Contribution of Existing Documentation in 3D Cadastre

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SUMMARY

Over the last decades, land exploitation is getting more intense in order to satisfy public and private needs of modern societies. The intensification of 3D space exploitation includes complicated rights, restrictions and responsibilities (RRRs) that need to be unambiguously registered. In this direction, the incorporation of 3D aspects of real property to cadastral systems may improve land administration systems, by reducing misinformation and clarifying complex property rights. To achieve this, current legislative and cadastral framework has to be adopted to the emerging needs, or 3D cadastral systems have to be introduced. During the course of time, each country has established a number of databases and registries for various purposes that maintain data describing 3D features of real property. Such data, although may not generate a full 3D cadastral system, can contribute, at some level, to 3D cadastral registration, clarifying complex real property situations. This paper investigates possibilities of extracting 3D property features from existing databases and registries, including availability, format and accuracy issues, taking into account national characteristics and international trends concerning harmonisation and interoperability issues. The investigation is implemented through two characteristic cases of complex property status in Greece that would greatly benefit from 3D representation, supported by existing documentation.

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1. INTRODUCTION

Introduction of 3D Cadastres has become an issue of global interest since the late 90s. However, depending on jurisdiction, legislative initiatives have been implemented to address issues of multi-surface property since 1960. Today, many countries have regulated or plan of regulating their legal and cadastral framework to accommodate 3D property issues. Although approaches concerning 3D property in each country differ, they share similar principles (Paulsson, 2012; Kitsakis and Dimopoulou, 2014). One of the most important aspects of implementing a 3D Cadastre is data acquisition defining real property, prescribed by national legal and cadastral legislation. However, the exact relation between legal and physical objects as well as the data needed to describe them has not yet been achieved (FIG joint Commission 3-7, Work Plan 2010-2014). Modern 3D data acquisition systems facilitate 3D object rendering; however 3D modelling for cadastral purposes remains costly, time-consuming and is required only in specific cases. Consequently, other alternatives of 3D data acquisition need to be implicated to accommodate representation of 3D features of real property.
This paper investigates:

- data that relate to 3D features of real property, maintained in databases at national level,
- whether these data may describe 3D rights, restrictions and responsibilities (RRR), and
- procedures of exploiting these data within 3D Cadastre.

The latter is related to cadastral requirements applied in each country, including legal, institutional and technical issues. The investigation is applied in two characteristic cases in Greece: a multi-surface property under customary law and a condominium property in urban area. The paper is structured as follows. Section 2 provides the outcome of a thorough worldwide investigation of databases and registries that record real property features that may generate 3D cadastral models. In Section 3, 3D modelling techniques and standardisation prototypes are presented, forming current framework on 3D cadastral modelling, while Section 4 focuses on the capabilities and constraints in generating real property in 3D. Section 5 deals with Greek legal and organisational issues concerning RRRs' description and representation, through two cases of complex property rights. Finally in section 6, conclusions and further research issues are discussed.

2. 3D REAL PROPERTY FEATURES IN REGISTRIES AND DATABASES

A variety of registries and databases maintain data concerning real property in varying formats, accuracy levels and accessibility. This information derives from different initiatives in recording property features in Cadastres, Building Cadastres, Municipal Building Authorities, Utility maps, Mineral Cadastres, public registers, sector cadastres or other registries. Spatial and/ or textual data is included, that may be individual or overlapping. Table 1 summarises such registries according to their features' type, format and spatial characteristics, including mainly used databases with 3D property features.

Table 1. Existing databases and registries and data features recorded

Registries	Data type (Graphical/ descriptive)	Data Type Format (Analogue/Digital)	Spatial data
Building Dwelling Register - BDR	Depending on country/State	digital	- x,y parcels' centroid coordinates - number of floors
Cadastre (may comprise more databases), Land Registry	- Descriptive data (legal/administrat ive db) - Graphical data (cadastral index map)	- digital (however may be scanned drawings) - analogue (paper drawings)	- x,y coordinates, footprint of multi-surface property, - depending on country/State, heights may be recorded
Utility Maps	Graphical data	digital	- x, y coordinates - Heights are not always recorded, may be incomplete or available for specific utilities or parts of utilities
Municipal Building Departments	Graphical data	depending on municipality	- Dimensions on construction drawings, - x,y coordinates (if cadastral sheet required) - elevation data in cross sections

Apart from the above sources and depending on national organisational frameworks, useful data may be also traced in Military Services and Thematic Registries maintained by Ministries, such as LPIS, aerial photographs, DTM and DSM. From Table 1, the following can be derived:

