TOWARDS A REAL ESTATE REGISTRY 3D MODEL IN PORTUGAL: SOME ILLUSTRATIVE CASE STUDIES

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Abstract

The 3D concept emerged as a key concept within geoinformation science. 3D geoinformation has been proved to be feasible and its added value over 2D geoinformation is widely acknowledged by researchers from various fields – such as real estate cadastre, indeed our ultimate field of interest. The growing densification of the urban land use is consequently increasing situations of vertical stratification of ownership rights in land. Traditional 2D cadastral models are not able, or only in a limited way, to handle spatial information on those rights in the third dimension. Thus, 3D cadastre has been attracting researchers to better register and spatially represent real world overlapping situations. This research report intends to be a first step towards the consideration and design of a prototype of a 3D multipurpose cadastral system to be implemented in Portugal. To start with, the country’s historical and current status in terms of real estate cadastre is revisited. After reviewing research undertaken during the past decade on the 3D concept as a whole, and also on 3D cadastral approaches more specifically, this report focuses primarily on the identification of some case studies illustrative of the pertinence of such a topic in the context of Portugal.

Keywords: 3D geoinformation, cadastral modelling, 3D property unit, 3D multipurpose cadastre.

1. Introduction

1.1 General context: 3D geoinformation

Most information needed by policymakers is related to locations on the Earth. Despite some practical difficulties, it is clear that 3D geoinformation is becoming increasingly important. Research has demonstrated the added value of 3D information over 2D in these cases: an overall more efficient integration of urban vs. regional planning and management especially dealing with 3D underground/aboveground infrastructures.

There has been consistent research within geoinformation science on the concept of 3D for more than a decade now. For instance, merits of 3D GIS techniques have been widely debated, tested, and have been proved to be quite advanced. Nevertheless, several individual parties potentially involved 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 geoinformation was not part of the process.

According to J. Stoter (2011) and Stoter et al. (2012a), a broad collaboration and exchanging of knowledge between stakeholders towards a generic 3D approach is essential to create a basic level of certainty for all parties involved. This has to be done at a national level since a national consensus lowers intrinsic risks – *i.e.* national authorities should avoid having municipal developments of something just for themselves. In addition, by complying with international standards the choice of technologies, such as software, will be wider. Finally, by connecting to international developments and organisations, such as Open Geospatial Consortium (OGC), a useful source of expertise will be available.

An everyday person, possibly policymakers too, is so exposed to mainstream 3D material, through videogames or the Internet, that may well think that everything about 3D has been already achieved and thus no need for further investments. On contrary, 3D geoinformation is a complex field and requires more advanced research
and techniques to be especially used in complex administrative procedures (Stoter, 2011).

In spite of all research undertaken and technologies developed in the field, 3D concept merits still need to be exploited further; indeed, more specific applications and associate products are needed. Geoinformation science is never a goal in itself, it is a “serving discipline” (Stoter, 2011), and without applications it may well turn useless. Examples include: automated change detection; integration of voxel and 3D vector data; generation, from laser-scanned point data, of tree and/or building models, which can be easily integrated in OGC CityGML models; interactive airstream simulations; 3D city models; integrated geospatial planning and management of 3D underground/aboveground municipal assets; or 3D cadastre. 3D cadastre – in fact, our ultimate field of interest – certainly has to build on 3D geoinformation science: 3D GIS as a whole, 3D geospatial data, 3D topology, and 3D datastructures. Even so, there is the need to take it further in order to tackle specific needs.

Recent developments within 3D geoinformation – with a particular emphasis on the pioneer “3D Pilot NL”, honored with an OGC 3D Info Management award in November 7th, 2011 – have strongly motivated the research whose first step constitutes the object of this research report.

1.2 Motivation

Regardless of the country, federal state, or province, an up-to-date property cadastral system is fundamental for a sustainable development and environmental protection. It is indeed widely acknowledged to be the basis of a healthy economy, and hence the pertinence of such topic.

Current worldwide property cadastral registries 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, or only in a limited way, able to reflect the spatial information about those rights in the third dimension. As a matter of fact, the growing density of land use in urban context is consequently increasing situations of vertical demarcation between real estate properties. Thus, 3D cadastre has been attracting researchers through out the world for nearly a decade now to better register and spatially represent real world overlapping situations. Furthermore, the pertinence of a 4th dimension related to time has emerged as well (FIG, 1995).

