3D Cadastre and LADM - Needs and Expectations towards LADM Revision

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3D Cadastre and LADM – Needs and Expectations towards LADM Revision

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Key words: LADM, LADM Revision, 3D Cadastre, Land Administration Developments

SUMMARY

The last decade, significant progress has been made in advancing the concept of 3D Cadastre and related technologies to facilitate its realisation. There are many examples of partial implementation and prototypes of 3D parcels registration around the world as stated by Kitsakis et al (2016) and Dimopoulou et al (2016) regarding selected countries. While standardisation in the land administration domain extends to 3D and even 4D representations, currently, there is no country that has a fully operational 3D Cadastre supporting all stages of the registration and dissemination (Van Oosterom et al, 2014). In the context of 3D Cadastre developments worldwide, the Land Administration Domain Model (LADM), ISO 19152, outlines the foundations for a 3D Cadastre and becomes one of the best candidates for unambiguously representing 3D Rights, Restrictions and Responsibilities (Kalogianni et al, 2017).

The spatial development life cycle of an object begins outside the cadastral registration cycle and has a direct impact on how a specific development application is processed. Thus, in considering the changes required to allow a jurisdiction to register 3D objects, it is important to note the sphere of influence that could have an impact on 3D registration. These include multiple stakeholders and processes, which generate different user needs, as addressed at the previous section and also new opportunities that could be addressed on the current LADM version.

To this purpose, this paper explores the needs and prospects towards further 3D modelling of the present LADM version, as derived by the current LADM experience in various countries worldwide in the context of the full spatial development cycle. Nevertheless, over the last few years the number of jurisdictions that are developing LADM-based country profiles, prototype systems and undertaking pilots using various physical models and data formats to achieve LADM implementation in the context of 3D Cadastre has become more significant.

Those approaches can be mainly categorised as “fully operational” implementations and “partly-operational” implementations focusing on different aspects of 3D cadastre development cycle; e.g. submission of 3D survey plans, prototype stage; implementations that focus on visualisation, implementations that focus on constraints and validation rules, etc.
Finally, within this context, this paper examines how current LADM version can efficiently meet the needs stated above and update user requirements for LADM in the context of the upcoming revision.

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1. INTRODUCTION

In many global documents land is considered as an issue of utmost importance (Lemmen, 2012) and thus, land administration systems emerge from the very old times (Zevenbergen, 2009). Cadastral systems are being recognized as the core of Land Administration Systems (LASs) and are normally understood as parcel based and up-to-date LASs containing identication of the individual parcels and a record of interests above/below/on land and water surface. The role of Cadastral Information Systems, especially the last decade, can be seen as the pivot of a sustainable economic and cultural development, as well as the development of smart cities: they assemble, manage and share information allowing citizens and governments to leverage an enormous national asset base (ICSM, 2014).

Furthermore, land administration should not be treated anymore as an isolated activity, but as part of a whole chain of spatial development activities which should all be well aligned with and support 3D representation (Figure 1). As also stated by Van Oosterom (2013), the naming and the order of execution of those activities (spatial planning/zoning, designing, permitting, financing, surveying, registering, constructing, using, maintaining objects) may differ from country to country, however they portray the general process followed and are related to 3D cadastral registration.

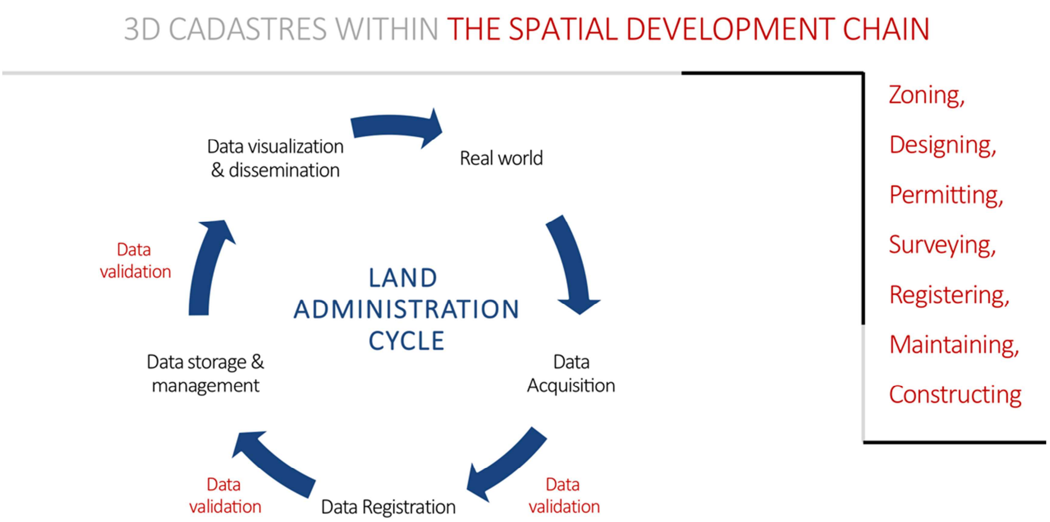

Figure 1. 3D Cadastre within the spatial development chain

In this scene, the increasing technological orientation of Cadastres should not detract from the fundamental role they have in society and the implications this has in supporting new connections between wider society and across traditional jurisdictional boundaries, contributing to facilitating the delivery of national visions, digital economies, fundamental datasets and realising smart, sustainable and resilient cities of the future (Rajabifard, 2014).