- *Building and Dwelling Registers (BDR)* are most common in Nordic countries and Central Europe. They usually include neither spatial data nor real property tenure status (Hjelm, 2012). In Sweden, buildings' location is achieved through the assignment of its centre coordinates (Karlsson, 2005) while in Denmark a pilot project was launched, relating buildings to their address coordinates (Stoter et al, 2004). In Switzerland, the Swiss Federal Register of Buildings and Dwellings provides for 2D coordinates of the buildings registered (www.bfs.admin.ch). BDRs may record buildings of specific use, e.g. totally or partially for habitation (Switzerland), for housing and commercial purposes (Sweden), or may be restricted to urban real estate units (Italy). Access to BDR data may be under fee, free for involved parties, specific professionals or municipal services and state organisations. Restrictions may be imposed on public access to individual data to ensure data privacy.
- *Cadastral maps and databases* maintain data related to planar location and RRRs on real property. Depending on country, state or province legislative framework, other land related data may be recorded comprising public restrictions, soil contamination and land use. In almost every national Cadastre, cadastral maps, plans, registries of legal data (e.g. Grundbuch) and deed registries are included, in descriptive or/ and graphical format. Interlink of data from different databases is possible through unique identifiers assigned to real property units. Despite efforts in many countries, cadastral reality remains in 2D, RRRs are assigned to land surface parcels and multi-surface property units may be presented as footprints on cadastral maps. These refer to a limited number of multi-surface property objects such as buildings, condominium units or specific types of utility networks. In Common Law jurisdictions, e.g.

states of Queensland and New South Wales, 3D drawings are used in multi-surface property units' recording.

In most cases, the boundaries of real property units are defined in national reference systems' planar coordinates. However, in most European countries under Civil Law, marks on the ground prevail over cadastral coordinates. Similarly, Common Law jurisdictions operate under concept of general boundaries which is controversial to planar coordinates.

Elevation data is usually not presented in cadastral maps, although may be stored in cadastral databases. Furthermore, height information, directly or indirectly derived from surveying drawings, may be also maintained, even if not available in public. The content of cadastral databases recording real property RRRs, may be further populated by deeds, establishing new parcellation As in BDRs, cadastral data is usually obtained under fee by specific parties and professionals, e.g. lawyers and surveyors.

- *Utility maps* are 2D maps maintained by the operator and/ or owner of each utility network and are not always accessed by public. In some countries, state utility maps defining their location are also established. Such maps usually maintain the technical features of utilities and do not bear any legal significance, e.g. Croatia (Vučić et al, 2011). Legal relationships between utility and land parcel ownership may be established through registration to legal rights registries. In Queensland and Denmark only utilities located on (above or below) privately owned land are registered, so the location of utilities as a whole is not accurately known. Network elevation data is usually not maintained, and therefore the vertical location of utilities cannot be defined.
- *Municipal Building Departments* maintain urban planning maps and documentation submitted for issuing building permits. This documentation includes among others, 2D surveying plans, floor plans, cross sections, and façade drawings, with detailed data regarding dimensions and elevation of buildings within municipal district. Despite the fact that national coordinate systems are not used in this documentation, buildings can be traced on cadastral maps or in attached cadastral extracts. Data format (analogue, scanned or fully digital drawings) varies, depending on each administrative region's framework, and access is subject to municipal regulations, ranging from free access to access under fee or for specific parties.

2.1 Data characteristics of existing documentation

The main data describing real property can be found in titles, deeds and various drawings. Deeds may be drawn up by notaries (Continental Europe), solicitors (British Isles), involved parties or licensed agents (Nordic countries and USA). Descriptive quantitative and qualitative information on real property is included in titles and deeds, while drawings comprise floor-plans, cross-sections, coordinates, usage, physical characteristics and buildings' technical information. According to the General Report of the Real Property Law and Procedure in the European Union (European University Institute and the Deutsches Notarinstitut, 2005) there is no official standard form of real property transaction contract; however, there are template documents in each country. Depending on country, state or province, deeds refer to attached sketches or topographic and cadastral survey drawings. Spatial data included in each document is presented in Table 2.

Classifying cadastral data is a complicated task because neither is cadastral infrastructure internationally uniform nor does it respond to the same needs. For example, in The Netherlands the building footprint is defined as the intersection of a building with the earth's surface while in most countries, footprints are defined as projections on the surface (Stoter et al, 2012). Similarly, cadastral database planar coordinates are not authoritative in Common Law jurisdictions, Nordic countries and The Netherlands, while in the majority of the rest European countries the authoritative source of planar coordinates are survey plans (FIG, 2010).