As far as Portugal is concerned, a centralised distributed cadastral management system, which implements a 2D cadastral model, has been conceived: the so-called SiNErGIC. Nevertheless, its technical implementation is far from being concluded mainly because most of surveyed geospatial data, referring to coordinated cadastre, is still being acquired in the field and processed. Moreover, from several experiences across the world it is known beforehand that a 2D model has limitations for it is not capable of modelling and handling very well complex 3D situations.

Every standard is generic in nature. Thus, the recently approved international standard ISO 19152 (November 1st, 2012) should be adapted to Portugal’s cadastral reality. The standard model has to be conveniently applied in order to incorporate Portuguese
Cadastral Law. The ultimate goal should be the implementation of a 3D cadastral model capable of handling the overall cadastral reality in Portugal. Ideally, further agreements between many stakeholders – ranging from governmental bodies, research centres, to commercial parties – should be achieved to assure optimal operability of such a model. As a result of such a nationwide agreement, a 3D national standard for large-scale topography should be set up.

1.3 Aim & objectives

In the light of the above, an investigation of 3D cadastre aspects appears to be pertinent both in the context of the Portuguese real estate law as well as in the more geometrical side. The main aim of this research report is to discuss the pertinence of such an investigation and launch its bases. Some objectives were identified as follows:

- To start with, the review of both some historical circumstances and current status of the Portuguese property cadastre;
- Secondly, to review literature on related work covering 3D spatial datastructures, 3D GIS, and 3D cadastral approaches;
- Also, in order to illustrate the pertinence of a 3D cadastre approach, the identification of some instances where the current 2D cadastral model in Portugal is limited;
- Finally, to draw recommendations with regards to the next investigation steps.

2. Portugal's real estate cadastre revisited

2.1 Some elementary cadastral concepts and definitions
Property cadastre information is usually managed by one or more government agencies. The central defining feature of any land management system is a property cadastre that states the record of all interests associated to land, describing in particular the rights, restrictions and responsibilities (RRR) (Figure 1). A cadastral system may be established principally for three somewhat traditional purposes or functions (FIG, 1995):

- Fiscal, *e.g.* valuation and equitable taxation;
- Legal, mainly in the support of legal transactions (conveyance);
- Territory management, *e.g.* to assist in urban/regional planning or other administrative purposes.

Regardless of being 2D or 3D, a cadastre is normally a land lot-based system, *i.e.* information is geographically referenced to unique, well-defined units of land – the so-called parcels. These parcels are defined by the formal or informal boundaries marking the extent of lands held for exclusive use by individuals or specific groups of individuals (*e.g.* families, inheritances, corporations, or any other communal groups). Graphical indices of these parcels, known as cadastral maps, show the relative location of all parcels in a given region. Cadastral maps commonly range from scales of 1:10 000 to 1:500. Large-scale diagrams or maps showing more precise parcel dimensions and features (*e.g.* buildings, irrigation units, etc.) can be compiled for each parcel based on ground surveys or remote sensing and aerial photography. Information in the textual or attribute files of the cadastre, such as land value, ownership, or use, can be accessed by the unique parcel code shown on the cadastral map, thus creating a complete cadastre (FIG, 1995).

### 2.2 Historical aspects & current status

The first official step towards the establishment of a national registry of land parcels in Portugal was taken in 1801. By royal decree, the cosmographers of the Kingdom of Portugal were appointed then to be in charge of the organisation of both a cadastre and a general registry book of real estates within the Kingdom. The fact that cosmographers were the practitioners in charge of such a task, states how aware authorities were in those days of the great value of a coordinated cadastre. For several reasons, such a registry was never launched though until 1836, when the national real estate registry (*Registo Predial*) actually started being implemented (Silva *et al*., 2005). Like in many other countries across the world, the Portuguese real estate registry system is based on the “folio principle”, *i.e.* each “land parcel” on the ground is related to exactly one ownership title registered in the land registry. Every land parcel has a unique parcel identifier number to which all parcel-relevant information is linked. The term “property” as such is not used in the Portuguese legislation, though the equivalent word does exist in Portuguese, *propriedade*, but is more informally used in everyday language. The official term used, as explained below, is *prédio*.