In this scene, the Land Administration Domain Model (LADM) ISO 19152 (ISO 19152, 2012) one of the first ISO spatial domain standards, outlines the foundations for a 3D Cadastre and becomes one of the best candidates for unambiguously representing 3D Rights, Restrictions and Responsibilities (Kalogianni et al, 2017) while supporting the link with physical counterparts through external classes. LADM increasingly plays a key role, as quite a number of countries are active in developing Cadastral Information Models based on LADM and adapted to their needs, also trying to integrate the 3rd dimension.

Six years after the final vote of LADM as ISO standard, a lot of research has been carried out and progress has been achieved from experts around the world, while limitations, needs and opportunities for further modelling of the initial LADM version have been identified. Today, the ground seems to be mature for its revision equipped with the collective knowledge and experience from many countries and the need to sharpen and explicitly model the scope of the model. The revision of LADM has been scheduled within ISO/TC 211 and is expected to be a joint activity with many stakeholders involved.

The scope of this paper is closely related to the upcoming revision of LADM as it aims to identify current needs of real-world cadastral situations through the knowledge and experience gained by the development and implementation of LADM country profiles in the context of 3D Cadastres. As a first step, developments towards an operational 3D Cadastre evolved in different countries around the world are briefly presented and linked with current possibilities of LADM v.1 in terms of 3D support. Needs and expectations identified through 3D LADM prototype implementations are addressed, while needs derived for LADM implementation through the most dominant technical models and encodings are listed. Finally, requirements and expectations for future developments in the context of the second edition of the LADM are presented and opportunities for refinements on current 3D LADM support are discussed at the last section. Legal and institutional aspects of 3D Cadastre are out of the scope of this paper, while attention is paid to the current 3D support of LADM in more technical aspects (i.e. Spatial Unit package) and opportunities to improve it.

2. 3D CADASTRE DEVELOPMENTS

In this section the necessary background information is briefly presented. Firstly, current operational solutions supporting at least partly the context of 3D Cadastre from several countries worldwide are presented. Following, current possibilities of the initial LADM version in terms of 3D support, as perceived by multiple country profiles, are underlined, while in the last sub-section requirements from LADM implementation through various technical models are considered.

2.1 3D Cadastre efforts

Nowadays, administration of land is challenged by unprecedented fast-growing demand for space use above and below earth's surface and for land information. Infrastructure density, leads to complex interleaving (overhanging structures and/or above- and below-ground infrastructure) triggering legal, organisational and technical challenges. Such complex situations are likely to increase given that demographic forecasts expect urban population growth to double by 2050 (PBL, 2014) and also, reveal the deficiencies of current description of land rights in 2D (Atazadeh et al, 2016; Kitsakis and Dimopoulou, 2016; Van Oosterom, 2013). In this scene, the last decade, the number of partial implementation of 3D parcel registrations around the world is increasing significantly (Kitsakis et al, 2016; Dimopoulou et al, 2016) taking advantage of the developments to support the third dimension in the field of GIS Technology. However, less than 50 countries around the world have mature land information systems (Dimopoulou et al, 2016), whilst currently no country has a complete operational 3D Cadastral Information System, incorporating all aspects (Van Oosterom et al, 2011, 2014):

- 3D legislation;
- 3D surveying techniques;
- 3D registration of Rights, Restrictions and Responsibilities (RRRs);
- management, validation and dissemination of 3D parcels,
- correspondence to parcel's physical counterparts.