Table 2. Spatial data characteristics included in existing documentation

Document	Spatial data type	Reference system	Data accuracy
Plans submitted to Municipal Building Departments	- horizontal dimensions (floor plans), - vertical dimensions (facades, cross sections, - 3D coordinates (isometric drawings)	- no reference system - relation to groundmarks	present the physical object (buildings) with dimensions
Cadastral maps and databases	- land parcel/ building footprint, horizontal coordinates - elevation data (usually stored but not presented in cadastral maps using orthophotos, LIDAR, DTM / DSM models)	- National or local reference systems - relative heights - absolute heights	Varying accuracy depending on land type (urban, rural), scale and surveying methods (few centimetres to some meters)
Deeds	Descriptive data (may refer to drawing or sketch)	Depending on Contract Law requirements	Literal descriptions of low accuracy except when related to survey plans

Concerning elevation data, except of some Australian and Canadian states, Central European and Nordic countries, there are no provisions regarding storage of 3D property units' elevation. Surface parcels' elevation is also not recorded to the majority of national cadastral databases; however may be available through state-wide elevation models, e.g. Queensland and Austria, or trigonometric and stable reference points, e.g. Italy and Russia respectively. National or local reference systems are used, depending on each country's regulations regarding elevation recording.

In order to combine data from different sources implying different accuracy, mathematic procedures, e.g. least squares method are required for data registration and adjustment. Moreover, data of different accuracy may be traced even in the same database, either due to the incorporation of data acquired through advanced surveying techniques into existing low accuracy data that satisfied specific needs (e.g. rural land) or derived from lower accuracy surveying techniques.

3. 3D CADASTRE MODELLING AND STANDARDISATION

The generation of 3D cadastres should take into account existing communication protocols and standards of data storage and representation. In this field, extensive research is being conducted including pilot, prototype projects and proposals for transition in cadastral systems, incorporating registration and representation of real property 3D aspects (Shoshani et al, 2004; Ying et al, 2011; Stoter et al, 2012; Elizarova et al, 2012; Aien et al, 2012). A recent detailed presentation of the requirements for sourcing data in 3D along with current data acquisition methods has been conducted by Jazayeri et al (2014). Research concerning current reconstruction methods and principles for 3D city modelling can be found on Haala and Kada (2010). Despite the effort and some recent operational 3D cadastral systems' implementation (Van Oosterom, 2013), introduction of a full 3D Cadastre has not yet been achieved. Within this framework, characteristic approaches applied towards implementing 3D cadastral systems and international standards that are used to organise and classify such data are presented in this section. The Inspire initiative, although not mentioned below, can also support organising infrastructure data in a 3D perspective.

3.1 The Spanish Cadastre

An approach that is most alike to 3D cadastral concept, regarding visualization of real property in 3D, is implemented by the Spanish Cadastre. The Spanish approach is based on creating buildings' or building premises' 3D models, by exploiting volumetric data such as the number of floors, and building use that are stored to a special layer of the Spanish Cadastre. 3D aspects of real property may be presented through shading, which is a presentation limited on building level, or in Cavalier perspective, presenting the individual volumes that a building comprises (Garcia et al, 2012). The Spanish concept provides an efficient approach in visualising real property in 3D, however diverges from the 3D Cadastre concept in the following:

- Geometric reconstruction of each unit is exclusively related with already built objects for which plans are available in a specific format (FXCC). Therefore, only built volumes can be visualised.
- Each unit's height derives from multiplication of the number of floors to typical 3 meters height; consequently, volumes of other height, or volumes that are not stratified in floors cannot be visualised. Furthermore, vertical accuracy of 3D models is limited and elevation data does not conform to the national height datum.
- The Spanish Cadastre provides for 3D representation of buildings and building units situated above or below the earth's surface while there is no provision regarding presentation of infrastructure and utilities.

The concept of the Spanish Cadastre of 3D model representation is based on KML data format that supports only basic semantic characteristics (Zlatanova et al, 2012); therefore, it cannot comply with applications that require presentation of extensive topologic and semantic data.