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1 One who studies, describes, depicts, and measures the Earth and/or the visible universe, including geography and astronomy.

2 From the Latin word *praedium*, standing for “real estate” or “legal immovable property” unit.
Like other property parcel registries across the world, Registo Predial has been serving in Portugal as the pillar foundation for property transactions and for securing the legal status of property boundaries. Even though the registration of real estates has been in theory mandatory since the registry was launched, in practical terms this was not really the case unless any legal transaction over a given parcel was in fact to be undertaken. In general, however, real estates in Portugal are historically likely to be passed on through generations by simply being inherited. They would be rarely sold/bought and it was not indeed until roughly the 1980s that such transactions became more common. As a consequence, many real estates are still omitted from the registry. Portuguese authorities are however somewhat in control of the situation for the national revenue and customs agency (ATA\textsuperscript{3}) is in charge of up-to-date records for taxation purposes (the so-called Matriz Predial) on the nearly 17 million real estates in the country.

Thus, the national records on real estates in Portugal are nowadays spread throughout two different databases: Registo Predial (set up for legal purposes) and Matriz Predial (set up for taxation purposes).

Like other cadastres across the world, Portugal’s cadastre also follows a real estate-based approach. In the Portuguese jurisdiction, real estates (prédios) can be classified into one of the three following possible types (Mendes, 2003):

- Rural (prédio rústico) – which may be situated either in rural or urban areas. The main characteristic of this type of real estates is that they are not meant to be subjected to any sort of construction development, and hence are principally devoted to agriculture or forestry activities. Besides land lots, this parcel type may also include water bodies and crops (separate from the land lot where they happen to lie on).
- Urban (prédio urbano) – which are situated only in urban areas. This type of real estates includes any manmade construction (i.e. meant for residential, commerce, industrial or services purposes), and may also include land lots meant to be developed.
- Mixed (prédio misto) – Although rare, this is a very specific type to classify those real estates that have both rural and urban characteristics and none of them can be identified as the main one.

Since both national records were implemented, cadastral information of both Registo Pedrial and Matriz Predial is based on text. Each real estate is geo-referenced by explicit reference to its northern, southern, eastern and western neighbouring parcels or geospatial features (e.g. roads, railways, water bodies, etc.). This is what actually still happens in most instances, as the coordinated cadastre is currently still being surveyed. Cadastral survey was launched in 1926 by the national mapping agency (IGP\textsuperscript{4}) and has not covered the whole country yet. It has been indeed a rather complex and demanding operation to undertake given Portugal’s territory tissue: a country of a few millions of literally microscopic real estates, especially in the mainland’s

\textsuperscript{3} Autoridade Tributária e Aduaneira

\textsuperscript{4} IGP- Instituto Geográfico Português
northern-half, also in Azores and Madeira archipelagos. Figure 2 and Figure 3 below illustrate respectively examples of a cadastral section map produced in the early 20\textsuperscript{th} century and a more recent general cadastral map digitally produced.

![Figure 2 – Map of a cadastral section produced early 20\textsuperscript{th} century (Source: IGP).](image1)

![Figure 3 - Cadastral map produced late 20\textsuperscript{th} century (Source: IGP).](image2)

Cadastral surveying started off in the mainland’s southern-half, where one of the main sources of the country’s economy in the first half of the 20\textsuperscript{th} century was: the *latifundium*. That is why it covered then only rural real estates; urban real estates were never surveyed until a pilot experiment was carried out between Jan 2006 and Feb 2008 in one of the civil parishes of Pombal district, Albergaria-a-Velha (mainland’s west-centre). This was a key step towards cadastre modernisation. Since then, Portugal has embarked on various other initiatives to modernise its cadastral survey. Cadastral surveying is currently being accomplished district-by-district covering both kinds of real estates, rural and urban. As depicted in Figure 4, by the end of 2011 more than 50\% of the mainland’s territory had been surveyed, though this only corresponds to roughly 1/3 of the total number of real estates in the country. Currently, 7 districts are being surveyed in Portugal’s mainland: Paredes and Penafiel (in the northwest); Oliveira-do-Hospital and Seia (in the centre); Tavira, São-Brás-de-Alportel and Loulé (in the Algarve).

