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Investigating 3D spatial units' types as basis for refined 3D spatial profiles in the context of LADM revision

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Key words: LADM revision, 3D Cadastre, 3D spatial profiles, spatial units

SUMMARY

Dense urbanisation has led to an increasing demand and pressure for land development, resulting in the partition of 3D space into different owners sharing delimited property interests on, above or below the land surface. Consequently, cadastral spatial units range from simple, but most common, 2D, to complex 3D collections of spaces worldwide, that are more difficult to handle in terms of surveying, storing in a database, maintaining, visualising, etc. Subsequently, this asks for the categorization and organization of the different types of spatial units that are physically identified and legally recognised in various jurisdictions worldwide. In the context of the Land Administration Domain Model (LADM) (ISO 19152, 2012), the “level” concept (LA_Level class) provides a framework for organising the different types of spatial units. Based on that, five levels of encoding are defined in ISO19152, providing a framework of categorisation of 2D spatial units, represented by five spatial profiles included in Annex E of ISO 19152.

Six years after the publication of the first edition of LADM as ISO standard, a lot of research has been carried out by experts from all over the world, and today, the ground seems to be mature for the LADM (edition I) revision, which started in May 2018, as a joint activity with many stakeholders involved (ISO TC211, OGC, FIG, etc.). One of the goals of the revision, among others, is to improve LADM's current 3D support. This can be achieved through the design of new 3D spatial profiles for the different types of spatial units that are recognised by cadastral authorities in various jurisdictions. New and different 3D spatial units' types may be considered for inclusion in the standard.

To this end, the aim of this paper is to investigate, examine and review - in the context of LADM revision- the different types of real-world spatial units, as they have initially been organised by Thompson et al (2015). Based on the revised taxonomy, spatial profiles for the spatial units' categories are introduced and (several) are further explored and designed. Hence, the focus on this paper lies on two levels: the taxonomy and the spatial profiles, while the level of encoding is not included in the scope of this paper. However, the investigation of the technical encodings that will be used for the implementation of the 3D spatial profiles is introduced at the paper as future work, underlying its importance. Within this concept, the scope and ambition of LADM revision are discussed.

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1. INTRODUCTION

Cadastral parcels range from 2D to 3D collections of spaces around the world and are defined at multiple levels of sophistication (Thompson et al., 2017), depending on the available data, the regulations of each jurisdiction, the land market requirements, etc. The complexity of volumetric spatial units worldwide is highly variable, but in practice the vast majority of 3D spatial units is composed of simple components. Even where the spatial units are apparently complex, most boundary faces of real cadastral spatial units are either vertical or horizontal, and a significant majority of them is composed of a simple polyhedral slice: a prism resulting from the vertical extrusion of a 2D polygon (Thompson et al., 2016a).

The last years, the spatial management of complex urban (and rural) environment is asking for 3D registration and representation of Rights, Restrictions and Responsibilities (RRRs). The first edition of the Land Administration Domain Model (LADM) (ISO 19152, 2012) allows for all those levels of complexity (2D, 3D, as well as integrated 2D and 3D spatial units) with various levels of accuracy, through the Spatial Unit Package and the Spatial Representation and Survey Sub-package (LADM, 2012; Lemmen et al., 2010). The LADM offers a very generic spatial representation model, as it has to be applicable worldwide for a variety of spatial units ("normal" land parcels, legal spaces inside and around buildings, legal spaces around constructions and around networks/utilities, legal spaces around telecom signals and legal spaces in the marine environment), according to the users' needs, the available data, the complexity of allowed geometric features and the capacity of the system to accommodate these complexities, etc.

