Initial Registration of 3D Parcels

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Key words: 3D Cadastre, Initial Registration, Data Source

SUMMARY

Registering the rights of a 3D parcel provides certainty of ownership, protection of rights and unambiguous spatial location. While not all cadastral jurisdictions in the world maintain a digital cadastral database, the concepts of such registration hold true regardless of whether it is a paper-based cadastre or a digital one. Similarly, the motivations and purpose for the creation of a 2D cadastre for individual jurisdictions applies for 3D cadastres as well. It provides a security of ownership of 3D parcel, protects the rights of the owners, and provides valuable financial instruments such as mortgage, collateral, valuation and taxation. The current life cycle of the development of a land parcel includes processes beginning from outside the cadastral registration sphere, such as zoning plans and permits, but has a direct impact on how a certain development application is processed. Thus, in considering the changes required to allow a jurisdiction to register 3D, it is important to note the sphere of influence that could have an impact on 3D registration. These include planners, notaries, surveyors, data managers and registrars; however for the purpose of this paper, the research is focused on the core 3D aspects that are institutional, legal and technical. This paper explores approaches and solutions towards the implementation of initial 3D cadastral registration, as derive by current procedures of registration of 3D parcels in various countries worldwide. To this purpose, the paper analyses the categorisations and approaches to 3D spatial units and examines the validation requirements (constraints) on a cadastral database, at various levels of maturity. In this view, 3D data storage and visualization issues are examined in relation to the level of complexity of various jurisdictions, as provided by the results of the country inventory combined with a worldwide survey in 2010 and updated in 2014 (Van Oosterom, et al, 2014). It seems that significant progress has been achieved in providing legal provisions for the registration of 3D cadastres in many countries and several have started to show 3D information on cadastral plans such as isometric views, vertical profiles or text environment to facilitate such data capture and registration. Moreover, as jurisdictions progress towards an implementation of 3D cadastres, much 3D data collected in other areas (BIM, IFC CityGML files, IndoorGML, InfraGML and LandXML) open up the possibility of creating 3D cadastral database combining the existing datasets. The usability, compatibility and portability of these datasets is a low cost solution to one of the costliest phases of the implementation of 3D cadastres, which is the initial 3D data capture.

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1. INTRODUCTION

1.1 Background

3D geoinformation is becoming increasingly important towards decision-making, land management and land development. Research has demonstrated the actual added value of 3D information over 2D in the cases of an overall more efficient integration of urban vs. regional planning and management, especially when dealing with 3D underground/aboveground infrastructures. Despite tha fact that there has been consistent research within geoinformation science (GISc) on the concept of 3D for more than a decade now, several potentially involved parties are still reluctant to invest in 3D data, 3D techniques, and applications. As a consequence, large administration processes relating to urban/ rural planning often run up financial losses simply because generic geoinformation is not part of the process (Stoter, 2011; Stoter et al, 2012).

A pertinent example of the above is what concerns property cadastre. Regardless of country, an up-to-date property cadastral system is fundamental for a sustainable development and environmental protection (Navratil and Frank, 2013; Stoter, 2011; Dale and McLaughlin, 1999). Current worldwide property cadastral registries mainly use 2D parcels to register ownerships rights, limited rights, and public law restrictions on land. In most cases this is sufficient to give clear information about the legal status of real estate. But in cases of multiple use of space, with stratified property rights in land, the traditional 2D cadastre is not able (or only in a limited way) to reflect geospatial information about those rights in the third dimension. As a matter of fact, the growing density of land use in urban context is increasing situations of vertical demarcation of property units.

In practical terms, issues stated above do really not refer to the need for simple 3D drawing or 3D visualisation capabilities of a stratified reality. The issue dwells in the linkage between two models: a conceptual one and a physical one. In other words, the real difficulty is the materialisation of the legal object (a 3D conceptual body) by linking it to its corresponding physical object (in a 2D or a 3D geometric/topologic structure).

1.2 The need for 3D parcel registration

Most modern cadastres register ownership and location details in the land register and therefore 3D registration is intrinsic to many of them. The concept of 2D parcels considered as a 3D column of rights has been around for a long time now. There are however specific extrinsic capabilities of a cadastral system that need to be fully or partially fulfilled so that it can be considered a 3D cadastral system.

The primary capacity for a 3D cadastral system is to be able to register space as a separate entity within the cadastral system. It is not an implicit 3D column of rights but rather an explicit registration of 3D spatial object. The 3D spatial object itself can be a physical 3D structure, an envelope of the physical 3D structure, a slice of rights above or below the surface that in turn may or may not be contiguous to any land or other 3D spatial parcels. In all cases, the main aims to be achieved in implementing a 3D cadastral model comprise the adoption (Khoo, 2012):

- to an official and authoritative source of 3D cadastral survey information,
- to open source format for data exchange and dissemination, and
- to international standards in data modelling.

The design of a smart data model that supports 3D parcels (the spatial unit against which one or more homogeneous and unique rights, onus or restrictions are associated to the whole entity, as included in a Land Administration system ISO/TC21 19152, 2012), the automation of cadastral survey data processing and official approval, as well as the integration of the temporal dimension either as separate attributes or via truly integrated 4D spatio-temporal geometry/ topology, may be also prerequisites in this process.

As these cadastral systems progress towards a maturity model of 3D implementation, the complexity of allowed geometric features and the capacity of the system to accommodate these complexities grow too. It thus becomes the responsibility of the cadastral jurisdiction to provide the institutional and legislative framework to facilitate the registration of 3D parcels and to provide the tools for land professionals to record and display 3D cadastral data within the provided framework.

In a 2D cadastre, the basic registration involves person, parcel and rights. Similarly, in a 3D cadastre, the simplest implementation should be able to register these, however, complexities arise when the 3D parcels are geometrically complex and the 3D rights are not clearly defined by legislation. In Shenzhen, pure 3D space (parking and commercial shop) are planned, granted and registered along with their easement to pass to the ground. In Queensland, any shape of the parcel geometry has been allowed on paper plans as long as it can be defined mathematically, while the registration of these parcels are treated as equivalent to 2D and ownership records are thus stored within the same titling system.

Registering the rights of a 3D parcel provides certainty of ownership, protection of rights and unambiguous spatial location. While not all cadastral jurisdictions in the world maintain a digital cadastral database, the concepts of such registration hold true regardless of whether it is a paper-based cadastre or a digital one. Similarly, the motivations and purpose for the creation of a 2D cadastre for individual jurisdictions hold true for 3D cadastre as well. It provides a security of ownership of 3D parcel, protects the rights of the owners, and provides valuable financial instruments such as mortgage, collateral, valuation and taxation. Owners of such 3D property have rights that are important enough for the jurisdictions to consider a further investment towards the modification of their cadastral systems to accommodate the current market push towards 3D cadastre.

The current life cycle of the development of a parcel of land includes processes beginning from outside the cadastral registration sphere such as zoning plans and permits, but has a direct impact on how a certain development application is processed. Thus, in considering the changes required to allow a jurisdiction to register 3D, it is important to note the sphere of influence that could have an impact on 3D registration. These include planners, surveyors, data management and the registrars, however for the purpose of this paper; the discussions are focused on the core 3D aspects that are institutional, legal and technical issues. Thus, the questions that need answering are among others:

- What makes a 3D cadastre? What do we register? Why do we register?
- What are the current procedures and what can be modified to adopt 3D?
- Whose responsibility is it? Who can assist with the registration?
- What are the technical challenges in data acquisition, validation, submission, processing, discovery, dissemination and utilisation?
- What are the benefits? What are the current trends?