3.2 Building Information Modelling (BIM)

The need of integrating semantic data for cadastral purposes has increased popularity of modelling approaches that support semantic characteristics such as BIM employing Industry Foundation Classes (IFC) standard. The statutory requirement of Building Information Model (BIM) for government building projects, mainly in Europe and the United States, also informally required for private projects may facilitate, to some extent, 3D property presentation especially in cases of urban real estate property. BIM models may provide extended details regarding the physical and functional characteristics of a building as well as of any other construction (NBIMS, 2006). Such models are less capable to visualise topographic features and RRRs, as they are optimal for analysis on building level and cannot accommodate 3D cadastral purposes in full scale. However, research towards integration of BIM models with GIS characteristics through GeoBIM (De Laat and Van Berlo 2011) can enhance BIM's contribution to 3D Cadastre purposes.

3.3 CityGML model

The CityGML standard is an Open Geospatial Consortium encoding standard since August 2008 (republished in version 2 in March 2012), that describes physical reality. It allows for a complete 3D visualisation of the real world objects including their semantic, geometrical, topological and appearance characteristics in different levels of detail (LoD) depending on application (Kolbe, 2007). Apart from its coherent semantical and geometrical design principles, CityGML is a data model comprising, among others, DTM, buildings and building parts, tunnels, water bodies and land use (Gröger et al, 2012). CityGML can be extended to include additional data features and attributes, and thus provide semantic modelling for 3D Cadastre.

3.4 Land Administration Domain Model (LADM)

Land administration data can be classified using the Land Administration Domain Model (LADM), an international standard (ISO 19152, 2012) that describes legal reality. A detailed description of the structure and the different versions of LADM since its introduction in 2003 are presented by Lemmen (2012). In literature, many countries propose national Land Administration Systems adjusted to the LADM standard to accommodate their needs, such as The Netherlands, Portugal, Queensland, Indonesia, Japan, Hungary, Korea and Cyprus (Lemmen, 2012). LADM allows for organising land related data in a standardized and interoperable way and also supports spatial data of different types, enabling representation of spatial units in 2D or 3D, which allows for efficient recording and management of 3D Cadastre data.

4. GENERATION OF 3D CADASTRAL MODEL FROM EXISTING DATA: CAPABILITIES AND CONSTRAINTS

Implementation of each of the different types of 3D Cadastre models, requires generation of 3D volumes representing either physical objects or volume parcels based on cadastral data (Stoter and Van Oosterom, 2006). Plane coordinates are needed so that objects are properly located horizontally along with elevation data, in order to assign each object's volumetric aspects. Real property units' dimensions may also be required in case that coordinates defining volumetric space are not available. Finally, semantic data are required for each property unit to define non spatial attributes of real property. According to FIG (2010), a 3D parcel is a legal object describing part of the space, often related with a physical object that is also described in 3D. Similarly to data requirements to develop 3D prototype real property model in Russia presented by Elizarova et al (2012), rendering a 3D real property model requires:

- parcel boundaries demarcation,
- demarcation of the object's dimensions,
- definition of physical objects' constituent parts and
- elevation or height data concerning earth surface and objects' constituent parts.

Data that may be used to generate the 3D model of legal spaces and physical objects are presented, respectively in Tables 3 and 4.

A high level of spatial and cadastral infrastructure is needed so that data maintained in existing databases and registries can be combined in producing real property models in 3D, mainly to support minimalistic or topographic 3D Cadastre realisation approaches. However, there are significant deficiencies that need to be resolved:

- *Fusing data accuracy*. As presented above, there is no uniform accuracy regarding different registries' real property data. Sometimes, diverse accuracy may also be found within the same registry (e.g. DKM). Combining data of different scale and accuracy, e.g. cadastral data and terrain elevation data through DTM/ DSM, demands for sophisticated data fusion and adjustment techniques.

- *Combining data formats*. Integration of different sources' data brings out data interoperability issues; CAD, GIS, LIDAR or other data need to be combined, that differ in syntax, semantics and operating systems. Furthermore, existence of data in analogue or scanned format intensifies accuracy issues as analogue data digitisation may reduce scanned data accuracy.

Table 3. Data required representing legal spaces in 3D

LEGAL SPACE	Data	Remarks
Location	- Planar coordinates (X,Y) on cadastral maps/databases in national reference systems	Earth's surface elevation is not always available/ is in low accuracy/ is in different reference systems
RRR definition	- Planar coordinates (X,Y) on cadastral maps/databases given in national reference systems - Descriptively in contracts/deeds	
"Spatial extents"	- Descriptively in contracts/deeds - Survey drawings	Isometric plans (3D) available in Common Law jurisdictions