Although there is no country incorporating all those aspects, there are several jurisdictions, which do have operational solutions supporting at least partly the context of 3D Cadastres. Those 3D Cadastre efforts can be mainly categorised as "fully operational" implementations applying a holistic approach achieved in different levels of maturity (Israel (Felus et al, 2014), the city of Shenzen in China (Guo et al, 2014), the States of Victoria (Aien et al, 2011; Aien et al, 2012) and Queensland (Karki, 2013) in Australia, Croatia (Vučić et al, 2017), Sweden (El-Mekawy et al, 2014)) and "partly-operational" implementations exploring the process of developing a 3D Cadastral Information System focusing on different aspects; e.g. submission of 3D survey plans, prototype stage (Malaysia (Zulkifli et al, 2014; 2014b), Czech Republic (Janečka and Souček, 2017), link with dominant physical models, as CityGML (Poland (Góźdź and Pachelski, 2014), implementations that focus on visualisation (Russia Federation (Elizarova et al, 2012), Trinidad and Tobago (Griffith-Charles and Edwards, 2014)), implementations that focus on constraints and validation rules (Greece (Kalogianni et al, 2017)). To this end, the first 3D cadastral registration of multi-level ownerships rights has been accomplished in The Netherlands, in 2016 (Stoter et al, 2016), as a result of many years of research.

The full cycle of the cadastral plan is part of a wider process, the spatial development chain. In this scene, considering the steps for a 3D Cadastre implementation, it starts from data acquisition using surveying techniques, moves to data management, then data storage to register at the responsible authority and finally, data visualization and dissemination to the users. Besides legal and technological aspects, 3D Cadastre implementation in specific country requires communication with stakeholders (surveyors, notary, banks, government agencies, public), and taking decisions.

This is a repetitive process in which research has progressed in all stages in terms of 3D. The use of standardisation techniques (both cadastral and technical models), appropriate legislative framework supporting this 3D process, validation at various levels and use of advances in technical issues regarding the visualization and dissemination, are prerequisites for the successful implementation of 3D Cadastre and facilitate data exchange and interoperability between information systems.

For instance, while most jurisdictions do not use the building construction plans to update their cadastre, Costa Rica use BIM, which leads to the fact that more spatial and administrative details are provided (Van Oosterom et al, 2014). Additionally, an appropriate 3D cadastral data model plays a key role to ensure successful development of the 3D cadastre. LADM has proved that it provides the framework to support a flexible, systematic and incremental approach in the development of a land administration and management system catering to the needs, priorities and requirements of users and society (Lemmen et al, 2017).

The afore mentioned selective cadastral efforts mostly focus on the development of a 3D Cadastral Information System (fully or partly functional), without taking into account the whole life cycle of 3D in the spatial development chain. Many of those are based on the LADM concept and the corresponding LADM-based country profiles, while several of them include prototype systems and pilots using various physical models and data formats to achieve LADM implementation. Although the number of country profiles that have been developed is increasing significantly, those are limited to the conceptual model design. As stated by Lemmen (2012), the development of country profiles based on the standard aims to understand the structure within the individual country land administration system and show examples of structures that can be useful in building profiles for other countries

Several approaches have been developed towards the implementation and representation of those LADM-country profiles, however they are usually at a prototype stage, providing initial results and address useful conclusions for the limitations discovered. As a particular benefit of 3D cadastral systems is that they offer better visualization support for complex multi-level situations, providing clarity about the boundary of the land or any kind of property unit (Lemmens, 2010), it is expected that further research will lead to successful implementation and representation of LADM profiles. It is noted that those profiles are usually research initiatives from academia, with less or no involvement of the competent national organisation/agency for the Cadastre, with limited exceptions such as the Ministry of Land, Infrastructure and Transportation (MOLIT) in Korea which has proposed an extended LADM country profile for Korea (Lee et al, 2015).

In this context, the cadastral developments so far, lead to the need to improve and revise the LADM in the 3D context.

2.2 History and potentials of LADM

2.2.1 Current possibilities of LADM v1

The standardisation project of LADM started back in 2008, when the first proposal for standardisation was submitted as a result of activities within FIG since 2002 and after a series of reviews, comments and updated versions of the standard, it completed its first "cycle" on December 2012.

As stated by Lemmen (2012), the basis for the development of the LADM was "*A common denominator, or the pattern can be observed in global land administration systems: legal/administrative data, party/person/organization data, spatial unit (parcel)/immovable object data, data on surveying or object identification and geometric/topological data are all included*". Subsequently, the initial version of LADM was designed by experts from all over the world, based on the common pattern of 'people–land' relationships, re-using existing international standards (ISO 19107, ISO 19111, ISO 19115, ISO 19108), being as simple as possible to be useful in practice. LADM is currently maintained by ISO/TC 211.

The innovation is in the availability of the LADM as a basis for structuring and organising representations of people to land related information, in databases, in a generic way (Lemmen et al, 2015). According to the first version of LADM, its implementation can be performed in a flexible way as it can be extended and adapted to local situations, while also provides external links to other databases (supporting information infrastructure type of deployment). Thus, the scope of this initial version is very wide in order to satisfy diverse user requirements.