5 A large landed farming estate.
Towards a Real Estate Registry 3D Model in Portugal: some illustrative case studies

2.3 The future: SiNErGIC

Overall, property cadastre has been traditionally serving the basis for both taxation and legal purposes. These functions are indeed of most relevance within any country’s economy, will not change as such and hence will continue to be significant. A third requirement for cadastre has emerged more recently: urban/regional planning. It is within this context that cadastral survey information became even more crucial. Given its level of detail and amount of data, cadastral survey information constitutes nowadays the most critical land base information to support development and planning in governance (Khoo, 2012).

Aware of the facts above, the Portuguese government took an historical decision in 2006 towards the implementation of a centralised distributed – through the World Wide Web – cadastral management system (formalised by Cabinet Resolution nr. 45/2006): the conception and implementation of the so-called SiNErGIC (PCM, 2006). The main goal of such a system is to make available the existence of a multipurpose cadastral system in Portugal setup as an “exhaustive, methodical, and up-to-date set of data able to uniquely identify and describe property parcels” (IGP, 2012).

The main objectives of SiNErGIC can be summarised as follows (PCM, 2006):

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Figure 4 – Portugal’s mainland districts and progress on cadastral surveying of rural real estates by 2011 (Source: IGP).
- To unify and concentrate within a single system both current and future cadastral data;
- To assure its compatibility with other institutions’ electronic systems involved in this project;
- To assure unique identification of each real estate;
- To assure that each real estate’s description includes a digital graphical plan;
- To assure its dissemination and usage by general state administration – thought subject to specific permissions and protocols;
- To assure both citizens and companies general access to the system – again, subject to specific permissions and protocols.

Because cadastral surveying has been taking so long to cover the whole country, what has actually been happening since the middle 1970s is that several private construction companies and state agencies directly intervening in territorial operations have technically undertaken themselves cadastral surveys as needs arise. In particular, local municipal authorities are in possession of virtually all construction plans within their territorial jurisdiction.

These facts above led recently to a further central government decision, formalised by Cabinet Resolution nr.56/2012 (PCM, 2012a). While formal cadastral surveys are being carried out, other existing cadastral data within both state and private organisations should be centralised in order to (PCM, 2012a):

- Be processed and checked against cadastral standards towards its official approval;
- Be articulated and incorporated thereafter within the official source of cadastral survey information.

Further to all governmental decisions above, efforts have also been taken in fact towards existing cadastral data crossing principally from both Registo Predial and Matriz Predial; thus, a merging of both national records is currently ongoing. These cadastral data will be indeed the pillar foundations of the future SiNERGIC.

3. 3D Cadastre

3.1 The need for a 3D cadastral approach

2D planimetric survey plans are overall adequate and acceptable to property owners. With increasingly complex developments above and underground – where structures and usage of space cannot be seen in 2D – this is no longer the case. Several authors (including Abdul-Rahman et al., 2012; Khoo, 2012; Soon, 2012; Stoter et al., 2012b; Wang et al., 2012; Ying et al., 2012; Zhao et al., 2012; Abdul-Rahman et al., 2011; Stoter et al., 2011; van Oosterom et al., 2011; Hassan et al., 2010; Chong, 2006; Stoter and van Oosterom, 2006; Valstade, 2005; Stoter, 2004; Stoter et al., 2004) have demonstrated that 3D representations of airspace and subterranean parcels are currently required for 2D+half representations are unable to handle 3D measurements, spatial queries, or visualisation. As reviewed in section 3.3, 3D cadastral technology has emerged recently; in fact, there has been considerable research work over the past
decade on the founding aspects of 3D cadastres, and some pilot studies have been accomplished so far.

Victor Khoo (2012) summarised the main aims to be achieved in implementing a 3D cadastral system, as follows:

- To adopt an official and authoritative source of 3D cadastral survey information;
- To adopt open source format for data exchange and dissemination;
- To adopt international standards in data modelling;
- To design a smart data model that supports “3D parcels” (vd. definition in section 3.4.1);
- To automate cadastral survey data processing and official approval;
- Finally, to introduce a 4th dimension related to time towards a 4D data model.