LADM has gained wide use and interest and is now moving forward to a next step, refining, extending and improving its initial scope to meet new requirements from different domains. This will result in the improvement of specific aspects of the current domain model, such as the design of explicit 3D spatial profiles to refine the modelling, storage and visualisation of 3D spatial units. Potential conceptual model extensions also include support of 4D functionality and datasets with the modelling of explicit 3D+time profiles. Spatial profiles are important to better express the different types of 3D spatial units, as they have been defined according to the use cases presented in previous works (Lemmen et al., 2010; Thompson et al., 2015; Thompson et al., 2016a; Thompson et al., 2016b; Thompson et al., 2017). Moreover, the need for refinement of its current 3D support has been highlighted through various national LADM-based profiles, prototype systems and pilots that have been developed (FIG 2018a, FIG 2018b). Additionally, the technical specification of LADM-based models through encoding models, which allow integration with other geo-information standards, like BIM/IFC, GML, CityGML, LandXML, LandInfra, IndoorGML, RDF/linked data, GeoJSON, INTERLIS (Lemmen et al., 2018) is a matter of priority for this revision. What is more, at the second LADM edition it is expected that detailed 3D spatial profiles will be designed according to the spatial units' categories, as initially provided by Thompson et al.

(2015) to explicitly model their characteristics. This is possible using technological advancements in techniques for 3D/4D modelling, storage and representation of such objects, and dissemination of this information to the land administration systems' and products' users that enable further and refined modelling of spatial units.

Thompson et al. (2015) realising the need for classifying the real-world spatial units recognised in various jurisdictions, have provided an initial categorisation of them. This taxonomy has been originally created to classify and count spatial units of different types and was partly based on the "local" needs of Queensland, Australia. In the context of this paper, this taxonomy is examined and validated and/or extended. When needed, based on the resulting taxonomy, corresponding 3D spatial profiles will be designed at a conceptual level and tested in an effort that covers use cases from the real world. At a next step, application schemas and encodings will be used for the technical specification of these profiles. This is an iterative process and thus, testing the proposed spatial profiles through encoding in order to enable interoperability with other standards, may result to the re-design of the profiles.

This paper's objective is to propose a modelling approach for the 3D spatial profiles that may be included in a future Annex of LADM II, aiming to initiate a discussion about the improvement of current 3D support of LADM I.

The rest of the paper is structured as following: Section 2 presents the intended scope and ambition of LADM revision, which has officially started in May 2018. Section 3 presents the modelling approach of spatial units within the LADM revision and use cases that will be used to test, at a next step, the taxonomy and the proposed spatial profiles. The next Section discusses the taxonomy of 3D spatial units as it has been introduced and now revised, providing a deeper insight into its concept and confirming its rationality. Following, the modelling approach/principles of LADM II spatial profiles for 3D spatial units is presented in Section 5. Furthermore, Section 6 summarizes the conclusions of this research, while the last Section discusses the importance of the next step; the investigation of the encodings that will be used for the technical specification of the 3D spatial profiles.

2. LADM REVISION

The New Working Item Proposal submitted to ISO TC211 in May 2018 provides an overview of needs and requirements of identified LADM improvements and extensions that are needed, as well as process models (FIG, 2018a). The upcoming revision will be a joint activity, supported by many organisations and institutions (ISO, OGC, World Bank, UN-GGIM, GLTN, FIG, IHO, RICS, Kadaster, TUDelft, etc.). Each one will be involved and contribute to different aspects of this process, i.e. OGC will provide steps towards implementations in encodings, IHO will contribute to the LADM support to marine environment/cadastre, etc. The ambition is to go beyond just a conceptual model by providing steps towards implementations (e.g. more specific profiles, technical model in various encodings, etc.), The first edition of LADM should be upwards compatible with future editions. In this Section, the core aspects of LADM revision, are introduced.

Firstly, it is proposed to extend the scope of LADM with a valuation perspective based on Çağdaş et al (2016) and Çağdaş et al (2017). This proposal provides a data model that could be used to construct information systems for immovable property valuation (as basis for taxation).

Moreover, the research on the integration of legal and physical notions of objects has received significant attention in recent years, and various approaches are being developed. Legal space and legal objects have their own geometry which is in many cases not (or not completely) aligned with physical space and physical objects. Legal space should be linked to physical objects – by IDs or re-use of descriptions of space. For instance, the users of indoor spaces create a relationship with the space depending on the type of the building and the function of the spaces. Applying LADM allows assigning Rights, Restrictions, and Responsibilities to indoor spaces, which indicates the accessible spaces for each type of user. An IndoorGML-LADM model is one example of linking physical and legal objects (Alattas et al., 2017).