The major impact of LADM is through its recognition as an ISO standard for the domain of land administration (Lemmen et al, 2015) in 2012. The growing recognition and influence of the standard is revealed by the multiple country profiles that have been developed; several implementations of them through different technical models and encodings considering existing application schemas or developing new; as well as parallel activities, such as development of land administration domain ontology, support of strata titles, etc. Besides, the above-mentioned achievements, some options offered by LADM are still to be explored.

From a 3D cadastral perspective, concerning the different spatial units supported by LADM within the Spatial Unit package and the Spatial Representation and Survey sub-packages, LADM provides an abstract framework to model the components in land administration domain, offering several representations ranging from text to 3D topology. Specifically, it allows for a representation only with descriptive text, where no geometry is used ('text based' spatial units); representation with sketched and photographs ('sketch based' spatial units); representation with coordinates of a single point ('point based' spatial units); representation with lines and incomplete boundaries ('unstructured line based' spatial units); representation with polygons, where spatial units are defined as separate entities and no topological relations apply ('polygon based' spatial units) and representation when spatial units share boundary representations ('topological based' spatial units). Mixed representations are also possible to apply.

Within this framework and in the context of LADM, the "true" 3D representation of spatial units is described with arbitrary oriented faces within the "LA_BoundaryFace" concept, while it allows for mixed representations - integrated 2D and 3D - of spatial units using "LA_BoundaryFace" and "LA_BoundaryFaceString" concepts, without complicating 2D. Taking into account that a 2D parcel actually defines a column of space above and below the land surface, a 2D parcel is in truth a 3D parcel which has no explicitly defined top or bottom (Stoter and Van Oosterom, 2006). Liminal spatial units, which are a combination of boundary face strings and vertical boundary faces, are on the threshold of 2D and 3D representations (ISO 19152, 2012). They are used for 2D spatial units which are adjacent to 3D spatial units, with a split in the shared vertical boundary faces.

As underlined by Janečka and Karki (2016) and according to the requirements of LADM, topological information alone is not sufficient to describe a 3D spatial unit and according to the requirements of LADM, geometrical information must also be associated with each topological primitive, either as direct or indirect geometries (via related topological primitives with geometries). Regarding the 3D topology model in LADM, volumes should not overlap but may be open on the bottom or the top corresponding to non-bounded 3D_SpatialUnits (in this case, the size of the volume cannot be calculated) (Zulkifli et al, 2015).

Zulkifli et al (2015) review different 3D topological models to choose the most suitable one for certain applications within LADM concept. The authors conclude, that there is no single 3D topology model best suitable for all types of applications, as it depends on the type of each application and therefore, the requirements of the 3D topology model should be defined accordingly. Based on their research, a "*topological structure to organize tetrahedrons*", Tetrahedral Network (TEN) introduced by Penninga and Van Oosterom (2008), is one of the most suitable 3D topology models.

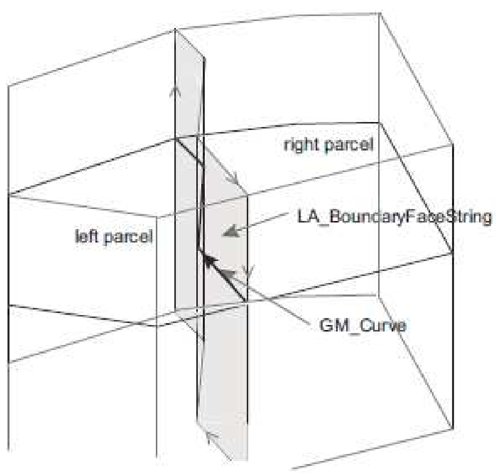

Figure 2. Spatial units defined by boundary face strings
(*Lemmen, 2012 – Figure designed by Rod Thompson***)**

Moreover, Ying et al (2015) propose a data model oriented towards the application and storage of a 3D cadastral system. Particularly, the authors extend the geometric-topological model in LADM, which is based on ISO 19107, and redesign the model to support non-manifold 3D objects to represent realistic 3D cadastral objects. They propose a method to efficiently recognize and construct solids and represent the topological relationships of valid volumetric solids in 3D space in a straightforward way, whether there is an isolated solid, or a multi-solid/solid set. Moreover, the internal structure and spatial relationships of a complex volume set are preserved by maintaining each volume under valid control. In terms of geometry, the concepts and classes of GM_Point, GM_MultiCurve and GM_Surface are imported from ISO 19107 (ISO 19107, 2003) and provide all the functionality needed in the context of LADM.

At the Spatial Unit package of LADM, the LA_Level class defines "*a set of spatial units, with a geometric and/or topologic and/or thematic coherence. This concept is important for organizing the spatial units in LADM.*" (ISO 19152, 2012). It is important to note that the principle of legal independence is supported through this class as the type of land register and different types of spatial units can be combined in one level and this allows for integrating data delivered by different organizations with different mandates and for integrating data based on different spatial units (Lemmen, 2012). The code list values of the "structure" attribute of LA_Level class (LA_Structure_Type) include the various spatial structure types (text, point, unstructured line, polygon, topology), used in a specific land administration profile implementation.