3.2 3D cadastral issues

3.4.1 3D spatial and semantic information

In the light of the international standard ISO 19152, on the Geographic-information Land Administration Domain Model (LADM), the notion of 3D cadastre with 3D parcels has to be understood in the broadest possible sense. What a 3D parcel exactly is, or could be, may well depend upon both the legal and organisational context of each specific country (or state/province). The broad meaning of a 3D parcel includes land and water spaces, both above and below surface. Nevertheless, a formal definition can be given as follows: “a 3D parcel is defined as the spatial unit against which one or more homogeneous and unique rights (e.g. ownership right or land use right), onus or restrictions are associated to the whole entity”, as included in a Land Administration system (ISO 19152, 2012).

The term “homogenous” above means that the same combination of rights equally applies to the whole 3D spatial unit; furthermore, “unique” means that it is the largest spatial unit for which the above is true. Hence, making the unit any larger would result in the combination of rights not being homogenous; making the unit smaller would result in at least 2 neighbour 3D parcels with the same combinations of rights.

A 3D parcel always refers to a “legal object” describing simultaneously a “part of the space”. Thus, in general property cadastres there are two different types of objects: the legal and the spatial ones. Often there is a direct relationship between a legal and a real world spatial object. It is the spatial object that in turn may be also described in 3D. More precisely, the focus in the context of 3D cadastres is on 3D parcels understood as “spaces of legal objects”.

Accurate collection methods of 3D spatial data are required so that relevant data acquired at a specific time may be incorporated in a 3D data structure. Spatial data may refer to information such as on: the ownership number; the parcel’s unique identifier; the parcel’s geometric shape and area; if it is the case, on the footprint of manmade constructions, e.g. buildings, within the parcel; building geometry; each building’s floor area (Hassan and Abdul-Rahman, 2010, cited in Abdul-Rahman et al., 2012). As far as semantic information is concerned, this has to be rich enough in
order to provide a description about the parcel as detailed as possible, such as: owner identity, e.g. name and national insurance number; parcel history; number of physical components; type of lease; if it is a building, number of floors, or volume space. In 3D modelling, implicit or explicit geometry may well be used to generate the 3D model itself. With this regard, the integration of Building Information Models (BIM) can also help in data collection process, though this should only be carried out if the integration of both CityGML and IFC standards can be achieved (Abdul-Rahman et al., 2012). The spatial unit package defines spatial units as being 2D (land parcels) or 3D (space), buildings, or utility networks. These include in turn topological, polygon, line, point, and text spatial units (ISO 19152, 2012).

3.4.2 Marine cadastre
This naturally makes sense in countries sharing borders within water bodies, e.g. oceans or lakes. Marine environment may consist of activities related to territorial waters control, sea navigation, fishing, tourism, and oil or gas exploration. As a fact of matter, in the specific case of Portugal, an historical maritime country, this type of cadastre is of most relevance. It is in fact the largest European country in terms of territorial waters, and thus this specific topic needs further investigation in the context of such a maritime country.

The marine space is slightly different from that of land and introduces complexities involving, for instance, rights and responsibilities that vary in time. These facts require the collection of sorts of spatial data different from those land-based (Abdul-Rahman et al., 2012).

Marine objects can be described as: sea surface, water volume, seabed, and sub-seabed objects – which can be demarcated up to a country’s Economic Exclusive Zone (Ng’ang’a et al., 2004). Typically the rights for marine cadastre are overlapping in nature that makes the demarcation of marine parcels a complex issue.

3.4.3 Underground utility networks
Possibly because underground utility networks are overall owned by government agencies in most countries, these are not seen to constitute real parcels to be included in cadastres. Moreover, underground utility networks are typically developed in 2D thus creating beforehand enormous overlay difficulties in terms of volumetric spatial data.

Several authors, including Abdul-Rahman et al. (2011), Cheng (2006), among others, have identified 3D underground utility networks to be one of the most important themes in a 3D cadastral database. Such a database is considered the fundamental basis for a sustainable underground usage management, enabling local authorities to establish exact locations for the various utility networks in a given urban area.

3.3 An overview on 3D modelling approaches in cadastral systems
Further to the International Federation of Surveyors (FIG) congress in April 2002, some work has been devoted to 3D aspects of cadastral registration systems both in a fundamental way and at an international level. This has been done mainly in the context of a working group set up as a joint sub-group of Commission 3 and
Commission 7 of FIG – which is in turn subdivided into three sections dealing with the legal, institutional, and technical aspects of 3D cadastre respectively.