LADM provides an international framework, conceptually effective to support 3D Cadastre and its worldwide is gaining ground as many 3D Cadastral prototypes and pilots are developed based on that. However, at its current version the 3D support is limited and there is need to compement and refine its 3D functionality and thus design detailed 3D spatial profiles for the different types of spatial units. Moreover, more functionality is required for 4D representations, including geometry or topology and time profiles.

Additionally, an extended survey model and legal model are needed. This implies adjustments from field observations to the spatial database and the generation of quality labels. Encodings models concern the further detailed technical specification of LADM based on existing standards: BIM/IFC, GML, CityGML, LandXML, InfraGML, IndoorGML, RDF/linked data, GeoJSON, INTERLIS. BIM is very important in order to establish a link between building information and land administration domain in relation to spatial planning and lifecycles of constructions/ buildings. Open data is about adding semantics to Coding of Rights, Right holders, Spatial Unit Types, etc. See Informative Annex J of (ISO 19152, 2012) – W3C.

What is more, LADM standard is applicable to Marine Cadastres. Today, there is need to have special attention for the transition zone from land – sea and Marine Spatial Planning (MSP). A normative reference to IHO S121 (Marine Limits and Boundaries) based on the LADM principles needs to be included in the second edition of LADM.

The Global Land Indicators Initiative (GLII), see UN Habitat/GLTN (2017) and UN ECOSOC and African Union (2016) seeks to derive a list of globally comparable harmonized land indicators, using existing monitoring mechanisms and data collection methods as a foundation. LADM edition II is considered to be among the internationally agreed standards that will play key role alongside agreed global concepts and evidence-based approaches.

Another goal of the revision is to include at the second LADM edition spatial planning/zoning with legal implications. In principle this is a matter of coding zones in meaningful code tables (based on the local situations). This further implies integration of spatial planning and land administration domain. For instance, re-use of zones from spatial planning into restrictions to land rights should be possible. Other legal spaces are related to mining, archaeology, utilities (2D or 3D), etc.

Moreover, for the domain of land administration, the localization issue extends from language names to the various organisations and institutions dealing with interests in land. This applies also to LADM and especially at the code lists and their values that are created for each jurisdiction. Paasch et al (2015), propose code lists as a mean of internationalization by which the classes of the LADM may be related to the jurisdiction concerned.

Generic process-related modules in data acquisition, data handling and also maintenance and publication are needed. Process information is information on who has to do what in approving the transaction. LADM in its current edition has roles already included as well a

series of dates as interaction to processes, however the standard does not include Land Administration processes for initial data acquisition, data maintenance and data publication (Lemmen et al., 2018).

In this context, cadastral map updating includes adjustments and transformations of field observations (collected at different moments in time and with different survey instruments or use of imagery from different sources) to the spatial database. Management of values/measures is needed – there may be more than one value to be maintained for the same spatial unit – the legal area and the accurate area as calculated in the cadastral GIS. Implementation of tolerances to manage the differences should be flexible and purpose related. Results of subdivisions of spatial units may need to be shared with other systems. This includes results of readjustments and land consolidation.

Similarly, blockchain technology in transaction processes could be very well applicable for transactions in land administration. Another type of UML diagram may be needed to represent processes – thereby creating a connection between the classes of workflow management module and LADM classes.

Finally, interoperability, data sharing and data integration is needed in development of land administration. Thus, at the second edition of the standard there will be a need for considerably more integration across the various national data and information systems and platforms in order to leverage the most effective data and analysis for evidence-based policy formulation and decision making. Image-based acquisition of cadastral boundaries needs access to huge image libraries – including historical imagery – to support large-scale implementations.