Furthermore, Annex E of LADM ISO 19252 (ISO 19152, 2012) describes six spatial profiles based on the "structure" attribute in class LA_Level, as follows:

- 2D point based,
- 2D Text based,
- 2D Unstructured line based,
- 2D Polygon based,
- 2D Topological based and
- 3D Topological based.

The spatial profile that will be used at a country profile is subject to its purpose, while it is also possible to combine several spatial profiles. Depending on the spatial profile implementation, some classes should be omitted (Annex E ISO 19152, 2012). For instance, for the 3D Topological based spatial profile, which describes pure 3D topological volumes without overlapping volumes, the LA_BoundaryFaceString class should be omitted as it represents 2D, while as part of the constraints and the conditions that should apply, the attribute "structure" is fixed to 'topological' in 3D_Level class, while in 3D_SpatialUnit class the attribute "dimension" is fixed to '3D'.

Normally 3D land space is bounded by vertical and default "ceiling and floor" faces (Ying et al, 2011), however, for cadastral purposes 3D objects may need to satisfy operations and associations different than those of other "simple" 3D objects, to reflect real-world situations.
Ying et al (2015) state that regarding 3D cadastral objects, a valid volumetric object is defined as a 3D primitive that can be represented by one close polyhedron, refined by a set of

connected faces, satisfying the following characteristics: closeness, interior connection, face construction and proper orientation. Thus, the volumetric object can have through-hole/ring or cavity that allows its boundary faces to touch each other, which is not a 3-manifold in some cases. Besides, practice has shown that most of the LADM country profiles that have been developed are limited to the conceptual model design and do not include implementations or 3D representations.

2.2.2 LADM-based country profiles in the context of 3D

Although LADM provides an international framework, conceptually effective to support 3D Cadastre development (Oldfield et al, 2017) encompassing a wide range of eventualities, it does not stipulate the requisite data format (encodings) for implementation (Janečka and Souček, 2017). Among the prototype and pilots that have been developed the last years, only a few have achieved direct LADM implementation. This sub-section briefly refers to selected country profiles focusing on the way they handle the 3D support of LADM.

To start with, in Israel, the concept of the 3D sub-parcel concept was introduced by Shoshani et al (2005) and is based on subdivision of the unlimited column of space implied by the 2D surface parcel into at least one completely bounded 3D volume and a remaining (unlimited) space. In Israel a holistic SDI approach for meaningful data exchange between various stakeholders was introduced. Felus et al (2014) developed the Israeli LADM country profile and the first step towards 3D parcels was the introduction of the 3D IL_BoundaryFace as a specialization of LA_BoundaryFace class.

One of the first countries to develop a pilot LADM country-based profile was Russian Federations (Elizarova et al, 2012). The proposed model included 5 types of property objects (land parcels, buildings, premises, structures and unfinished construction projects), 3D models for buildings were developed and 3D objects were represented as polyhedrons. For technical implementation, an interface containing a 3DViewer was selected to support selection of attributes. Web dissemination of 3D cadastral objects was enabled, while added reference objects such as DTM, walls of buildings and scanned map allow for spatial interaction with data in 2D/3D environment and selections/queries.

Furthermore, Góźdź, K. and Pachelski, W. (2014) developed the 3D LADM Polish country profile where the registration of 3D cadastral objects is supported by the new classes: PL_3DParcel and PL_CadastralParcel and two specializations PL_RestrictedParcel and PL_UnrestrictedParcel. An instance of the class PL_UnrestrictedParcel is a cadastral parcel representing "infinite column" (a column with inaccurate vertical boundaries determined by social and economic purposes of land use), whereas an instance of the class PL_RestrictedParcel is a cadastral parcel representing a column reduced by volume of legal space of: 3D parcel(s), building(s) or utility networks (Góźdź et al, 2014). For the technical implementation of the country profile the authors proposed a CityGML-LADM ADE, drawing particular attention to the buildings as cadastral objects. The link between legal objects and the corresponding physical is an association between the classes LA_LegalSpaceBuildingUnit (from LADM) and _AbstractBuilding (from CityGML).

Janečka and Souček (2017) proposed a comprehensive LADM country profile for Czech Republic in the context of a multipurpose land administration system. The Czech LADM country profile uses 2D topological based spatial units for the representation of spatial units. The concept of LA_Level has also been used and there is a base level (Level 1) with topologically-defined spatial units (structure: CZ_StructureType = topological) and a Level 2 with polygon-based spatial units (structure: CZ_StructureType = polygon).