The joint sub-group above has promoted so far three international workshops: Netherlands, Nov 2001 (www.gdmc.nl/events/3dcadastres2001); Netherlands, Nov 2011 (3dcadastres2011.nl); China, Oct 2012 (www.cadastre2012.org). A wide range of papers have been presented throughout those workshops on 3D modelling approaches towards what has been defined as “smart cadastre” that supports 3D parcels (Khoo, 2012).

Before 3D approaches towards 3D cadastres were actually conceived and implemented, there was initial work some time ago reviewing the status of different cadastres across the world. Back in 2004, Steudler et al. (2004) started a worldwide comparison of cadastral systems. In the context of a comparative analysis on the cadastral systems in the European Union (EU), Manthorpe (2004) carried out a review on the UK really. In turn, starting off from a comparative analysis of cadastral systems across the European continent, Valstade (2005) undertook a similar study on Norway. Yavuz (2005) carried out possibly the first comparative analysis of cadastral systems in the European Union (EU) countries according to basic selected criteria.

In the meantime, there has also been considerable research for more than a decade now on the foundations of 3D geospatial datastructures as a whole, not necessarily towards 3D cadastral systems. Several authors have worked specifically on the identification of possible topological relationships in the 3D context and their validation. For instance, by considering two-dimensional topology and modelling as a starting point, Gröger and Plümer (2005) took it further in order to be able to deal with topological concepts and models that are necessary to represent three-dimensional urban objects in a geographical information system (GIS). Ellul et al. (2005) initially derived a generic topological datastructure for 3D data, and defined the fundamental requirements for the implementation of topology in 3D GIS (Ellul et al., 2006). Further to the need for efficient and scalable techniques for storage, validation and query of 3D models in terrestrial data management, Kazar et al. (2008) focused on the problem of validation of 3D geometries, and presented an Oracle’s data model for storing 3D geometries. Verbee and Si (2008) employed “constrained Delaunay tetrahedralisation” to check the validity of a single 3D polyhedron. Ellul et al. (2009) reviewed the 9-intersection framework for boundary representation in 3D GIS, and then outlined modifications to that structure to improve binary relationship query performance. Brugman et al. (2011) developed a series of topological rules to validate a 3D topology structure for a 3D space partition. Having in mind their application to 3D cadastre in particular, Thompson and Van Oosterom (2011a, 2011b) in turn extended Brugman et al.’s rules to axiomatic definitions to validate a 3D parcel and its relationship with adjacent 3D parcels within a space partition. By defining an axiomatic characterisation of 3D city models, Gröger and Plümer (2011a) worked on consistency checking tools to assess the suitability of spatial data for their applications.

As far as 3D cadastre in particular is concerned, Jantien Stoter and van-Oosterom (Stoter, 2004; Stoter and van-Oosterom, 2006) have analysed the needs and opportunities for a 3D cadastre. Starting from the Dutch cadastral reality, these
authors set up one of the very first frameworks for modelling both 2D and 3D cadastral situations in a worldwide context, and developed a general prototype model for a 3D cadastre. Karki et al. (2011) specifically discussed geospatial data validation in 3D cadastre including a single 3D parcel and its relationships with other 3D parcels. Further to Verbee and Si (2008), Brugman et al. (2011), Thompson and Van Oosterom (2011), and Karki et al. (2011a), Zhao et al. (2012) proposed a novel method towards the validation of spatial relationships among 3D parcels, by identifying either correct or even incorrect topological relations in 3D. Furthermore, geovisualisation aspects in 3D cadastre have been also tackled. Wang et al. (2012) have been working on the visualisation principles in 3D cadastres and investigated which variables among visual variables are appropriate for geovisualisation of 3D legal units in a 3D cadastre system. In 2011, Oosterom et al. accomplished a worldwide inventory of the status of 3D cadastres in 2010 and stated what the expectations were for 2014.