3. MODELLING OF SPATIAL UNITS WITHIN THE LADM REVISION

In the context of LADM revision different spatial representations will be investigated and proposed for the various types of spatial units. To efficiently model those representations, it is important to observe the aspects that are involved when classifying the spatial units and modelling the spatial profiles. Within the framework of this paper, regarding the modelling of spatial units, focus will be given at two levels: at the taxonomy of the spatial units and the spatial profiles. The aspects that are involved may occur at both levels, or in other cases only at one of the levels. As a next step the level of encoding should be investigated, but this is out of the scope of this paper.

To start with, the taxonomy proposed by Thompson et al. (2015) is based on the complexity of actual physical shape of spatial units (e.g. number of bounded faces, open or closed volume, single-multi volume, etc.). This also affects the modelling of spatial profiles and consequently the application schemas and encodings that will be used for their technical specification. In this paper, this taxonomy is further analysed and enriched in some cases, while the aspects that affect the modelling of spatial units are included at the proposed modelling approach and the UML models that describe the spatial profiles.

An aspect that should be considered is that depending on the jurisdiction's laws and regulations, boundaries are defined by topographic objects, as in the United Kingdom, or they are described by their own coordinates usually derived by surveying (as in the Netherlands). When talking about general/topographic boundaries, a reference to the topographic object should be included at the corresponding spatial profile to specify one or more 3D boundary

surfaces. This issue affects the modelling of spatial profiles, while the changes that occur at the parcel and the profiles when the refereed object is changing should be considered. At the next step regarding the technical specification of the profile, this reference can be linked with BIM/IFC models, building format plans, etc. to enable interoperability with other standards.

Similarly, many spatial units are defined (partially) referring to another surface. The link with the surface (could be earth surface or another spatial unit) should be included at the spatial profile level. There is also the case that spatial units cannot be modelled and treated as individual, stand-alone units and they need to be defined in the context of neighbour(s) spatial units. This relation should be defined both at the levels of taxonomy and spatial profiles.

What is more, the structure based on what the spatial unit is defined should be depicted at the spatial profile level and then at the encoding level. Particularly, whether the spatial unit is defined as part of a coherent set forming space partition and should be defined at a topological structure, or the spatial unit has its own independent description and is defined using geometrical primitives are aspects that need to be considered through the modelling of UML class diagrams for the spatial profiles.

Furthermore, spatial units can be categorized in terms of surveying, storage, visualisation and administrative purposes. Moreover, they can be sorted depending on the spatial development lifecycle phase or BIM cycle they occur, for instance at the design phase (data acquisition, data modelling), management and maintenance (data storage and registration), permitting, construction, operation phase, etc. Particularly, the same spatial unit may use different 3D spatial profiles and encodings; e.g. for data acquisition phase a point cloud could be used, then for storage/data management this will be converted and included in a 3D topology structure, but for visualization a 3D geometry / solid type could be used.

What is more, some real-world 3D parcels (the simplest ones, such as slice, semi-open spatial units) may be quite different for land administration system's and product's users, however they may not be that different in their implementation (e.g. attributes such as top or bottom surface, with or without a volume).

In this regard, there are various criteria and aspects that need to be considered and modelling dilemmas and decisions to be taken, when classifying the real-world spatial units and modelling the spatial profiles, while it is crucial to decide the level of detail of the approach to be followed. Particularly, the "simplest" form of the spatial units can be modelled as it usually covers a big percentage of the recorded and registered units.

Given this background, use cases of various types of spatial units are the starting point for their modelling and classification, while they will also be used to test the efficiency and functionality of the taxonomy and the proposed spatial profiles. The refined 3D spatial profiles that will be designed for LADM revision are part of the implementation and thus, a single profile may suit multiple use cases.