An interesting approach was developed by Lee at al (2015) who proposed a 3D land administration model for Korea using a cadastral resurvey form, including the representation of 3D physical properties and 3D rights. The model is based on the initial Korean LADM-based profile (Kim et al, 2013) which was limited to 3D and the new model supports underground utility and superficies information to present the physical and legal information on both buildings and underground feature. A specialization class of LA_Parcel has been added, 3D_UndergroundParcel, to include 3D information such as 3DSurface, ConstructionParcel, LegalSpaceParcel, FragmentParcel and ConsolidatedParcel. Accordingly, the Surveying and Representation Sub-package has been extended with a new package, 3D_Surveying and Representation Sub-package, to support the structures of 3D_UndergroundParcel class.

Last but not least, a lot of work has been carried out for the development and the implementation of the Malaysian LADM country profile (Zulkifli et al, 2014a, Zulkifli et al, 2014b, Zulkifli et al, 2015). The Malaysian profile includes support for strata objects and the Spatial Unit package includes support for 3D spatial unit representing building (MY_Building class), utility and lot. The class MY_Shared3DInfo is a specialization of LADM's LA_SpatialUnit class and has two subclasses: MY_Building and MY_Utility containing common attributes such as a GM_Solid geometry attribute, a variable length volume attribute with at least one LA_VolumeValue and a Boolean attribute indication whether the object is provisional or not (Zulkifli et al, 2014b). The class MY_GenericLot is a subclass of LA_SpatialUnit class and comprises of two subclasses; MY_Lot2D and MY_Lot3D representing 2D and 3D lots correspondingly. Topology is not used. For the technical implementation, 2D cadastral objects (MY_BoundaryFaceString) were represented using polyline (GTYPE=2002) and 3D strata volume objects (e.g MY_ParcelUnit, MY_Shared3DInfo) are stored by multipolygon method (GTYPE = 3007) using Oracle Spatial (MDSYS.SDO _GEOMETRY type). The prototype allows for the representation on Bentley Microstation, where queries and 3D editing of objects are supported.

Similarly, the concept of LA_Level has also been used at the LADM country profile for Greece (Kalogianni, 2015) as presented in Figure 3 below. Different types of spatial units have been organized in levels (class GR_Level) allowing the flexible introduction of spatial data from different sources and accuracies. The organization of spatial units in different levels allows also for different spatial representation according to the nature and framework of each object, thus providing the option to use topology and/or geometry according to the requirements of each "level".

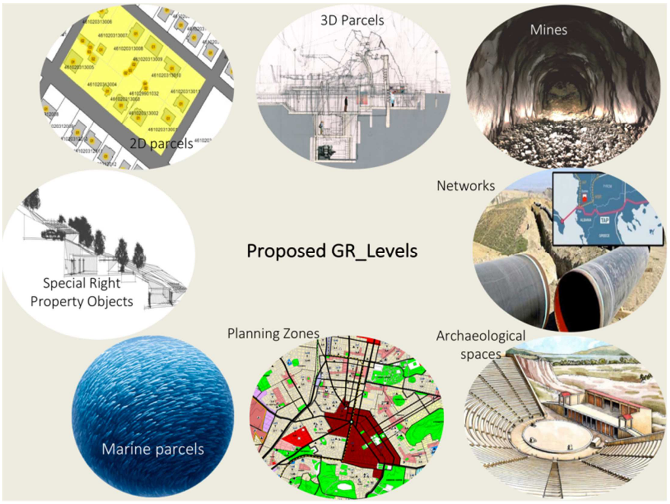

Figure 3. Levels from different types of spatial units created for the Greek LADM country profile (*Kalogianni, 2015*)

2.2.3 Linking LADM with physical models

In the context of the significant developments in computer graphics in terms of modelling and rendering 3D models of urban structures in different formats and Levels of Details (LoDs), the research on the integration of legal and physical aspects of objects has received significant attention (Kalogianni et al, 2017). Legal information refers to legal interests, boundaries and attributes, as well as it is a prerequisite for managing Rights, Restrictions and Responsibilities (RRRs), maintained by cadastral data models (LADM, ePlan). On the other hand, data associated with physical objects is characterized by geometric and semantic information in various LoDs, maintained by physical data models (CityGML, BIM/IFC, IndoorGML), which do not support legal or cadastral information. Throughout the research that has been carried out the last 5 years since the adoption of LADM as an international standard, more and more researchers (Alattas ET AL, 207; Atazadeh et al, 2016; Soon et al, 2014; Góźdź et al,2014, etc.) investigate the integration between legal and physical data models (for reference/ orientation purposes) to simultaneously manage both legal and physical dimensions of 3D RRR data, as well as its technical implementation through application schemas and technical models (CityGML, IndoorGML, BIM/ IFC, LandXML, InfraGML, etc.).