Other authors have developed in turn relevant work on the extension of 3D GIS to 3D cadastre. 3D GIS offers indeed some techniques that can be directly applied in 3D cadastre – for instance, 3D GIS provides proper methods for the representation of geometry of 3D cadastral objects and to associate to them property rights, semantics, and transaction attributes. Nevertheless, other techniques should be improved in order to be able to deal with management operations within 3D land administration. This is mainly because 3D GIS and 3D cadastre objects are different. For instance, Gröger and Plümer (2011b) extended the axiomatic characterization of 3D surfaces proposed by them (Gröger and Plümer, 2011a), which guaranteed consistency between geometry and topology, to the case of “handles” (e.g. tunnels, bridges, or arcades); by doing this, the authors closed the gap between the global topological definition of handles in surfaces and the local definition of semantical handle objects in GIS. Frédéricque et al. (2011) presented a benchmark exercise in which an architecture, combining both desktop GIS applications with server based RDBMS, was used to implement different scenarios for a 3D Cadastre (full 3D and hybrid); results obtained by the authors illustrate how possible it is to combine advanced CAD and GIS technologies to create and update intelligent objects corresponding to both 3D urban features and 3D property units. Ying et al. (2012) applied 3D GIS techniques to 3D cadastre in urban environment as an attempt to build the bridge and fill the gap between urban simulation and urban space management; details of such application were elaborated through three main aspects: 3D data and 3D modelling, 3D simulations and 3D visualisation, practice and decision-making support.

Furthermore, a remark should be done on the increasing prevalence of building information models (BIM). New technologies on BIM are continuously being developed which means that we can expect to see very detailed building models available in the planning stage. Consequently, these models appear to be useful to generate 3D volumes for properties (Frédéricque et al., 2011; Smith, 2012).

More recently, various pilot 3D cadastre systems have been developed and tested for the specific cadastral context of some countries, like: Australia (Karki et al., 2011b), Brazil (Barros-de-Souza, 2011), China (Guo, 2011), Korea (Jeong et al., 2011), Malaysia (Abdul-Rahman et al., 2012), Russia (Vandysheva et al., 2011), Singapore (Kho, 2012; Soon, 2012), or The Netherlands (Stoter et al., 2011, 2012b).
Finally, as far as Portugal’s cadastral context is concerned, Hespanha et al. (2006) worked on the evaluation of an initial FIG core cadastral model (Lemmen et al., 2003) by applying it to Portugal’s cadastre. Based on that previously proposed standard, an object oriented, conceptual model for the cadastral domain was then adapted to the Portuguese cadastre and associate real estate registry Registo Predial. Their approach however covered essentially the 2D reality and needs to be taken further towards 3D cadastral modelling purposes.

3.4 A 3D cadastral approach in Portugal – possible case studies

Recent encouraging governmental decisions described in section 2.3 are absolutely vital when envisaging a centralised cadastral management system. Nevertheless, 3D aspects of cadastral data towards a possible 3D cadastral system have not been covered in this project.

As elsewhere in the world, many examples can be identified in Portugal’s context where the 2D cadastre is limited. For instance, the work being currently accomplished by Coimbra city council (CMC⁶) can be placed amongst the initiatives undertaken by some state institutions as that described in section 2.3 above. Our interest on this topic prompted a series of informal contacts between some CMC staff, particularly from its department of cadastre and land management⁷, and us. Preliminary discussions allowed the identification of some case studies three of which are hereby proposed to be taken into consideration in further research on the matter. They correspond to different cadastral situations in Coimbra somewhat complex that demonstrate by themselves the pertinence of a cadastral system implementing a 3D datastructure.

3.4.1 Case study 1: Dom Pedro V lift/funicular

Dom Pedro V lift/funicular is constituent part of the public transport system in the rather hilly city of Coimbra – west-centre of Portugal’s mainland. Built in 2000, and started operating in 2001, it is owned by the city council and is run by the local transport municipal company, SMTUC. The whole infrastructure consists of a 20m vertical lift, a 24m overpass, plus a 51m sloping funicular, which connects Dom Pedro V Market area, in Baixa (which stands for downtown in Portuguese), to Alta (uppertown in Portuguese) where the historical and main campus of the University of Coimbra is located.

As illustrated in Figure 5 below, the overpass in particular raises a clear example of a 3D issue in terms of cadastre. The whole infrastructure itself constitutes “municipal domain”⁸, both the vertical and funicular lie on municipal domain; however, the

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⁶ CMC - Câmara Municipal de Coimbra
⁷ DCS - Divisão de Cadastro e Solos
⁸ For the purpose of this research, “municipal domain” (in the Portuguese legislation, Domínio Privado Municipal) stands for state rights over a particular real estate – land parcel or manmade infrastructure – owned by the local city/town council whose jurisdiction covers the district territory where the given property happens to be located.
overpass goes over public domain\(^9\) relating to the road underneath (in dashed yellow lines).