Finally, albeit 3D cadastre has been attracting researchers throughout the world for nearly a decade now to better register and spatially represent real world overlapping situations, 3D cadastral technology is only now emerging. Some pilot studies have been accomplished so far and several authors have demonstrated that 3D representations of airspace and subterranean parcels are indeed currently required for 2D+half representations are unable to handle 3D measurements or 3D spatial queries (including, El-Mekawy et al, 2014; Karabin, 2014; Abdul-Rahman et al, 2012; Khoo, 2012; Soon, 2012; Stoter et al, 2012; Wang et al, 2012; Ying et al, 2012; Zhao et al, 2012; Abdul-Rahman et al, 2011; van Oosterom et al, 2011; Hassan et al, 2010; Chong, 2006; Stoter and van Oosterom, 2006; Valstad, 2005; Stoter, 2004; Stoter et al, 2004).

2. CURRENT STATUS OF 3D REGISTRATION

2.1 Inventory of the current procedures and workflows of registration of 3D parcels in various countries

In this section, a short report of the current procedures and workflows of registration of 3D parcels in various countries is provided:

2.1.1 Portugal's case

As far as Portugal is concerned, a prototype of a centralised distributed cadastral management system, implementing a 2D approach, has been conceived: the so-called SiNErGIC (PCM 2006). This in turn will be the basis of SNIC, the national cadastral information system. Its technical implementation is however far from being concluded due to a major issue: geospatial data capture in the field has revealed to be an endless task for it is laborious and expensive. The first official step towards the establishment of a national registry of land parcels in Portugal was taken back in 1801. Clearly stating how authorities were aware in those days of the great value of a measured coordinate-based cadastre, cosmographers (One who studies, describes, depicts, and measures the Earth and/or the visible universe, including geography and astronomy) were the practitioners of those days appointed by royal decree to be in charge of the organisation of both "a cadastre and a general registry book of real estates within the kingdom". For several reasons, such registry was never launched though until 1836, when the national real estate registry (the "Registo Predial", see Figure 1) actually started being implemented (Silva et al, 2005). However, it was not until 1926 that coordinated cadastre surveys were actually carried out. Given Portugal's territory tissue, with a few millions of small real estates scattered across a rather irregular topography, fieldwork has revealed to be a rather complex and demanding operation and has not covered the whole country yet. Coordinated cadastre surveys are currently being accomplished district-by-district covering both kinds of real estates, rural and urban (Figure 1). By the end of 2014 more than 50% of the mainland's territory had been surveyed, though this only corresponds to roughly 1/3 of the total number of properties in the country.

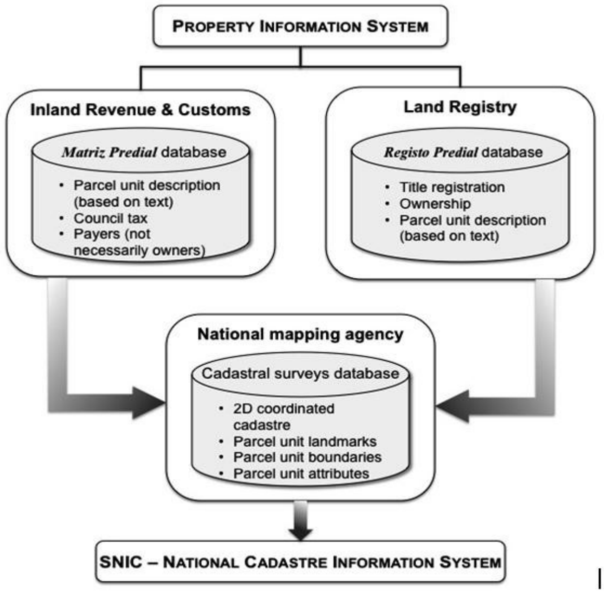

Figure 1. Overview of the current property information system in Portugal

2.1.2 Trinidad and Tobago's case

The cadastre in Trinidad and Tobago is currently incomplete and out of date. Digital data exists as shown in Figure 2 but thousands of plans have been scanned but not yet added to the cadastre. Cadastral survey plans continue to be submitted in hardcopy and this further restricts the speed of updating of the cadastre. The cadastre is a digital index of uncoordinated surveys that provides information on the location of the field survey plans. However, because of the cadastre's lack of currency, searches for information can become frustrating or, at worst, futile. There is no unique parcel identifier that can assist with this search and addresses are non-standardised although a new initiative is attempting to rectify this latter issue with a proposed zip coding. Parcels are defined and redefined relative to the surrounding parcels and their boundaries, which are marked at the turns by boundary irons. Coordinates, therefore, have no legal standing.

There are no immediate plans to upgrade the existing 2D cadastre to a 3D cadastre as there is much rationalisation of the existing data to perform first. In the meantime, strata (condominium) rights are indicated in vertical sections in insets on the 2D cadastral plans (see Figure 3), and subsurface reserves and mining rights are shown on 2D plans related to the surface parcels. No elevations are recorded on these plans to a standard datum but heights relative to the ground can be included in the vertical sections. The graphical cadastre is also not linked to the deed and title information on interests that is located at the legal registry of the Registrar General's Office. Rights, restrictions and responsibilities are therefore not graphically displayed in the cadastre. Urban and regional development plans are held at a separate state institution are approximate in definition of extent, and are not linked to the cadastre. The majority of registered interests are deeds based with a small minority being supported by title registration. While all title documents refer to or contain a graphical description of the parcel in a survey plan, many deeds that date back several decades do not contain a survey plan but a verbal description of the parcel referring to adjoiners who no longer exist. A new project is in progress to upgrade the Cadastral Management Information System (CMIS) which includes the procedure for receiving new cadastral plans, checking and approving them, and entering them on the database. As part of this project new software will be installed that is anticipated to speed up the maintenance of the cadastre, however the limited human resource is still an issue that can restrict this progress.

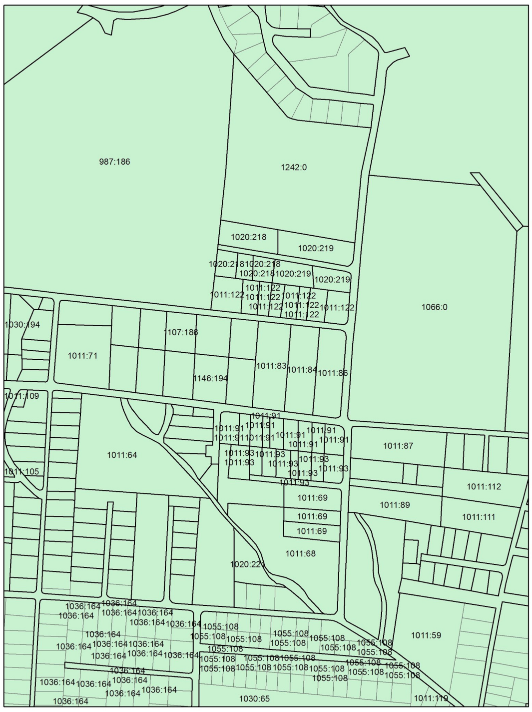

Figure 2. Trinidad and Tobago's digital 2D cadastre

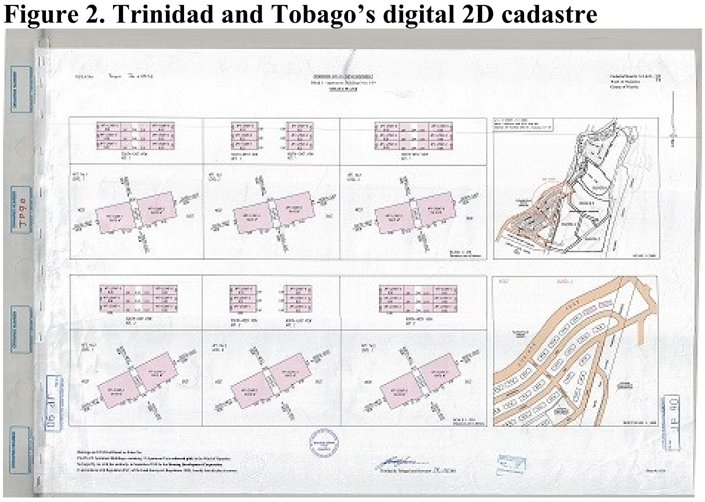

Figure 3. Vertical sections on survey plans depict 3D rights

2.1.3 Greece's case

The ongoing Hellenic Cadastre (HC) Project aims at replacing the existing Registration and Mortgage Offices by an integrated information system that records legal, technical and other data about real estate properties, along with the rights and restrictions on them. These property data and registrable rights are collected during the "cadastral survey" procedure; each person or legal entity that has rights to specific land parcel in the area under surveying, is invited to submit declaration for its real properties while depicting them on cadastral diagrams. The declaration form also includes the geographical description of the properties (shape, location and size) and information about deeds that establish or change rights on real estate properties. Current administrative source documents are deed based, although after completion of the HC project, title based registration will be implemented.