Given the nature and structure of such models, it is important to identify the needs for further 3D modelling, regarding code lists, associations, constraints (including those between legal spaces and physical models), data types, validation rules, visualization aspects, etc. as well as outline the expectation for the future. Additionally, technical issues that arise from data acquisition, submission and validation need to be addressed.

Thompson et al (2016) have already addressed some technical issues regarding the encoding of cadastral information through LandXML and InfraGML. Specifically, they recognise that within the LandXML structure, the integrated footprint and LA_BoundaryFace volumetric approach can be encoded in two different schemes: Simple Faces Method and Nested Parcels

Method. According to the authors, spatial units transferred as full 3D polyhedra can be converted to the integrated footprint and LA_BoundaryFace form in the database.
The same authors underlined that an important topic to further explore is the link with ExtPhysicalBuildingUnit (as represented according to CityGML or IndoorGML or BIM/IFC) in terms of which LoD level is being referred to. Obviously, when a single building contains multiple spatial units, then indoor is needed (LoD4 in CityGML or perhaps better use IndoorGML or BIM/IFC representations).

Considering the different LoDs of CityGML, Thompson et al (2016) discussed that LoD0 in City Models could be represented as a 2D footprint, LoD1 as a "Prism" (footprint with top and/or bottom), while LoD 3 and LoD4 as a complete 3D geometry, including indoor, as one building may contain multiple spatial units).

Furthermore, Oldfield et al (2017) proposed a mapping of the LADM to the IFC. The LA_SpatialUnit has been mapped at the level of IfcSpace. It is noted that the IFC works primarily with solids rather than boundary representation (BuildingSmart, 2017). There are many types of solids in the IFC, which are can made by extruding from a circle, rectangle, or polygon, although the IFC also allows many types of boundary representation. The authors choose three forms of geometric boundary representation from the variety of options provided by the IFC: points (nodes), edges (straight lines), and surfaces (faces). None of them involve curves, unless they are planar. They are open shell by means of infinite prisms, closed shells, polygonal bounded half-spaces, and faceted boundary representation (brep). Open and closed Shells and faceted brep can straightforwardly be mapped to the LADM. The cartesian points, which are their most basic building block, map to LA_Point (GM_Point); the polyloops formed from the points equate with LA_BoundaryFaceString (GM_Multicurve) and the connected faces, which edge them (IfcConnectedFaceSet) to LA_BoundaryFace (GM_Multisurface).

Last but not least, Alattas et al (2017) investigate the combined use of IndoorGML and the LADM and propose an IndoorGML-LADM extension by linking the Spatial Unit Package of LADM with the spatial features of indoor space from the CellSpace in the IndoorGML through an association. Particularly, the cell space associates the primal space to the LADM, providing the spatial information about the indoor space type to LA_SpatialSource, which associates the spatial information to LA_SpatialUnit.

3. LADM REVISION: REQUIREMENTS

Last year in Delft, the "UN-GGIM Meeting of the Expert Group on Land Administration and Management" and the "6th Land Administration Domain Model Workshop" were organized. Lessons learnt from currently operational and proposed country profiles and their implementations of the first version of LADM have been discussed and the main conclusion was that a second LADM revision is needed (Van Oosterom, 2017).

The aim of this revision will be to refine and further model in detail aspects that are already in the scope of LADM. Analysing the most important results from the LADM country profiles

experience it is concluded that in several cases a specialization of LA_Parcel class has been created in order to support the needs of 3D cadastral objects in each jurisdiction, accompanied by the corresponding newly added classes at the Surveying Representation sub-package. In some implementations, LA_Level is used in order to classify the spatial units according to their topology/geometry or in modules according to the different levels of spatial units that are included. However, at most of the cases the classes of the Spatial Unit Package are used as proposed by the core LADM model. Main conclusions from the work that has been carried out the last four years within FIG Joint Commission 3 and 7 Working Group on 3D Cadastres should be taken into consideration (Van Oosterom, 2018).
At a conceptual level, the need for explicitly model all the use cases of 3D Cadastre, including different types of spatial units (marine, archaeology, planning, mining, air, etc.) has been underlined and could be added as a new user requirement.

For the purpose of this revision it is considered that user requirements for LADM should be updated in order to address current needs. From its begging LADM has been developed based on a set of user requirements, which has been updated for each three initial Versions (A, B and C) before its standardisation as ISO (Lemmen, 2012).

Based on the current possibilities of LADM, the challenges derived from country profiles and the link with physical models, this Section briefly discusses some of the core User Requirements for LADM (as presented in Lemmen, 2012) that need to be updated during this revision, paying attention in placing 3D Cadastres in context the whole chain of spatial developments and not seeing it as an individual activity.

