

3D Real Property Legal Concepts and Cadastre: A Comparative Study of Selected Countries to Propose a Way Forward

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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 six selected countries: Austria, Brazil, Croatia, Greece, Poland and Sweden, based on the authors' national experience. 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

Cadastrals are being recognized as the core of land administration systems. The cadastral map should be able to represent complete and comprehensive spatial information for representing land rights, restrictions and responsibilities (RRRs) on the land parcels (Kaufmann and Steudler, 1998). However, until today most of countries around the world use 2D land parcels as the base for their land administration systems (Ho et al, 2015). Thus 2D projectional presentation of RRRs on land parcels cannot accommodate complex, overlapping real property so needs to be extended to three-dimensional (3D) space and properties. This 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 works 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. 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 (FIG, 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.

There are several countries already implementing 3D cadastrals. 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 paper provides a comparison and discussions of 3D property concepts in selected countries. The countries were selected as examples based on the experiences of the authors’

own countries, which represent a variety of countries in different stages in 3D cadastral development. In addition to that, the authors aim through this paper 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.

2. ANALYSIS OF 3D LEGAL ISSUES EXEMPLIFIED BY CASE STUDIES

Several countries around the world already implement 3D cadastres, while 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 paper highlight different, national concepts of 3D property.

The goal was to provide information concerning 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?

2.1 Austria

2.1.1 Background information

The Austrian cadastral system has a long tradition. The current system was initiated in 1817 and developed since that time, e.g., by adding the synchronised land register in 1871, or by digitizing the cadastral maps (1991 - 2004). Currently, the focus is on digitizing the survey archive, a project that shall be finished in 2024 (Lichtenberger et al, 2015, p. 31). Since this effort requires significant resources, other endeavours, like the realization of a 3D cadastre, have to be postponed.

2.1.2 Status

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 then 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

as the legal 3D city. Every “occupied space” is a part of the city and should be considered in the urban data bases of the cadastre (Erba and Piumetto, 2012).

In Brazil, the municipalities regulate the use of urban land. Given that the potential for development is defined by the municipality, the air space in which buildings stand belong to the State, which then represents a clear and distinct difference between a Right to Build and a Right to Own Property.

The right to build is regulated by the municipality, through the land use law. The proprietary may transfer this right to build to another person or to the municipality. Figure 2 shows a case in which the zones of cultural preservation and zones prone to flooding were defined as eligible for the transfer of the right to build. If the municipality deems the use of the transfer of the right to build adequate, the definition of the zones in which the owners may transfer the building potential and the zones that may receive it must be in municipality legislation.

This is being discussed by researchers and by the industries that develop land policy in Latin American cities, and it is a clear example of the importance of starting to see the city as an accumulation of 3D plots on which there is the intersection of private and public interests.

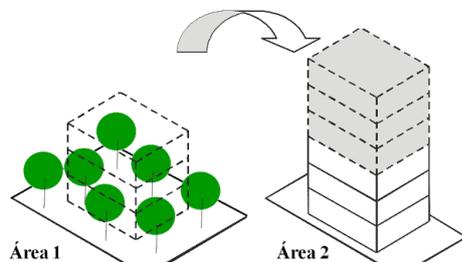


Figure 2. The municipality transfers the right to build from the owner of area 1 (under environmental protection), which then exerts this right in area 2 (Saboya, 2008)

2.2.3 Legal definition of 3D objects

The parcels are identified in both the cadastre and property registry by unit number based on an orthogonal projection. There is no three-dimensional graphic information. Besides apartment buildings, other cases of surface, subsoil and airspace occupation must be addressed by the cadastre and land registry given that, under the Civil Code, ownership covers spatially designated subsoil and airspace. The owner cannot object to activities performed by a third party at a height or depth without justification for preventing such use. However, the ownership does not include deposits, mines and other mineral resources, hydraulic energy potential, archaeological monuments and other property covered by special laws. These come under Federal jurisdiction and their use depends upon concessions.

2.2.4 Types of rights that can be registered in 3D

The right to property has a 3D connotation from its origins (in the Civil Code, as described in section 2.2.3), but its limits have always been described by 2D elements, due to limitations of the technology or its smaller relevance in the past. Today, the land scarcity and the complexity involved in its planning bring the need to also consider volumetric data. Traditional 2D registration has not been efficient in the correlation of spatial information, or in preventing conflicts of interest. In these cases, a 3D cadastre would have the ability to

advertise the differences of property rights and use of surface, airspace and subsoil. Among the situations that could be registered in 3D, we can identify the control of the air and underground space occupied by network infrastructures, mining rights and aeronautical and urbanistic restrictions of the current legislation.