The current digital cadastral database (DCDB) includes all information collected during the cadastral survey and is organized into descriptive and spatial part, comprising administrative divisions, land-parcels, buildings (only the building footprint is presented on the cadastral maps), mines, sites of exclusive use, easements, true-orthophotos, DSM, topographic drawings, as well as beneficiaries, registered rights, titles etc. The DCDB does not contain representation of 3D parcels, although a separate layer will be used to incorporate objects with 3D aspects.

In Greece, almost all 3D parcels (3D spatial units in LADM terminology) are constrained to be within one surface 2D parcel, with limited exceptions described in the Greek Civil Code. They usually relate to physical objects with some exceptions providing for encroachments or the right of superficies and of course the Special Real Property Objects (SRPOs), underground parking lots and potential floors that do not related to physical object. Disconnected parts of a single 3D parcel are only allowed in case of condominium. Concerning spatial limitation of 3D parcels, Greek C.C. stipulates that ownership extends above and below the surface, however the landowner cannot object unless he has practical interest in opposing to it. Limitations on the range of rights related to 3D spatial units exist only in case of lands where ancient antiquities are discovered, mines and rights of superficies. Legislation for 3D descriptions of parcels includes Horizontal Property Law 3741/1929, Civil Code Articles 1001, 1002, 1010 and Law 3986/2011. For natural resources (groundwater, mining rights), the Law regulating cadastral operation stipulates recording of mining rights but not as 3D parcels, while infrastructure and utility networks' registration as an entity is not operational.

Apartment units in condominium schemes are the most important types of registered 3D building units, in accordance to the Horizontal Property Law, and their 3D boundaries are the middle of floors, walls and ceilings. Common property inside the building is commonly owned by the apartment owners and is not directly registered in the Cadastre. Each apartment gets a unique cadastral number specified in terms of building lot code, parcel number, building code, floor and apartment code. Apartments are described in deeds and the building's footprint as drawing, submitted in paper format or electronically. Dimensions are shown on survey plans. No provision of isometric views, nor stored in the DCDB.

For the geometrical representation of 3D spatial units, plans of survey guarantee x/y coordinates in relation to the Greek national reference system (HGRS87), while older plans in older or arbitrary systems may also exist. Height representation is referenced to the Greek national system, although z coordinates are not stored in the DCDB. The earth surface (height) is not stored in the DCDB, although there are DTMs and DEMs available in the NCMA and the Hellenic Military Geography Service (HMGS). The sources of elevation for the 2D surface parcel are trigonometric points of principle reference network even as in most cases, elevation source is arbitrarily defined. Survey plans do not carry 3D parcel representation, though in recent plans, point heights are included. The legislation describing the requirements for plans of survey in 3D only includes regulations for height recording but there is no provision for 3D. SRPO are registered as dwg at a different layer. 3D property entities (condominium, mines, SRPO) are registered to the 2D DCDB. Specific symbols are used to depict presence of 3D cadastral objects (in case of SRPO) on the 2D cadastral map.

According to the competent authority (National Cadastre and Mapping Agency -NCMA), so far, the HC is operational for 20% of real estate rights through 103 Registry Offices while cadastral surveying is in progress for another 20% and tendering procedures are running for the rest 40% of them (Rokos, 2014), based on IT infrastructure and digital orthophotomaps' national coverage. Therefore, the HC has still a lot to do to reach its goals and adequately address issues that relate to 3D registration and representation of cadastral data.

2.1.4 Croatia's case

Land Administration System in Croatia consists of two fundamental registers (Cadastre and Land Book). The description of the land/property as information for property sheet A of the Land Book is registered in the Cadastre. For registered property, rights and charges are recorded in sheets B and C. The Cadastre was created for the entire Croatian territory in the 19th century as a part of the Austro-Hungarian Francis survey. Until 1880 the documentation, cadastral plan and lists of holders for all cadastral municipalities have been produced. Cadastre was created for the purpose of fair taxation of land. It was maintained in accordance with the regulations and was changing according to political changes since its establishment. The main purpose, the calculation of land tax was retained until 1995, when such land taxation was abolished. At that point the cadastre lost its tax purposes, and became increasingly used for legal purposes.

After the establishment of the Cadastre in the late 19th century, judicial authorities have established Land Book based on the description of the land (information on the cadastral parcels). Land description (number and other attributes of cadastral parcels) was marked in the sheet A, for each cadastral parcel the owner was registered in the sheet B, and charges in the sheet C. Unfortunately, changes in social and political arrangements violated the consistency of these two registers. Today, the registered data does not correspond to the real situation for considerable number of land parcels. Bringing these two register up to date is the greatest challenge for Land Administration System in Croatia.

Changes in the Land Tenure system, which radically changed in 1990's when Croatia declared independence and left the socialist political system, have significantly contributed to inconsistencies. Under the socialist system two types of ownership existed, private and social. The latter one was preferred. Various political actions (nationalization ...) tried to make as much land/property become social. After independence only one form of ownership was introduced. Social ownership was abolished by regulations, and private owners were determined depending on the situation. The principle "superficies solo cedit" was reintroduced. That significantly influenced registrations in Land Administration System. In accordance with that principle, everything connected with land (buildings, trees, etc.), above or below the Earth's surface, is one property, respecting a functional approach rather than "vertical" (Roić, 2012).

Since 2010 all cadastral and Land Book data are in the electronic form, but they are in different models and databases maintained by various software. The establishment of the Joint Information System which provides integrated management of Cadastre and Land Book is in progress. The system has been established, and data migration should be completed by the end of 2015. This should enable coordinated functioning of those two registers and uniform handling which was not the case in the past. JIS is designed as a central repository of data. Access for data maintenance and viewing is provided by a web client. Officers, depending on the role can modify data, and external users have view access only.

Property description in the registers is based on a two-dimensional representation from the cadastral map which does not allow the registration of interests in strata. Implicitly, the legal unity of the property indicates the legal objects that belongs to individual (co)owner. Registration of separate parts of property (apartment, office space) was regulated in 1997. Production of documentation with a spatial representation (2.5D) of separate parts of the whole property is prescribed for buildings. The documentation determines the co-ownership share of each owner in the entire property with the presentation of common parts (Figure x). Plans of the parts of property are in the local system (building) without absolute Z coordinates. It is also used for the allocation of costs for management and maintenance of the property. Documentation for registration and registration are regularly made for new buildings and are rare for those built before 1997 (Vučić at al. 2013).

In addition to Real Property Cadastre in Croatia, there is also the Utility Cadastre. The Utility Cadastre is a register of technical features of public utility infrastructure having no legal impact. Legal relations regarding utilities are registered in Land Book, in practice very rarely, as an easement right on land where these infrastructure are placed.

Apart from the possibility of registration of private rights in the strata, the registration of legal regimes (maritime good, protected areas, by spatial planning defined land use etc.) is foreseen in the Real Property Cadastre since 1999. That and the registration of public utility infrastructure should give users a more complete description of the interests that exist on a particular land. For now, the registration of public rights is in its beginning. Legislation and data model of Joint Information System don't yet foresee spatial representation in 3D, and it is not possible to store the 3D geometry of 3D legal objects. Also Utility Cadastre is not in electronic form and not part of JIS. Therefore, it still cannot be combined with the Real Property Cadastre.