![Google Earth bird's eye view of the pedestrian overpass (Dom Pedro V lift/funicular) over both public domain and municipal domain.](image)

**Figure 5** – Complex 3D cadastre occurrences in Coimbra (Portugal): Google Earth bird’s eye view of the pedestrian overpass (Dom Pedro V lift/funicular) over both public domain and municipal domain.

### 3.4.2 Case study 2: Pedro e Inês pedestrian bridge

*Pedro e Inês* Bridge is a pedestrian bridge over the river Mondego connecting both sides of the so-called *Parque Verde do Mondego* (Mondego green park) on the riverbanks.

Like in case study 1 above, the pedestrian bridge infrastructure constitutes itself municipal domain. The interesting particularity of this case study is the fact that on the south bank bridge’s foundations are constructed on “private domain”\(^10\); in turn, on the north bank, the infrastructure lies on municipal domain. Importantly, the private property above was not object of expropriation; nevertheless, the simple existence of a public infrastructure defines by law both: a buffer around it (which is indeed a 3D buffer where private rights are limited), and also establishes state right of way running across private land.

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\(^9\) For the purpose of this research, “public space” (in the Portuguese legislation, *Domínio Público*) stands for citizenship rights over the general public space – managed though by a specific state institution, depending on each instance.

\(^10\) For the purpose of this research, “private domain” (in the Portuguese legislation, *Domínio Privado Particular*) stands for private rights over a particular real estate – land parcel or manmade infrastructure – owned by a single or any sort of corporate person.
3.4.3 Case study 3: Private garages vs. public roof

Finally, a third situation is presented. This case study covers a 3D cadastral instance in a residential neighbourhood where, very much induced by the local orography, a couple of rows of private garages are located under public surface. As illustrated in Figure 7 below: garages are not underground; they are accessed via a local road, hence public domain; their roof happens to be the ground of an upper public terrace.
4. Summary and future work

At the centre of any land management operation there are private/state property issues. That is why property cadastre and cadastral systems play such an important role in property taxation, property conveyance, and urban/regional planning or any other administrative purpose. The statements above show how pertinent this topic is and how it is indeed widely recognised to be the bases of a healthy economy.

All cadastres implemented so far across the world typically implement a 2D modelling approach. As reviewed in this report, it has been proved in the literature that there are instances though of multiple use of space, with stratified property rights in land, where traditional 2D cadastre is not able to reflect in the third dimension the spatial information on those rights. Thus, the need for a more sophisticated modelling approach towards 3D cadastral system of land registration.

As far as Portugal is concerned, SiNErGIC, a centralised distributed cadastral management system was conceived, though it has not been implemented yet. Such a system is based on a 2D model approach. One of the main conclusions of this preliminary work is that it is believed that there is room for the investigation on the suitability of a 3D modelling approach instead; three case studies were identified to illustrate the pertinence of such investigation (vd. section 3.4). This should not be confined only to topological-geometric representations but should also be extended further in order to be able to incorporate the legal/administrative component, as generally recommended in Lemmen et al. (2010) and Lemmen (2012).

As stated in section 3.3 above, it seems that previous work developed by Hespanha et al. (2006) should be taken as the starting point. There is the need to take their approach further towards a prototype of a 3D cadastral model for Portugal’s context. We strongly believe that this can be achieved by considering the international standard ISO 19152 and by conveniently adapting it in order to incorporate the Portuguese Cadastral Law. The final result should be a 3D cadastral model capable of handling the overall multipurpose cadastral reality in Portugal.

Previous related work summarised in section 3.3 should also be of interest and worthy of being considered. However, further investigation is required in order to evaluate to what extent the approaches reviewed suit Portugal’s cadastral context and what the eventual adaptations are. In addition, before a prototype is developed, a first step towards a strategic vision should be the identification of cadastre information users and understand their needs. A second step should be to understand how 3D cadastre data are actually acquired in the field and processed thereafter. Further to the design and implementation of a possible 3D cadastral prototype, experiments should be performed taking into consideration some case studies, such as those illustrated in section 3.4.

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