2.2.5 Concluding remarks

The current situation of rural and urban cadastres in Brazil shows that many challenges remain to be overcome. Existing cadastres are still based on 2D data that is dispersed in different institutions under different standards, but the Brazilian cadastre is now undergoing significant legal and administrative reforms.

The first studies conducted in Brazil on the 3D Cadastre address technical issues involved in implementation (Souza, 2011; Holzschuh et al, 2009; Souza et al, 2009). Carneiro et al (2011) presented also legal and administrative issues, based on models proposed by Stoter (2004), and concluded that a 2D Cadastre with tags is suitable for immediate application in Brazil, especially because it does not require significant changes in the administrative and legal structure. On the other hand, 3D registry of physical objects can also be applied, since it highlights cadastre information above and below the land surface among the most urgent needs.

2.3 **Croatia**

2.3.1 Background

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. Parts of the land of a building and other structures permanently associated with the land, but legally partitioned by real property rights authorizing the owner to have this building or other structure on other’s property (building right), are also not.

2.3.2 Status

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. 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 alphanumerical 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.

2.3.3 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.

2.3.4 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.).

2.3.5 Concluding remarks

3D descriptions of land features currently are poor in Croatia. Particular parts of real property are registered in 2D diagrams with indication of the floor where they are located. One could consider this as a 2.5D approach (Fig. 3). 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. Goals of the new Law on Real Property Cadastre **Figure 3. Figure**

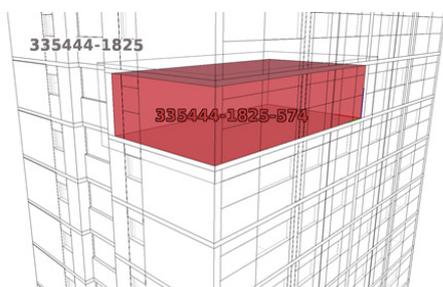


Figure 3. Example of the visualization of apartments

and State Survey, which is being prepared, are legal regulation of 3D cadastre in the Republic of Croatia (building cadastre - which is in the process of study making). Also the central repository of Utility cadastre under the authority of the State Geodetic Administration is on the bringing procedure.

2.4 Greece

2.4.1 Background

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 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, as presented below.

2.4.2 Legal Definition of 3D objects

Although real property objects with 3D characteristics are registered to the Hellenic Cadastre, such as horizontal and vertical ownership, mines, servitudes and Special Real Property Objects (SRPO), registration is limited on 2D land parcel. In case of underground antiquities or infrastructures, thematic cadastral projects have been established, e.g. the ongoing Archaeological Cadastre, or data is recorded by the agencies responsible for each utility.

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 in order 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), "syrmata" (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 4.

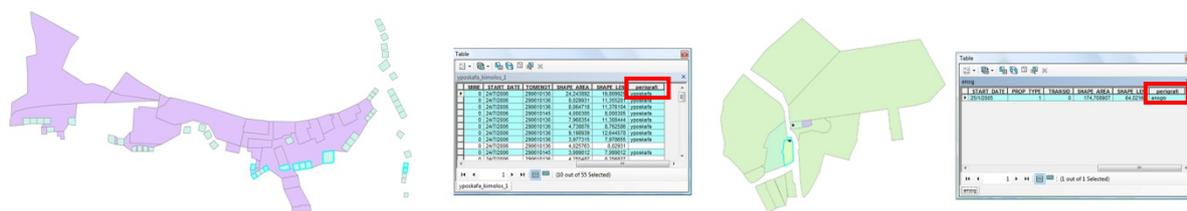


Figure 4. Presentation of "yposkafa" (left) and "anogeia" (right) on a cadastral map (in blue) and tags (red boxes) on a descriptive database. (Source: NCMA S.A. National Cadastre and Mapping Agency)

2.4.3 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) 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.

2.5 Poland

2.5.1 Background

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.

As said in Karabin (2011), 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.

2.5.2 Status

There is no 3D cadastre in Poland. Only some proposals from academic centers exist. Complex model for Poland was worked out by Karabin (2013; 2014). Karabin 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 5 left).

2.5.3 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: 1 - Potential building/constructing space right owned by the State or the Local Authority, 2 - Potential building/constructing space right owned by the parcel owner/s, 3 - Existing building owned by the parcel owner/s, 4 - Parcel owned by one or more private parties, 5 - Land space under the parcel owned by the State or the Local Authority.

Karabin (2013) proposed a small modification and considered the necessity of registration of the space owned by the State which will never be a subject of private ownership (for example space necessary for assurance of the air traffic, 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.