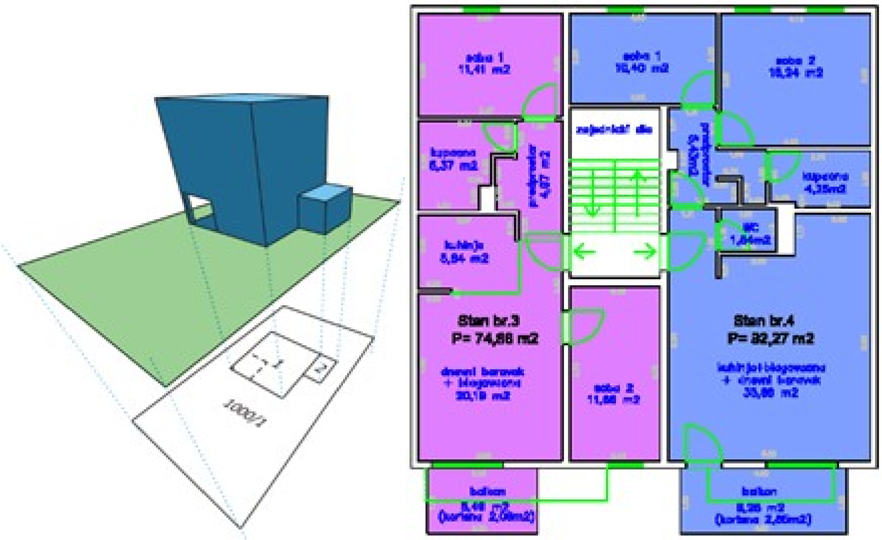

Figure 4. Property on the cadastral map and presentation of parts (separate and common) per floor

2.1.5 China's case

The establishment of 3D cadastre needs legal support. China has our own property system with specific characters. According to China law, all the lands are owned by the country, and the government on behalf of the nation to manage them. Any party or citizen, except the government, only have the usufruct or the use right of the land through public auction, land transaction or land assignment. Land and space management is strongly relevant to land and house, and generally, there are at least two branches (ministries or departments) to take charge of the land and the house. However, there is only one municipality to response the land, house, urban planning, surveying and map, geology and sea. That means, almost all the resource related to geographic space are united by one department, which provide the potential feasibility to implement full space planning and management. In China, Shenzhen, a high developed city from a small village during 30 years, is facing huge challenges of 3D space development and use. The first pure underground 3D pace was sold in 2005 and was granted with certificates, separating from the land on its surface. It was the first case in China .That 3D space is a special commercial street named Fengshengding under the main Shennan Boulevard' in Shenzhen city. There is a need for a bazaar for intensifying retails in this area where no any land on the ground is available to build a bazaar. Instead, this overall bazaar is designed under the main avenue for two layers and its total built area is about 24km2. Each layer can accommodate a lot of small stores along its pavement within such the construction. Figure below shows the use of land space under the ground, and from then, yo satisfy these requirements, Shenzhen municipality put forward a 3D cadastral management to support full processes of 3D land/space management.

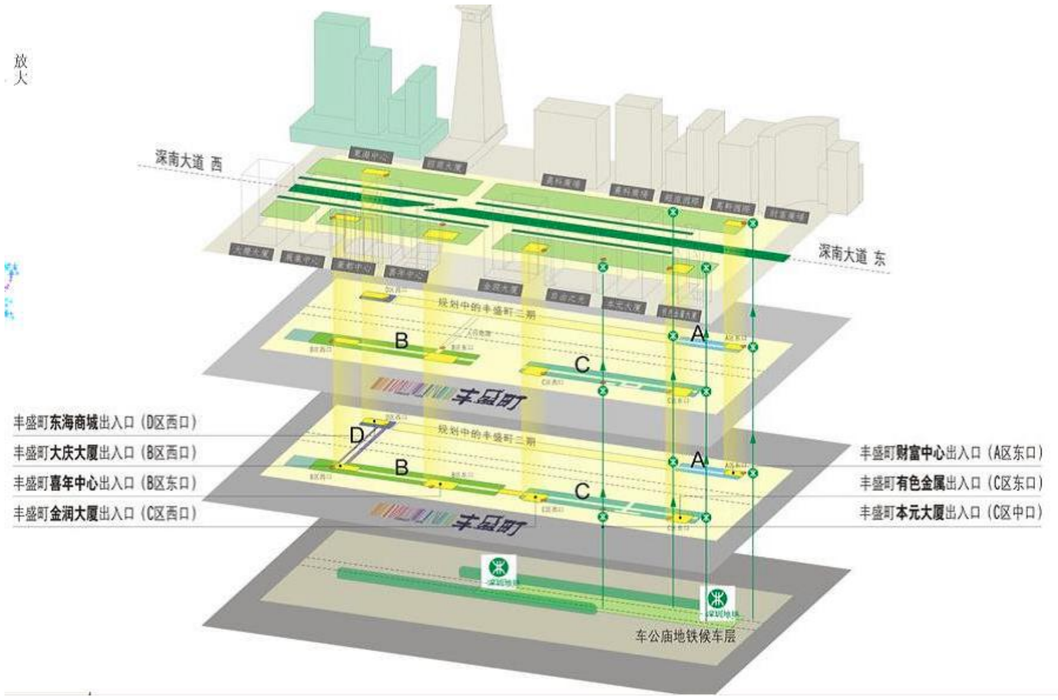

Figure 5. 3D land use of pure 3D underground space

The Interim Regulation on Real Estate Registration was enforced in 2007 and the 136th article points out that the use right of construction land may be created separately on the surface or above or under the land. It provides the legal foundation for 3D Cadastre.

In 2007, there is a case on a real 3D parcel with multiple jurisdiction in the Shenzhen Bay Port (Guo, Ying et al, 2011), which is regulated by Shenzhen government and by Hong Kong government. The party of Hong Kong is involved to register the new legal status of a 3D part in the area at the Shenzhen side (as Figure shows). Although Shenzhen and Hong Kong are all unified in P.R. China, they enforce different legal systems, which results in the particularity of this area. This special case illustrates that multiple land administration jurisdictions can be imposed on the same 3D cadastral objects as corresponding rights, responsibilities and restrictions taken by corresponding parties.

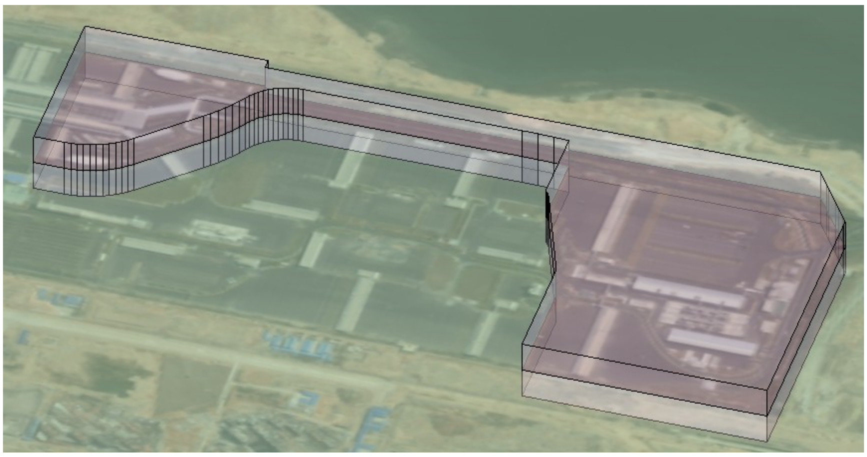

Figure 6. 3D space with multiple jurisdictions in Shenzhen Bay Port area

In order to satisfy the rapid need of 3D space in Shenzhen, in 2012, Shenzhen Municipal People's Congress revised the law "Shenzhen special economic zone real estate registration ordinance", to support the auction, transaction, grant and certificate of 3D space. During the Third International Workshop of 3D Cadastre, the online automatic office system of Urban Planning, Land and Resources Commission of Shenzhen Municipality are demonstrated on the air to illustrate the support the workflow of 3D land space planning and management. From the first pure 3D space granted in 2005, Shenzhen Municipal Government have handled more than 8 hundreds cases in 3D land planning, granting and registering, totally with more than 1500 km2with vertical projective areas. (Guo and Luo et al, 2014). These 3D space applications and practices include the subway, underground garages or shop center, arcade, etc. A new zone named 'Qianhai', from the start of zero, the empty sea region, has been enforced to plan, construct, management and use in fully 3D from the beginning, and this will completely promote the application of 3D planning and 3D cadastre.