Table 4. Data required representing physical objects in 3D

PHYSICAL OBJECT (PO)	Data	Remarks
Parcel location	Planar coordinates (X,Y) on cadastral maps/databases, mineral cadastres available in national reference systems	- Varying accuracy - Scanned or paper drawings may exist
PO location	Building footprints are recorded to the cadastral maps/databases in national reference systems	- Varying accuracy - Scanned or paper drawings may exist
PO dimensions	Horizontal and vertical dimensions are available on building permit drawings (floor plans and cross section drawings)	no coordinates available
PO constituent parts	- Can be found in building permit drawings - in descriptive form in contracts/deeds	no coordinates available
Elevation and Height data	- PO's relative heights can be obtained from cross section drawings - Surface heights in most countries not recorded directly	- 3D drawings mainly in Common Law jurisdictions and The Netherlands (optionally) - Z coordinates reduced to national reference systems (Common Law jurisdictions)
Infrastructure, utility networks	Drawings, maps from utility owner, operator	Data cannot be easily obtained

5. CASE STUDY

In this section the current situation of representing 3D property units in Greece is presented within the existing framework concerning databases and registries where real property data is recorded. Through two case studies, the contribution of such data in generating 3D real property models is investigated.

5.1 Legal framework: main characteristics

In Greece there is no legal framework supporting 3D property units. Greek legislation regulating real property consists of various laws and codes including the Constitution, Contract Law, Law of Succession, Urban Planning Law, Agricultural Law, customary laws, the Civil and Mineral Code. The Greek Civil Code is in line with the Roman principles "*superficies solo cedit*" and "*Cujus est solum, ejus est usque ad coelum et ad inferos*" (Art. 954 and 1001 respectively). However, C.C. Article 1001 defines that vertical limits of real property extend as far as the owner has no real interest in opposing against it. Stratification of property for apartment ownership purposes is based on stipulations of Horizontal Property Law of 1929 that operates as unitary condominium systems. Real property objects with 3D characteristics in Greece are land parcels, apartments, buildings, mines, tunnels, metro, underground antiquities, telecommunication cables, water pipes and electricity cables, of which only land parcels, apartments, buildings and mines are registered to the Hellenic Cadastre database (Ntokou et al, 2002).

5.2 Organisational framework

Similarly to the complex legal framework regulating real property, Hellenic Cadastre's implementation is also regulated by a significant number of laws dating from 1995 to 2013. Furthermore, thematic cadastres exist as well as separate registries that record real property data for taxation purposes. Geographical data covering the entire Hellenic territory are at disposal of the Hellenic Military Geographical Service (HMGS). The main registries along with real property data maintained are presented in Table 5 below.

Some deficiencies observed are:

- There is no centralised coordination of relative institutions or agencies (since 2013, an electronic document submission to municipal Urban Planning offices for issuing of building permits is required).
- Overlapping data produced by various providers may exist in different reference systems
- In many registries data are in analogue format.
- Data update is partial and not systematically organised.

5.3 Extraction possibilities

In the following sections, data from separate databases are combined, investigating 3D model generation of two characteristic cases of stratified real property in Greece, including customary property rights in Sikinos island and multi-surface real properties in urban area in Chalandri.

5.3.1 Customary rights in Sikinos Island

This case study presents a typical case of customary property rights in Greece where real property is situated above a public road in the island of Sikinos. The actual situation is shown in Figure 1.

Table 5. Databases and registries maintaining real property data in Greece

Registries, Databases, Maps	Data
Hellenic Cadastre/ *Mortgage Register Offices*	- Real property boundaries and RRRs - National datum coordinates - Building footprints - Real property owned by the State - Sea-shore and forest land (ongoing) - Areas to be expropriated for public constructions (not yet recorded) - DTM/ DSM/LSO/VLSO - *Deeds(that may include survey drawings or sketches)*
Municipal/ Regional Urban Planning Offices	- Documentation required for issuing building permits (construction drawings, plans of survey, cadastral sheet) - Municipal street level
Utility operators	- Maps of individual utility networks
Thematic Cadastres (mainly maintained by separate ministries such as Ministry of Rural Development and Food, Ministry of Environment, Energy and Climate Change and Ministry of Culture and Sports)	- L.P.I.S - Mineral activities (to be incorporated to the HC) - archaeological sites, historic places, protected locations of the cultural environment and monuments (Archaeological Cadastre) - Forest maps (not completed-to be incorporated to HC) - Municipal real estate property and constructions under municipal authority (Municipal cadastral offices) - Drawings and data of informal buildings or informal building parts
- Taxation databases - Municipal Registers (municipal tax) - Registry of Public Power Corporation	- Use of real estate parcel/building - Location (defined by address) - Area - Ownership type
HMGS	- Aerial photography - Analogue maps and digital data - Topographic products
Hellenic Statistical Authority	- Digital cartographical data (based on HMGS maps including the axis' of the streets and their names (when possible), the outlines of the blocks and their numbering, the outlines of the buildings and their numbering within the blocks) - Data related with building and construction activities