Referring to the User Requirements for LADM as described in Christian Lemmen PhD Thesis (Lemmen, 2012, p. 92):

- Requirement C08, "*System boundary of LADM, external classes and information infrastructures*": considering external classes and more specifically ExtPhysical-BuildingUnit and ExtPhysicalUtilityNetwork, more explicit and specific relations with the physical models that those classes are linked (CityGML, BIM/IFC, IndoorGML, Infra-GML, LandXML, etc.) should be established.
- Requirement C10, "*Miscellaneous*": should be updated in order to cover the needs generated from current experience. Specifically, a new requirement may derive from C10 regarding code lists, as more explicit modelling and semantics of code list are needed, since currently they are not structured and need to become more normative and use hierarchical structures. Adopting the principles of the ISO 3166 (the International Standard for country codes and the codes for their subdivisions (ISO 3166, 2006)) could be discussed.

Moreover, considering 3D Cadastre as part of the whole spatial development chain will probably generate new user requirements that should be addressed in the context of this revision. Indicatively, as the implementation of LADM through an existing application schema or a new one will be a matter of priority in this revision, the general requirements for this link should be addressed.

Lastly, further requirements include among others, formalisation of constraints and establishment of validation rules, further and explicit modelling of RRRs, attention at the temporal aspect (4D) for both space and time, etc.

4. OPPORTUNITIES FOR REFINEMENTS ON CURRENT 3D LADM SUPPORT

To conclude, from the knowledge and the collective experience gained through the last 6 years since the adoption of LADM as an ISO standard, there are lessons learnt and many conclusions that need to be taken into account in the context of this revision.
The current spatial development life cycle of an object begins outside the cadastral registration cycle and has a direct impact on how a specific development application is processed. Thus, in considering the changes required to allow a jurisdiction to register 3D objects, it is important to note the sphere of influence that could have an impact on 3D registration. These include multiple stakeholders and processes, which generate different user needs, as addressed at the previous section and also new opportunities that could be addressed on the current LADM version.

To start with, the implementation of LADM has been achieved with multiple technical modes, application schemas and encodings. This is due to the fact that the spatial package of current LADM version is abstract and can be implemented with many ways, according to the needs of the user, the purpose of the model, the available data, the complexity of allowed geometric features and the capacity of the system to accommodate these complexities. Accordingly, not a single encoding may be used for converting the conceptual model to the technical, but multiple application schemas can be used to achieve it. However, this leads to incompatibility within systems and does not allow for data exchange, which is a fundamental requirement of LADM.

In this direction, it may be wise to discuss multiple directions/approaches and further model current (e.g. topological profile) or sharpen new spatial representations and spatial profiles (e.g. point clouds profile, for non-topological 3D parcels) dedicated to the most dominant technical models used for the implementation. The proposal and exploration of technical encodings possibilities (for initial registration, for dissemination/ visualization, etc.) and more explicit modelling of links with external physical objects enhance a fit for purpose approach.
In all cases, validation is necessary and for each proposed spatial profile the corresponding validation rules and tests, constraints, functions and semantics should be defined. Indicatively, (automatic) check of 3D cadastral object before input in DBMS, use of proper (spatial) data types in DBMS during storage, check for possible conflicts with other 2D or 3D objects, check for possible conflicts with earth/water surface, validity check of spatial data types, check for consistency between legal/admin and spatial attributes, etc. It is considered wise to also define "cross-model" associations and constraints referring to both the legal and the physical aspect of the cadastral objects. In this context, apart from the geometrical aspect, the semantic aspect of data sources should also be considered as data in BIM/IFC, CityGML LandXML, InfraGML, IndoorGML, etc. are produced based on different domain knowledge and this may cause conceptual and terminological differences between data sources if these data sources are to be integrated (Soon, et al, 2014).

Similarly, the need for further modelling of LADM Rights, Restrictions and Responsibilities (RRRs) has been underlined in multiple country profiles supporting all kind of land and property rights, as well as Fit-For-purpose approach and is expected to be addressed at the second version of LADM.

Furthermore, the development of a process and workflow standardisation (initial registrations, ISO TC307, survey workflow, etc.) for new/updated 3D parcels to serve as part of the whole spatial development chain, as well as possibilities for 3D web-based dissemination (usability, man-machine interfaces, including Augmented/ Virtual Reality) should be discussed as possible aspects of LADM revision.

Last but not least, extensions of current model are expected to be addressed in the context of LADM revision. More specifically, valuation information (which could might help to support Fit-for-Purpose approach) is an important aspect that should be included at the second LADM version and provide an information model for valuation databases based on LADM (Kara et al, 2017). In this context, the development of a 3D underground cadastral data model with LADM (Lee et al, 2015) as an extension of current model should be examined.

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