2.1.6 The Netherlands's case

The design and implementation of the cadastral system extension for registration of 3D rights and restrictions in the Netherlands (Stoter et al 2013) is fitting within the ISO 19152, Land Administration Domain Model (LADM) international standard. The implementation is conducted in two phases. The first phase of the solution did not require a change of the legal and cadastral frameworks, it is a short term solution for most urgent cases, and it is also used to gain experience in the challenging domain of 3D cadastre. In the first half of 2016 the first actual 3D Parcels were registered at the Netherlands Cadastre (after many years of research)[1]. This procedure to improves the registration and it includes an extension of the cadastral system to accept 3D descriptions in 3D pdf format as part of the deed. This solution improves the 'old practice', where the multi-level property situations are projected on the plane and with the potential consequence is that the ground parcel(s) will be subdivided based on those projections. The resulting fragmentation in the registration was in several cases quite unclear because many small parcels may be necessary to register one single object (Stoter et al 2013).

The first phase of 3D cadastre implementation exploits one of the LADM conceptual modelling options, more specifically association LA_SpatialUnit with a 3D drawing (LA_SpatialSource, playing the role of a sketch). The solution fits within current cadastral and legal frameworks and could therefore be implemented within a short time frame. In fact the major breakthrough is that the option to register a digital 3D drawing (possibly legally binding) will actually be practiced (by training/ involving stakeholders, notary, project developers, municipalities, etc.). In addition, because the 3D drawing provides insight into the spatial dimensions of the right, new 2D parcels do not need to be created to delineate the exact boundaries of the 3D property on the ground parcel and creation of fragmented parcels can be avoided. The information required in the 3D representation to understand the multi-level property situation are identified as follows: 2D ground parcels that overlap (and footprint of 3D legal Volumes), 3D (graphical) description of legal space, 2D cross sections with accompanying annotations (for apartments), objects needed for reference and orientation in the 3D environment (3D topography/ buildings, same as for the 2D Cadastre), and localise the

[1] The pdf can be obtained from: https://www.kadaster.nl/web/artikel/download/Nieuw-Downloadpagina-24.htm and https://www.kadaster.nl/web/Nieuws/Nieuwsberichten/Bericht/Wereldprimeur-inschrijving-met-rechten-in-3D-1.htm

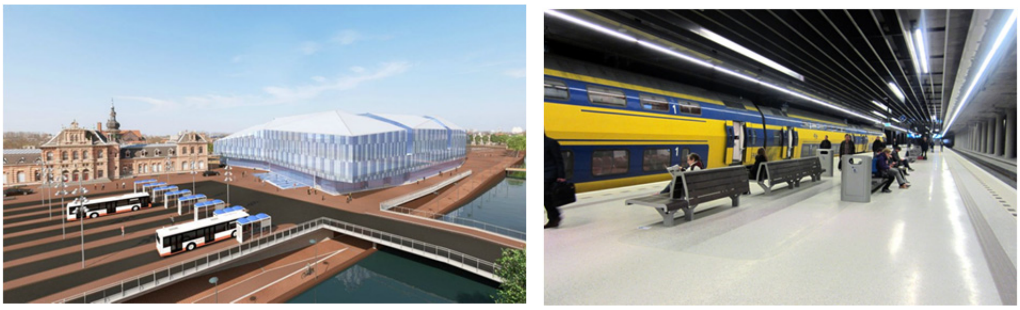

Figure 7. Impression of the 'Spoorzone Delft' project

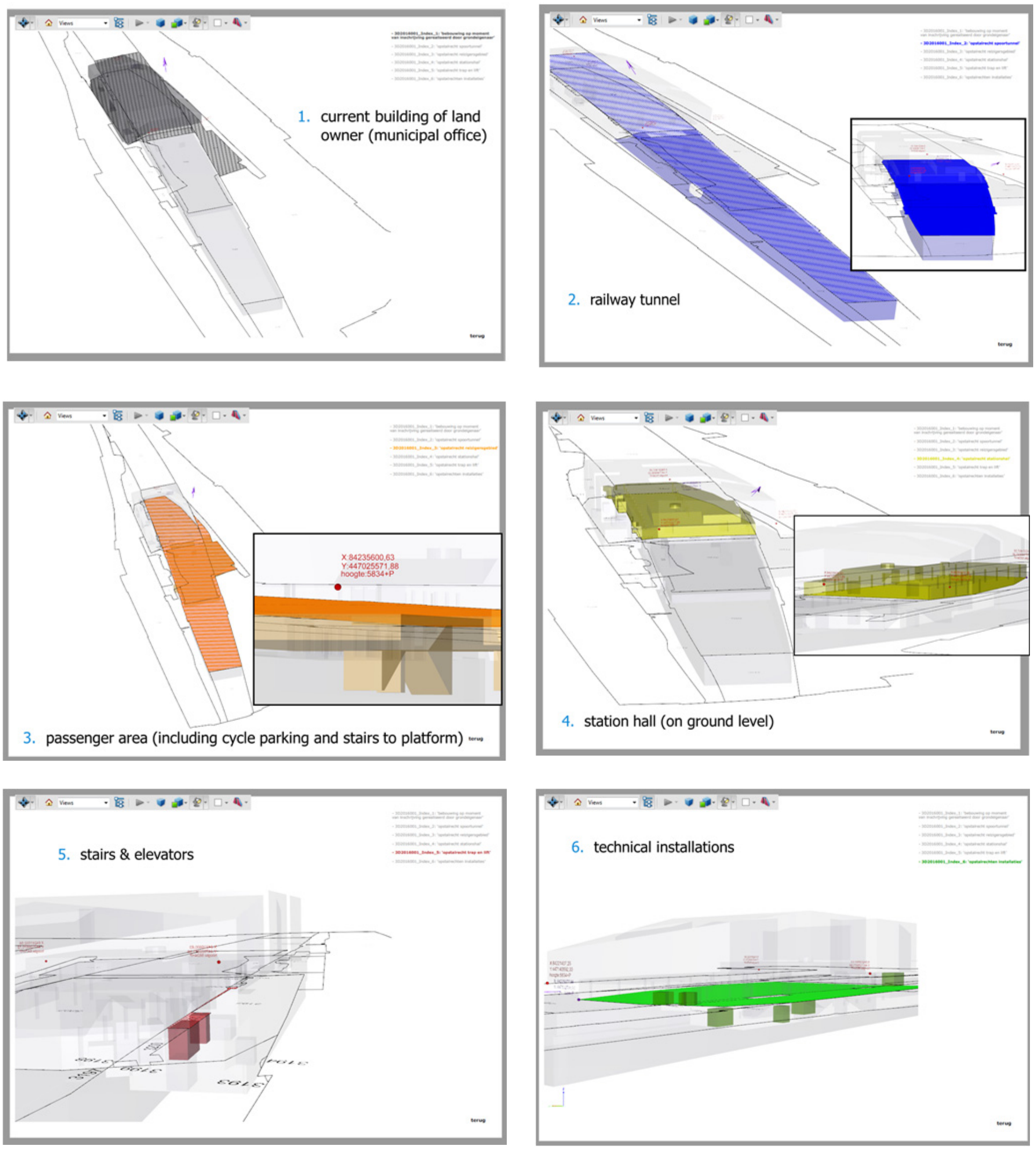

Figure 8. The six legal volumes described in the 3D pdf in land register

3D legal volume in both a local coordinate system and the national height datum system. The first registration (Stoter et al, 2016) concerns the 'Spoorzone Delft' project (see Figure 7 above) and includes six legal volumes described in the 3D pdf in land register (see Figure 8 above):

1. current building of land owner (municipal office)
2. railway tunnel
3. passenger area (including cycle parking and stairs to platform)
4. station hall (on ground level)
5. stairs & elevators
6. technical installations

The various owners (holders of rights involved) are Delft municipality, NS Vastgoed, and Railinfratrust.