Figure 1. Customary rights in Sikinos: house above public road

Data used are:

1. The deed of the acceptance of succession, including real property descriptive data. It describes the surface parcel while reference to the 3D aspects of real property is made only by stipulating that the land parcel is *"sectioned by a municipal road"*.
2. Topographic survey plans from NTUA's Summer Practical Course in Geodesy, including height data.
3. Large Scale Orthophotos (LSO) available in the Hellenic Cadastre website.

The procedure implemented to generate the 3D model of the real property is presented in the Figure 2, while Figure 3 presents the stages of the 3D modelling procedure, and the real property model in 3D.

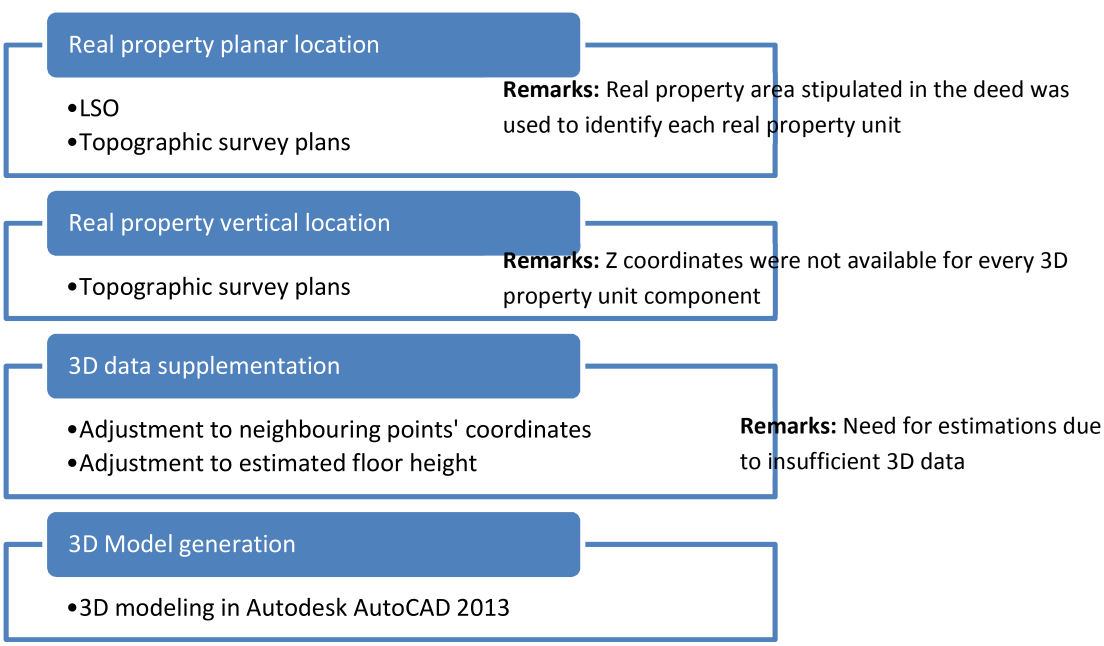

Figure 2. 3D model generation procedure

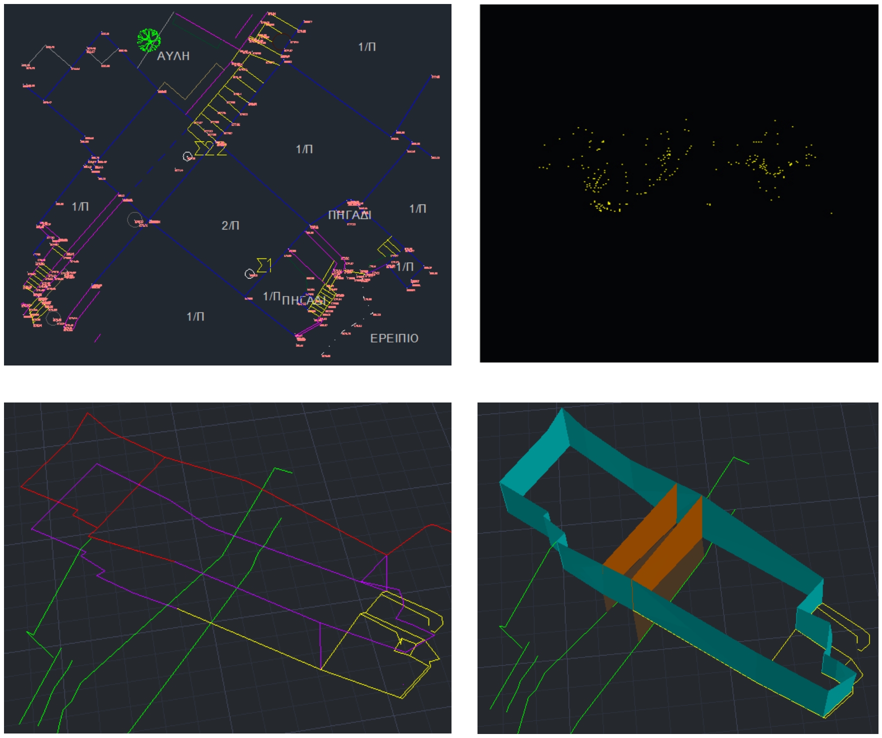

Figure 3. Stages of 3D modelling procedure Left Up: Topographic survey drawing Right Up: 3D point cloud of topographic survey Left Down: Surface rendering from survey points (Red: Roof level, Yellow: Floor level, Green: Surface level, Purple: Level derived through adjustment) Right Down: Surfaces defining volumetric spaces (Brown: Public road space, Cyan: House space, Orange: House space above public road)

The above 3D cadastral model generation also considered validation issues described by Karki et al (2010). The consistency of the produced model with the real object was not cross-referenced, due to:

- Insufficient data concerning the buildings' volume, as provided by the available documents, and
- the use of neighbouring points instead of missing points' height.

5.4 Apartment units in urban area