2.5.4 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,

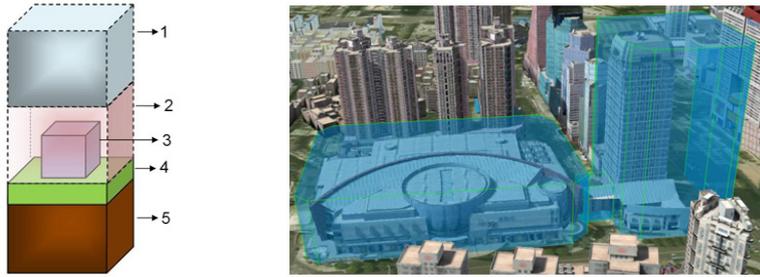


Figure 5. (left) The “layer” approach to the 3D cadastre (Source: Dimopoulou and Elia, 2012), (right) The structures visible in blue - the legal space of the 3D cadastral parcel. Space of construction in the form of a 3D city model (inside the legal space). (Source: Ying et al (2012))

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 5 (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).

2.6 Sweden

2.6.1 Background

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 in Sweden.

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.

2.6.2 Status

The concept of 3D property was introduced into the Swedish legislation in 2004 and expanded in 2009 by the addition of condominium (apartment) ownership. It 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 (El-Mekawy et al, 2014).

2.6.3 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 (Fig. 6). 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).

2.6.4 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 (El-Mekawy et al, 2014).

2.6.5 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 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.

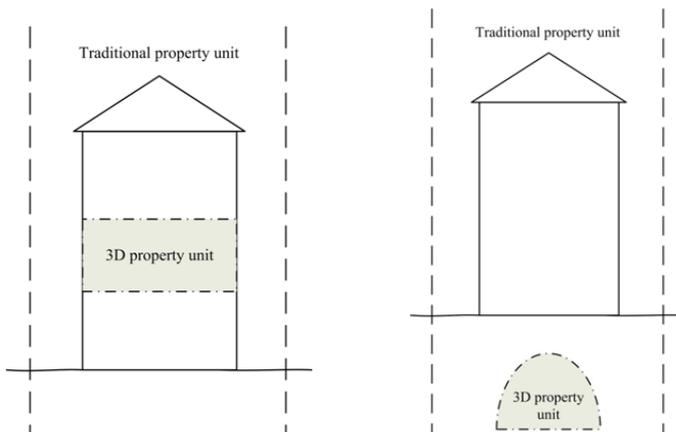


Figure 6. Principle of Swedish 3D property (Paulsson, 2012)

3. DISCUSSION AND CONCLUSIONS

3.1 Discussion

The case studies from the various countries have been a valuable tool for identifying and comparing issues of interest for legal concepts of 3D cadastres. They can be summarized in the tables below.

Table 1. Summary of national case studies

Country	Background	Status	Legal definition of 3D objects	Rights that can be registered in 3D
Austria	Long established cadastral system. Currently focuses on digitising analogue cadastral archive	Only 2D spatial restrictions registered	N/A (Does not apply)	No rights registered in 3D
Brazil	Non unified urban cadastre under municipalities' authority	The difference between building rights and ownership is highlighted	Parcels identification derives from unit number based on orthogonal projection	No rights registered in 3D
Croatia	Superficies solo cedit principle - parts of a building and other land associated features with temporary purpose not registered. Parts of a building and other structures permanently associated with land based on building rights are not registered	Registration of part of building ownership alphanumerically to Land Registry – Apartment ownership is a kind of 3D registry	Rights referring to use of limited space will be registered in land book on a 2D parcel registered in the cadastre.	Same as in 2D – Situational draft displaying position and elevation data on visible natural and built features
Greece	No 3D cadastre legislation although significant number of 3D real property objects	Significant number of laws regulating real property objects with 3D characteristics	N/A (Does not apply)	No rights registered in 3D
Poland	2D parcels registered	“Layers” approach is proposed for Polish 3D Cadastre	N/A (Does not apply)	No rights registered in 3D
Sweden	Complex RRRs on real property	3D Cadastre legislation since 2004 – Condominium legislation established since 2009	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

Table 1 above summarises information provided for each of the examined countries. Despite their, Civil Law origins each country is based on different background, reflecting both conceptual 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 and centralised systems to systems managed in 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.

Examining current status of 3D cadastral objects recording (Table 1, “Status” section), a number of differences in legal and organisational framework can be traced. Swedish operational 3D cadastral legislation constitutes a distinct category compared to the rest of 2D, Roman principles based legislation. 2D based real property recording applies to each of the examined countries, except from Sweden, while different issues are highlighted in each case, as following.