One of the drawbacks of this solution is that it is not possible to validate the 3D cadastral representations (Are the volumes closed? Are the neighbors non-overlapping?) The second phase is research in progress and comprises the actual inclusion of the 3D data in the registration, enabling complete validation and even better 3D data management and dissemination. Based on experiences to be collected from the first phase and experiences from other countries, the solution for the second phase will be further refined and subsequently implemented in due time.

2.2 Analysis of categorisations of and approaches to 3D spatial units

More detail on the classes of 3D spatial units can be found in (Thompson et al, 2015). The following is a summary. The first major division of spatial units is between:
2D Spatial Unit: The spatial unit is completely defined by the 2D location of points (x/y or latitude/longitude) along its boundary. This type of spatial unit is in effect a prism of space unbounded above and below. If a point (x, y, z) is within the spatial unit, then (x, y, z') is also within the spatial unit. There may be restrictions on the allowable value of z', but there is no explicitly defined "top" or "bottom" of the spatial unit (Figure 9a).
Building Format Unit: This spatial unit is legally defined by the structure of the building that contains the unit. It may be defined to the outside of walls, or to the middle of walls etc. There may or may not be a diagram of the unit, but any measurements on the plan are not normative (Figure 9b).

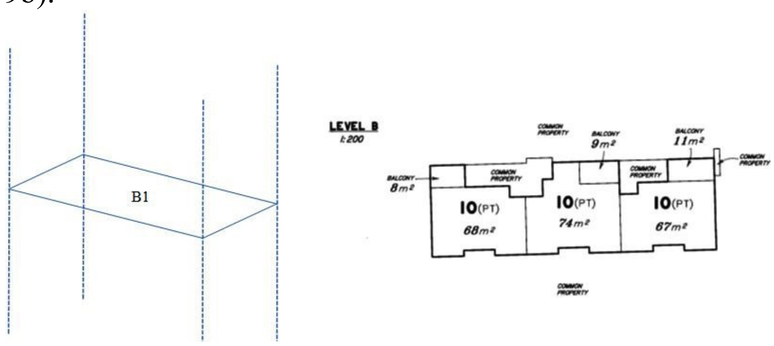

Figure 9. a (left) 2D spatial unit b (right)/spatial units defined by the structure (the buildings walls)

3D Spatial Unit: This spatial unit is defined by a set of bounding faces, which are themselves defined by a set of 3D points and an interpretation. For example, a set of planar faces, cylindrical faces etc. There are many variations, including whether the boundaries are defined by natural features or fiat (Smith, 1994) lines, how they are fixed, what datum is used etc.
Within the set of 3D Spatial Units, there are several categories:

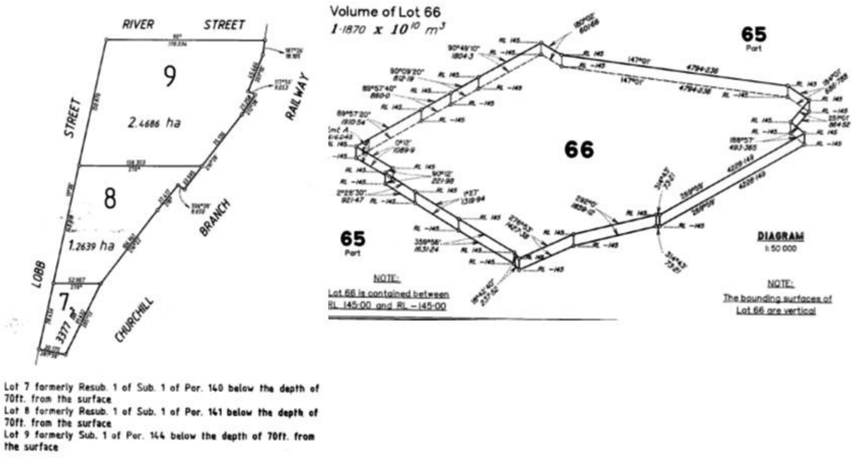

Figure 10. a (left) Below the depth of spatial units b (right) A (very large) simple slice

Above/Below Depth or Height: These are commonly used in mining areas, but could also be used to limit building heights - for example near airports / transmission towers etc. These are simply 2D Spatial Units with a height restriction (Figure 10a, above).
Polygonal Slice: This is the most common form of 3D spatial unit. It is in effect a 2D spatial unit, with a defined top and bottom. It can also be considered to be an extruded polygon (Figure 10b, above). As with the 2D Spatial Units, these can be defined in terms of natural features. For example, a Spatial Unit could be defined as extending to 100m below ground level.

Single-Valued Stepped Slice: (Figure 11a) This is also a fairly common 3D Spatial Unit. It can be viewed as the union of a number of Polygonal Slices so that for every point (x,y,z) in the interior of the Spatial Unit, there is exists z_{max}, z_{min} such that $z_{min} < z < z_{max}$ Þ (x,y,z) is interior to the spatial unit. These spatial units can be quite complex.
Multi-Valued Stepped Slice: (Figure 11b) This is a Spatial Unit whose boundary faces are all either horizontal or vertical.
General 3D Spatial Units: (Figure 12) This is the “catch-all” of spatial units, which fail to fit in one of the above categories. These can be difficult to store or visualise, but tend to be relatively few in number.

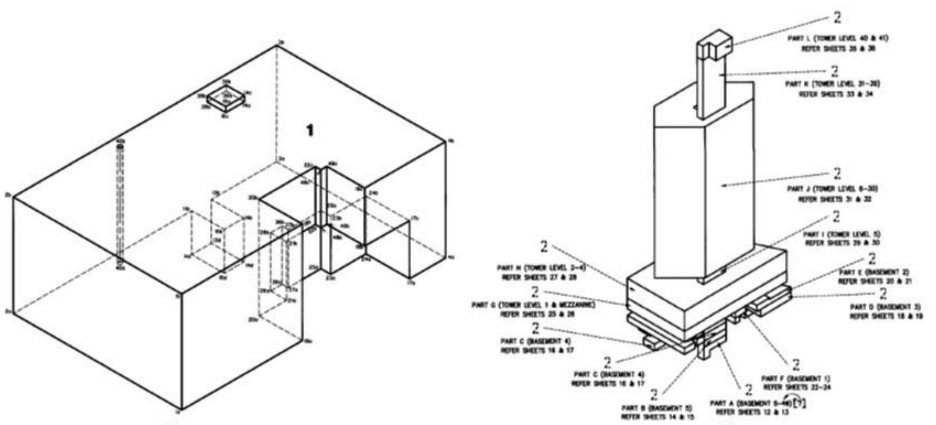

Figure 11. a (left) a single-valued stepped slice b (right) a multi-valued stepped slice

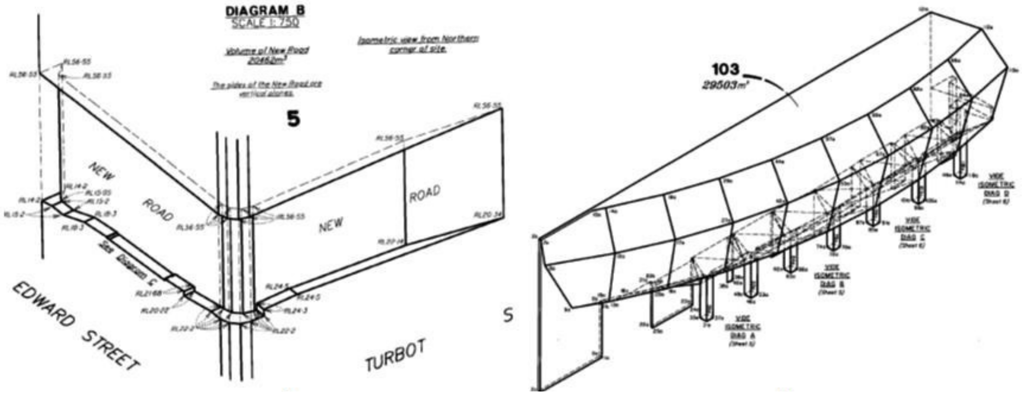

Figure 12. Some general 3D spatial units

There is also the very important Balance Spatial Unit. This can be of any complexity as above, but represents the remainder of a 2D spatial unit when all the 3D spatial units defined within it have been excised (Figure 13).