The second case study examines an apartment unit in a block of apartments in the city of Chalandri in Greece. The data used in this case are:

- Architecture drawings (floor-plan, cross section) obtained in paper format from the Municipal Urban Planning Office.
- VLSO available in the Hellenic Cadastre website (VLSO are available for urban area).

Paper construction drawings were scanned and digitised in Autodesk AutoCAD 2013 and 3D volumes were generated by extruding each floor plan according to the height data of the cross section. To incorporate the 3D model to the Greek national datum (HGRS87), the building was located in the VLSO of the Hellenic Cadastre. Building's and boundary corners' coordinates in HGRS87 were defined through the Hellenic Cadastre website's VLSO and were used to georeference the model. Since March 2013 the Greek Ministry of Environment and Climate

Change imposed submission of survey drawings and architectural plans in Greek national datum (www.ypeka.gr) for approval of building permits along with pilot electronic document submission; therefore real property georeference can be achieved directly from drawings. The georeference procedure is schematically presented in Figure 4, while Figure 5 presents the stages of 3D modelling procedure that was applied to generate the basement's 3D model. The same procedure was applied separately to each building's floor.

Figure 4. Adjustment of real property 3D model in HGRS87: Left: Location of real property coordinates in GGRS87 in the VLSO of the HC. Right: Real property 3D model after the coordinate adjustment placed over HC VLSO

