there are no problems in most of the buildings, even they are complex, as long as 3D information is available

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(3D models, height information, descriptive 3D data, etc). However, in all countries, the real problem in defining, establishing, registering and managing stratified real property appears in big cities for the underground integration of different activities related to different constructions such as tunnels (cars, rains, subways, etc.), parking, infrastructure, utilities, mines, etc. Installation of utilities is, in most cases, achieved through the establishment of utility servitudes. Although there is no provision for registration of utility networks in national cadastres, utility servitudes' encumbered land parcels can be traced on cadastral maps and databases. Even in this case, only the 2D projection where servitudes apply along with the servitudes' type are recorded, while information such as height or depth of above or underground networks, along with restrictions or responsibilities deriving from each servitude's type, are not available.

Presentation of 3D objects to cadastral map: It can be derived from the examined case studies that 2D presentation is provided for 3D objects either through projections on surface parcels, as in the majority of the examined countries, or through annotations for the existence of 3D objects on surface parcels (e.g. Quebec, Queensland and specific cases of Greek SRPO). National specifications can be traced, involving 2.5D representations such as use of tags, descriptive height data, e.g. floor number, use of specific symbology or separate thematic layers. Registration of subdivision plans and vertical profiles as provided in the province of Quebec in Canada, or 3D isometric views in the cadastral plans in Queensland, constitutes a different approach presenting 3D characteristics of 3D objects that could facilitate reconstruction of 3D object volumes. However, it needs to be noted that even in countries where 3D Cadastre systems apply and 3D RRRs can be established, there is no provision for 3D objects modelling, that presents both the influence of “surface parcel” concept in land administration, as well as the technical deficiencies in establishing full 3D cadastral systems.

Type of cadastral parcel: Case studies show that only Sweden, Queensland, Victoria, and, to some extent, the Netherlands for condominium rights, have 3D parcels, while the others still have only 2D parcels available. Although 3D cadastral objects may exist, there is still no legally delimited 3D real property parcel available in those countries lacking 3D parcels, although the possibility should be useful in many respects. Only apartment ownership rights are possible in some of the countries. Here it is of importance to consider the difference between 3D objects and 3D parcels, where the 3D parcels can be considered as the legal volumes formed with real rights. Introducing 3D property has been introduced as a tool in e.g. Sweden to efficiently manage complex situations of ownership and other rights, restrictions and responsibilities associated with land and could be a possibility also in other countries to legally secure existing 3D objects.

4. CONCLUSIONS

This chapter presents and examines legal status of 3D objects and cadastre of fifteen countries, states and provinces around the world. It examines both Civil and Common Law jurisdictions, also covering different types of cadastral systems. The case studies examined vary as far as the level of 3D Cadastre legislation implementation is concerned, including countries with already operating 3D Cadastre legislation [e.g. Sweden, Australia (Queensland, Victoria)] and others where introduction of 3D Cadastre legislation is under discussion (e.g. Croatia and Poland) either at an advanced level or at an early stage. These, in combination with the different level

of cadastral infrastructure among examined countries and national priorities on land administration, constitute a significantly differentiated background, inhibiting comparative process.

Each country applies different terminology to describe 3D objects, although examination of different 3D objects' nature presents that national approaches share similar characteristics. Summarising the concepts of the exemplified case studies in this study, it seems that implemented solutions are not significantly different, although different aspects of 3D property are taken into account, deriving from variations regarding cadastral systems' structure, types of recorded objects and other issues related to national peculiarities of each country's legislation. Apartment ownership concept constitutes the basic 3D object registered in all of the examined countries, although based on 2D registration. Although various other types of 3D objects can be traced in each country, similar or specific nationally-based, the lack of statutory 3D real property legislation results in case specific real property stratification and registration. On the other hand, Swedish, Queensland's and Victorian 3D property units allow for direct real property stratification, thus addressing complexities that the lack of statutory 3D cadastral framework in the rest of the examined countries fails to accommodate.

As it can be concluded from examined case studies where 3D cadastre legislation has been established, introduction of a 3D cadastral system initially requires re-defining real property in 3D space using unambiguous 3D terminology as well as the establishment of legal instruments to subdivide, consolidate and manage 3D real property in 3D space. Examined case studies of Sweden and Australia (Queensland, Victoria), present that such regulations facilitate real property management and clarify, to a significant extent, complex RRRs imposed on land. However, considering the extent of 3D RRRs regulatory framework, it needs to be enhanced by introduction of 3D Public Law Regulations (PLR), amendment of cadastral survey procedures and data recording to incorporate 3D characteristics of real property, as well as transition of current 2D real property to 3D.

5. FURTHER RESEARCH

The research in this chapter shows that researchers from many countries have been investigating the need for 3D documentation of RRRs in their countries. However, only a limited number of them have established an operational 3D cadastre. From the studies the importance of legal aspects of 3D cadastre is evident and we believe that research towards this direction should be continued and promoted. Not only researchers should continue this important task, but also legal professionals should be motivated to participate in 3D cadastre research, using an interdisciplinary approach. The study presented that among the examined countries only Sweden and Victoria provide the possibility to register 3D parcels. This opens several questions:

- To what extent do the authorities realise the need for 3D and how can it be facilitated?
- What are the necessary extensions to existing legal rules to be set if advancing an existing cadastre from 2D to 3D?
- What are the departments or expert fields that should be involved in each country to facilitate a 3D cadastre system?
- To what extent is it possible to create a theoretical framework for a 3D cadastre that is independent of the national legislation?

- What are the needed changes in the legislation systems for the transformation from 2D to 3D?
- How can a terminological framework/ontology for 3D cadastre be based on the international standard for land administration, LADM, ISO 19152?
- How can the 3D cadastre and building information modelling (BIM) brought together into a mutual benefit?
- How should such a framework be structured and how could it be translated into geometrical concepts?
- How should economic questions such as cost-benefit-analysis and valuation issues be handled?
- How to raise awareness of 3D issues among other professions, e.g. spatial planners and economists?

These questions will require different kinds of research activities. Given that this study focused on authors' national experience, a more extended research including African and Asian countries, would be of great benefit to 3D cadastre research and the establishment of national 3D Cadastres. It will also be necessary to investigate problems with current implementations and separate technical issues from legal limitations, e.g., is it technically impossible to define a specifically shaped 3D parcel or is this kind of shape not allowed in the legal framework? Therefore, research on empirical guidelines or frameworks for each country, i.e. guiding a process towards the implementation of 3D cadastre systems, might be seen needed for better communications and consensus decisions among the involved stakeholders with their responsibilities. Considering the different levels of the studied countries on the 3D cadastre process, an important outcome from this study might be targeted as a starting point for comprehensive ontology that can potentially be used in integrating land administration information resources. This ontology might be further developed as an evaluation standard for measuring the development and progress level for 3D cadastre in each country.

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