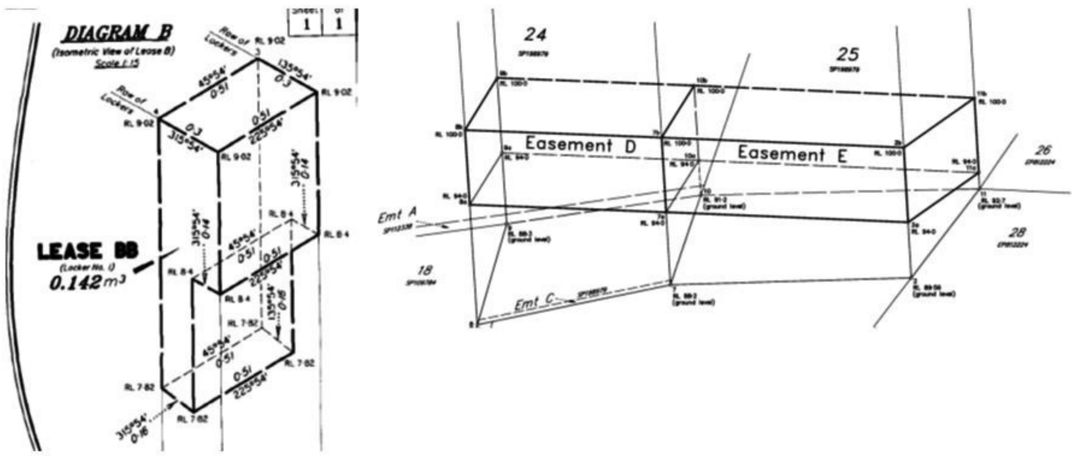

Figure 13. a (left) a small lot excised from a much larger 2D spatial unit (a golf course) b (right) 3D easement within 2D parcel (but this is not excised)

Constraints (validation requirements) on a cadastral database can be at various levels of maturity:

Non-overlapping 2D spatial units: In all cases, there seems to be an underlying requirement that a 2D "base cadastre" should be identifiable. This should allow the range of the jurisdiction to be defined by a set of non-overlapping 2D spatial units.

Complete non-overlapping 2D: In many cases this coverage is also required to be complete. (I.e. every point in the jurisdiction must belong to one and only one base 2D spatial unit).

Non-base 2D spatial units: Frequently, there is a requirement to define a non-base spatial unit that represents a secondary interest in part or all of a base spatial unit. (e.g. the right to traverse land). Thus a non-base spatial unit may overlap one or more base spatial units, and one or more other non-base spatial units.

3D spatial units represented as footprints: The next level of sophistication is to carry all 3D spatial units in the cadastral database as "footprints". Here a 2D "flattened" representation of the spatial unit is stored as if it were a secondary interest over the base (2D) spatial unit. The term "footprint" is slightly confusing, because what is stored is usually the projection

(“shadow”) of the spatial unit to the base level rather than the foot of the parcel at ground level.
Simple 3D as extruded polygons: There is very little extra complexity to attribute the “footprints” of 3D spatial units with a minimum and/or maximum elevation. This will allow a correct representation of simple 3D spatial units (such as slices), or an approximation of any 3D spatial unit. Even such an approximation may be sufficient to ensure separation between parcels.
Non-overlapping 3D coverage: One important aspect of a 3D cadastral database is to ensure that overlap of 3D spatial units is prevented (as is the case with the 2D coverage).
Complete non-overlapping in 3D: By considering the 2D spatial units to be infinite height prisms of space (see ISO91952), it is possible to ensure a complete, non-overlapping 3D coverage of space.
Non-base (secondary interest) 3D: Because, even in 3D there is the possibility of secondary interests on part or all of a 3D spatial unit, there is the need to allow non-base (may need a new term) to overlap one or more base parcels in 3D.

3. TECHNICAL AND LEGAL ISSUES

3.1 Sources of 3D data

To minimize the financial and human resources required to establish 3D cadastres particularly in developing countries, low cost and existing sources of data may be leveraged. This may mean that intermediate stages of development will be necessary before a complete and precise 3D cadastre is achieved. As with the systematic adjudication and titling that is necessary to convert from deed systems to title systems, a systematic instead of sporadic process is required if the 2D system is to be converted to 3D. A mandatory process is also necessary and preferred over a voluntary process. Legislation will therefore be required to mandate upgrading from stage to stage. While manual survey processes may be cheaper where modern equipment is expensive, laser scanning of internal and external 3D details can speed up the data acquisition and make it more efficient.

3.2 Legal framework

The legal framework for establishing 3D cadastre can be divided into one that refers to the establishment of property and other that stipulates registration of property in the official registers-Cadastres. Property rights relations among persons regarding the properties are usually regulated by the real property rights legislation (Civil Code …) and the registration of properties by the cadastral legislation. The real property rights legislation defines properties and determine the rights that may exist on it. It "turns" physical objects into legal objects. Registration of legal objects and related rights in the official registers and level of detail required, usually prescribe cadastral legislation. Common law jurisdictions and Civil Law jurisdictions may vary to some extent (Kitsakis and Dimopoulou, 2014).

3.2.1 Legal objects

Legal framework on property rights is always been in "3D". In the reality there is no dispute what belongs to whom, or what are integral parts of the property, whether it is on the Earth's surface, above or below it. Definitions of legal objects usually start from the earth's surface, which is divided into parcels of rights holders. Furthermore, whatever is attached to land is part of it, whereby the attachment considers the functional principle. This approach has once meant: who owns the earth's surface is the owner of all from the center of the earth to infinity (hell / heaven) (Figure 14).

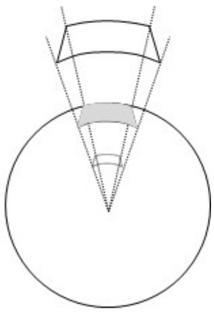

Figure 14. Legal object

However, today it is distant past. By many regulations of public law, which are or will be adopted at the national or the local level, in this space are drilled holes. The owner has very little else. If, for example, the owner finds mineral resources beneath the earth's surface and began to use them, very soon he will be warned by the competent public authorities that his right below the earth's surface goes a very shallow. If the archaeological site lies beneath the land, the owner will have the opportunity to become familiar with numerous of special regulations that define these conditions and restrict its right of ownership. Generally, digging caves on the land may be irregular, if it is of sufficient depth, if for this has not been obtained special permission.

Similar situation is if we go in the opposite direction and begin to build on the land. The air belongs to all, to the land owner only what is built. Using vacant space is subject to conditions of spatial planning documents as public law regulations. So, to the owner of the parcel was left only a thin layer of the earth's surface and what is built. Rights to mineral resources has took the state by public law regulations. For the exploitation of mineral resources is often necessary to obtain a concession (e.g. mining). Rights are always established in "3D", but for registration in the cadastre was prescribed simple modeling. The complexity of the physical/legal objects and a number of public law which are set up, requires improvements of property registration regarding their spatial extension.