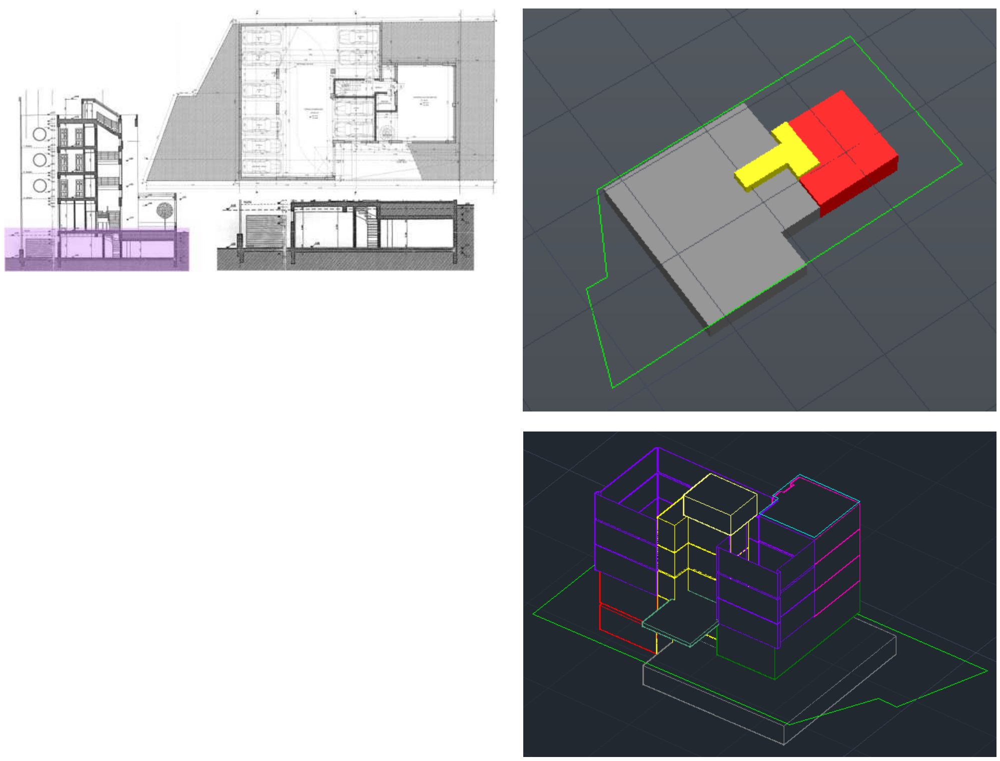

Figure 5. 3D model generation procedure:
Left-Up: Building cross section and floor plan Right-Up: Surface parcel (green line) and basement 3D model (Red: storing space, Grey: Parking lots, Yellow: Common use space including stairwell and elevator) Right-Down: 3D building model (Grey: Parking space, Red: store and storing space, Dark Green: Pilotis, Purple: Offices, Pink: Semi-open air space, Yellow: Common use space, Light Brown: Attic

5.5 Case study findings

Through these case studies the possibility of generating 3D models of complex real property situations in Greece was investigated. Out of the extensive amount of data related to real property in Greece, topographic survey data, deeds, LSO/VLSO and construction drawings were used to generate the 3D model of each real property. The research outcomes show that despite its' complexity the Greek organisational framework may provide sufficient data to generate real property 3D models that can serve a minimalistic or topographic 3D Cadastre. However, 3D model generation in Greece is limited in relatively recent constructions, where vertical data is available.

In case of *customary rights*:

- Using deeds' literal description as input data, fails to clarify the real situation.
- Real property may has been created through non recorded customary rights, despite the fact that the Civil Code regulations prevail over them.
- Topographic diagrams, survey diagrams or sketches of real property are usually not available or may include insufficient vertical data for 3D model generation.

Other issues apart from customary rights that need to be taken into account are:

- Data availability and accessibility.
- Inconsistencies between architectural drawings and reality.
- Old or/ and arbitrary reference systems of plans, that are scanned or in analogue format, affect generation and accuracy of the final 3D model.
- Legal space in 3D can be poorly defined as the Greek legal framework describes RRRs in 2D.
- Existing databases and registries mainly comprise data related to formal constructions. In Greece, there is significant number of informal constructions that can only be traced to taxation registries including address and area.

6. CONCLUSIONS AND FURTHER RESEARCH

6.1 Conclusions

The realisation of 3D cadastral models requires sufficient elevation data, and therefore, cadastral legislation should introduce height measurement methods and requirements for 3D Cadastre modelling, e.g. Navratil and Unger (2011), Sanecki et al (2013). The existing real property data maintained in various databases may include vertical aspects of real property, but their exploitation requires data quality evaluation and communication protocols. 3D models of real property generated, can clarify proprietary status of complex constructions with limited or no semantic data. This is a concept that is already applied, to some extent, in The Netherlands (where 3D models of real property in 3D pdf format can be submitted during cadastral registration), in states of Canada and Australia (where isometric drawings are required to be submitted), in Spain and central European countries with established 3D city models. Furthermore, the recent introduction of BIM models may be useful, to some extent, towards this direction.

In most cases, although deficiencies related to proper presentation of RRRs in 3D are traced, existing data may operate in an intermediate step to visually clarify complex situations, until introduction of full 3D Cadastre systems. The same difficulty applies to volume measurements, editing, updating, incorporation and processing of semantic data (Shojaei et al, 2012). The whole procedure would benefit from the adjustment of national land administration systems to the

LADM that incorporates and classifies available data even if stored to databases that are outside its' scope (Lemmen, 2012).

6.2 Further research

Although generation of 3D real property models for 3D Cadastre is feasible, even in primitive stage, further research could include:

- Possibilities in combining data from data sources, fusing different accuracies,
- Incorporation of infrastructures and utility networks,.
- Application of methods to supplement insufficient data,
- Automation options and relative procedural and
- Data validation

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