A kind of 3D registration of apartment ownership applies in Croatia and Poland, while the need of clarification between building rights and ownership is highlighted in Brazil; in Greece, a complex legal framework regulates real property which, combined with delays in completing the on-going Hellenic Cadastre, inhibits focus on 3D cadastral issues.

Legal definition of 3D objects also varies. Apart from the Swedish case where a precise 3D real property definition is used including also residence-purpose-based condominium, 2D definitions apply in all other countries. Real property objects are also 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. 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.

As for rights that are registered in 3D, except of Sweden where no limitation of 3D RRRs registration exists, none of the examined countries register RRRs in 3D, although, depending on each country's phase of 3D Cadastre legislation establishment, different concepts are considered.

From the case studies it is evident that the areas discussed in the legal framework working sessions at the 3D cadastre workshop in 2014 (Paasch, 2014) in which 3D legal research could be improved are still relevant. The workshop concluded that comparative studies on the use of 3D property concepts are a valuable input for understanding other legal systems and receive input for e.g. further development of one's own legal system(s). This paper has presented such comparative case studies which have shown the presence of issues still to be solved. As noticed, several such issues are reported as obstacles and discussion points when developing 3D cadastres in the studied countries. Questions concerning the status of 3D real property, the national legal definition of 3D objects and what types of rights that can be registered in 3D have briefly been shown.

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

Country	Existing 3D cadastral objects (registered or not)	3D cadastral objects (registered)	Presentation of 3D objects to cadastral map	Type of cadastral parcel (2D/3D)
Austria	Tunnels Condominiums Wine cellars	Tunnels ¹ Condominiums Wine cellars	2D	2D
Brazil	Surface occupation Subsoil occupation Air space occupation	Apartment buildings	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
Greece	Horizontal ownership/ condominium Vertical ownership Mines SRPO Utility servitudes	Horizontal ownership/ condominium Vertical ownership Mines SRPO Utility servitudes	2D ²	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 limitations 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 is used

³ Special symbology of 3D property units

All of the examined countries share the Roman principles' approach regarding real property, although legal definition of 3D property in each case varies significantly. Condominium concepts are mainly recognised as 3D property objects registered in almost every one of the examined countries (however in 2D), while in each one, separate objects with 3D characteristics (such as underground infrastructures and SRPO) are also recorded exploiting various techniques including unique identifiers and 3D tags. Issues such as real property recording in 3D, or management of cross boundary objects within cadastral databases, still remain unresolved. Furthermore, contradictions between the 3D property concept with constitutional stipulations of real property still need to be compromised.

Literature also provides research towards exploitation of Building Information Modelling technology to real estate (e.g. Clason, 2007; Quie and Ziao, 2014). In this study, use of BIM models is broadly applied in Sweden; El-Mekawy et al (2014) conclude that although BIM aims for other purposes except of 3D Cadastre, it can provide 3D information for building components. The rest of the examined countries do not statutorily require BIM models, while in most of them use of BIM technology is on primary stage and limited for construction modelling and not real estate purposes. Incorporation of countries that statutorily implement BIM solutions in real estate in similar future studies could contribute to clearer conclusions regarding influence of BIM technology to 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.

3.2 Conclusions

In the 4th International FIG 3D Cadastre Workshop, different interesting topics and approaches were discussed with examples from different countries. Even though most of the presented articles focused on proposed technical solutions for 3D cadastre and its related issues, the legal aspects were emphasized in the workshop. In addition to that, the legal aspects were discussed as main key players of the design and requirements for developing complete and real 3D cadastral information systems and applications. In this paper, we take the discussion further by emphasizing the role of the legal aspects as bases for developing legal cadastral systems that cope with the rapid development in the building industry, building information modelling (BIM) and geospatial information systems (e.g. GIS) for urban development.

Summarising the concepts of the exemplified case studies, 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. 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) 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.

Based on case studies analysis, it can be concluded that introduction of a 3D cadastral system would require re-defining real property in 3D space using unambiguous 3D terminology, the establishment of legal instruments to subdivide, consolidate and manage 3D real property in 3D space, 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.

4. FURTHER RESEARCH

Although researchers from many countries investigated the need for 3D documentation of RRRs in their countries, only a limited number of them already have a working 3D cadastre. The study presented the situation in six different countries but only the Swedish cadastre provides 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 sets if advance 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?
- How can a terminological framework/ontology for 3D cadastre be based on the international standard for land administration, LADM, ISO 19152?
- How can 3D cadastre be further the use of Building Information Modeling (BIM) and vice-versa?
- 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 six 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.

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