3.2.2 Registration of legal objects

Legal objects, as defined by the legislation, are materialized by physical objects. Legal object is generally identical to the physical object. If this is completely not the case, then it is indirectly determined by physical objects (eg. safety zone is x meters from ...) and can be modeled /visualized in 3D. Cadastral legislation prescribes measurement, modeling and visualization of legal objects in the cadastral map. Part of the land (parcel), as a legal object, can be easily registered in the cadastre. The most commonly as a polygon which consists of boundaries. Polygon is shown in the plane cadastral map. However, for the registration of increasingly complex physical objects, which are usually divided into more legal objects and influenced by numerous public rights, cadastral legislation is not prepared. Predrilled parcel space (fig. 1) cannot be easy modeled and visualized on 2D cadastral map.

Physical object that has footprint under/over more parcels, are functionally attached to only one parcel and are part of that legal object. Footprint registration/visualization may create

confusion for users and misinterpretation of the legal relationships. In some jurisdictions it solves the registration of legal objects in layers by 2.5D representations that are separated from the cadastral map. Such an approach may help temporarily, but is not a solution because it is difficult to get a complete information about property right relationships. Visualization on 2D cadastral map can only be an indication of the complexity of the relationship on the land.
Although regulations on Cadastre change slowly, for the successful registration of legal objects in 3D it is necessary to improve the cadastral legislation. 3D cadastre is only advanced modelling and presentation of existing real world relationships regarding rights on properties.

3.3 Data submission and validation

Through the data acquisition techniques, 3D data can be created in different environment to model the 3D shapes. In the process of constructing 3D models, users need to submit or upload the data source to data center to create 3D model, in order to build spatial topology of 3D models and spatial analysis (e.g. spatial conflict detection). Data formats can be SketchUp file, AutoCAD file, 3D Max file and coordinate file in excel format, even CityGML file (YING, JIN et.al, 2014). According to different 3D spatial application and spatial complexity, users can select the appropriate data source to deliver 3D shapes. For example, for a complex building, users can divide it into several parts and describe them each with a coordinate file, and after submission, there will be special process to rebuild the holistic 3D model through the geometric locations and topological relationships.

To ensure the later correct spatial analysis, many judgment rules and validations on 3D data and 3D models are necessary. 1) Basic data examinations. These tests include the eligibility of coordinates. Are they in correct range with suitable precision? Are there many points with same coordinate? Replicated point or same point? 2) Possibility to construct a 3D model. Is it possible to construct a 3D model or several models with input 3D data? These are many rules to test this possibility/impossibility, including face-connecting, Euler formula (JIN, YING et al, 2015; Thompson and van Oosterom, 2012). It should be worth mentioning that 3D model here is not limited to simple solid defined in ISO19107 and LADM, includes the 3D non-manifold model (YING, GUO et.al, 2015). 3) Spatial location and confliction test in 3D scene. The input or submitted data many have spatial relationships and conflictions with other existed data in database, either 2D data or 3D data surrounding them. If there are spatial occupation conflictions, the input data should be sent back to check their geometrics and locations. If there are small gaps between them, this situation is acceptable to ensure these is no spatial conflictions among the close 3D models, which is vital factor in urban 3D planning and construction. On the other hand, sometime, these gaps should be handled to merge into neighbour/adjacent 3D models in order to keep consistent geometric data and topological relationships for efficient data management. Spatial relationships between the input data/models and existed models, including 2D overlay and connection, 3D topological connections, should be correctly recognized after the submission.

3.4 Data storage, processing, dissemination and visualization in 3D

The approach to storing and visualization of 3D spatial units depends on the level of complexity that exists within the jurisdiction. For example, if the highest level of complexity is the Polygonal Slice (or the Above/Below level of) the level of functionality required for storage can be a simple 2D database that allows for overlapping non-base polygons and can carry the height limit attributes.

Where the full complexity of 3D Spatial Units is needed, a more sophisticated database, and even more importantly, more sophisticated visualization tools will be needed.

3D as external database objects It has been suggested that the 3D spatial units be kept separate from the 2D spatial units (because the issues in storage are so different). So that a GIS type solution is used to store and retrieve the 2D spatial unit coverage, while a CAD system is used to hold the 3D spatial units. This is not an optimal solution because the 3D spatial units must be represented in the GIS (as flattened "footprints") to avoid holes being left in the coverage. Thus we are left with two representations of the same spatial unit in different databases, having to be independently updated.

- From time to time, it is necessary to adjust the corner positions of a cadastral database - to account for improvements in accuracy of measurement, changes of datum, or even movement of the land itself. It is vital in these operations that the 3D spatial units do not become detached from their position in the 2D coverage.

Some cadastral databases have persistent identifiers for cadastral corners, and these can be used to ensure that the 2D and 3D spatial units that share corner locations can be kept in registration.

Considering all these issues, the ideal form of storage of 3D parcels in a Corporate Database is that 2D parcels and 2D versions of the 3D parcels be kept in a single table (thus visible to 2D GIS), with the extra information required to represent the 3D parcels in full in a linked table or location.

Specifically:
3D spatial units represented as footprints: If the decision is made only to store "footprints" a simple 2D spatial database is sufficient.
Simple 3D as extruded polygons: If the decision is to approximate all 3D parcels with simple polygonal slices (or if the jurisdiction has no spatial units more complex) a 2D spatial database, with attributes of top and bottom elevation is sufficient. This is also true for databases with above/below height/depth spatial units.
More complex 3D spatial units: Here, it is still probably justified to extract and store the "footprint" of all 3D parcels, so that a complete 2D view of the database using classical GIS is available. In addition to this, it is preferable that the 3D version of the spatial units are closely associated with the 2D version. When adjustments are made to the 2D spatial unit fabric, the association between the 2D and 3D representations must be preserved.
Dissemination and Visualisation: As has been discussed above, a 2D view of all parcels is essential, and this should be available to a classical GIS. In addition, a 3D "view" of the cadastre is needed, showing all 2D as well as the 3D spatial units in a common form similar to a 3D city model. In this view, it is essential that sub-surface spatial units are accessible and viewable.

4. CONCLUSIONS AND FUTURE TRENDS

From a worldwide survey (2010 and updated in 2014), it was found that no country has a fully implemented functional 3D cadastre. There are many examples of partial implementation, but the functionalities are always limited in some way. Significant progress have been achieved in providing legal provisions for the registration of 3D cadastre in many countries and many have started to show 3D information on cadastral plans such as isometric views, vertical profiles or textual information to facilitate such data capture and registration.

In all cases, the whole cycle of the cadastral plan starts from survey data capture, progresses to data processing for plan creation, then data storage with registering authority, then data visualisation and dissemination. Although, research has progressed in all aspects of the plan life cycle, the current research seems to have focused on the data creation aspect. As jurisdictions have progressed towards a partial implementation of 3D cadastre, much 3D data has been collected in other areas such as Building Information Models (BIM) which have opened up the possibility of creating a 3D database from existing dataset. The focus of such research is the usability, compatibility and portability of these dataset which might be a low cost solution to one of the costliest phases of the implementation of 3D cadastre which is the data capture.

Other sources of 3D data which are being explored currently are 3D topographical data, Lidar data, 2D or 3D floorplans which are not from BIMs, Laser surveys of individual building units, and data from volunteer geographic information (VGI). The true cost of such rapid data acquisition however comes when attempting to link to the existing cadastral framework and validating such data. However, for initial implementation these are invaluable sources of information and when a cadastre reaches a certain level of maturity it might even serve as a source to these BIM and VGI datasets. Complex solutions may not be required for initial implementation of 3D cadastre when none exists previously and such cost effective solution will assist to establish a proper 3D cadastre quicker.

When such implementation takes shape, the future consideration is on cleaning these datasets to be as close to the accuracy and functionality of the existing 2D Cadastre as possible. These may however be done in refresh cycles with progressive levels of maturity or a systematic upgrade process can be undertaken with focus on an area at a time. Attention can then be given to 3D data capture and creating an institutional, legal and technical framework for its successful implementation.

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