The LADM identifies and supports the need to organise spatial units with different criteria through the class `LA_Level` of Spatial Unit package. A "level" is a collection of spatial units with a geometrical, topological or thematic coherence. This concept is important for organising the spatial units and is used for the implementation of the notion of "legal independence" from "Cadastre 2014" (Lemmen et al., 2010). In this way, a possible organisation of spatial units would be in allocating levels for types of spatial units depending on their spatial representation: text based, sketch based, point based, line-based, polygon based, volume based, or topology based (Lemmen et al., 2010). Another approach is a level structure for urban areas, rural areas, forest areas or mining areas; or a level with informal

rights and another with formal, etc. Hence, there are multiple ways supported by LADM to organise the spatial units that need to be spatially represented and thus corresponding spatial profiles should be designed.

In this context, Kalogianni (2015) has proposed a way to organise the wide range of spatial units for the proposed Greek LADM country profile using the “level” concept. This model allows for the flexible introduction of spatial units and related information from different sources and accuracies, including entities with different requirements which are not currently registered at the Hellenic Cadastre. Therefore, for Greece, the following levels were proposed (Figure 1) according to their thematical coherence: level 1 for archaeological spatial units, level 2 for “normal” 2D spatial units, level 3 for 3D spatial units of any complexity, level 4 for mines, level 5 for Special Real Property Objects – SRPOs (very common cases in Greek islands where land parcels and buildings are partially or totally overlapping to each other.), level 6 for planning zones and level 7 for marine parcels.

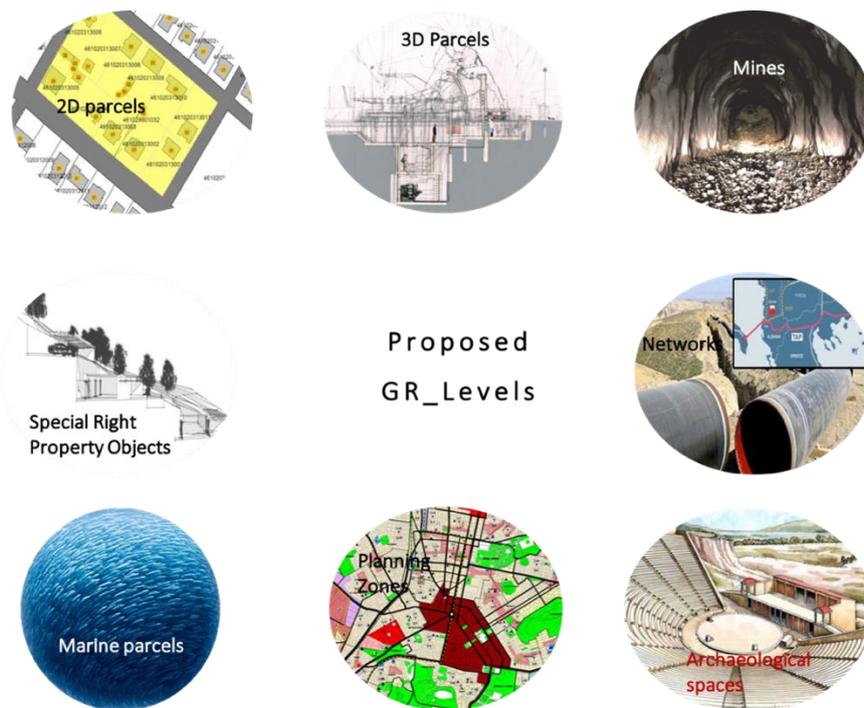


Figure 1. Levels from different types of spatial units created for the Greek LADM country profile (Kalogianni, 2015)

Since those levels have been created considering their thematical coherence, they present similarities and mismatches in their geometrical or topological encoding, as well as their technical specification(s). Within the scope of this research, representative real-world 3D cases of Greece will be used at a later stage, to test spatial units’ classification (as described in Section 4).

Figure 2 presents an overview of the specialisations of GR_SpatialUnit class that form the “levels” of the Greek model. For each level a corresponding class with attributes, constraints, operations and code lists has been created. At a next step the link between those classes and the spatial profiles will be investigated. For instance, the spatial units that will be stored at the

GR_LegalSpaceBuilding and GR_LegalSpaceUnfinishedConstruction classes, could fit into the building/construction format spatial units and be represented through BIM/IFC models.

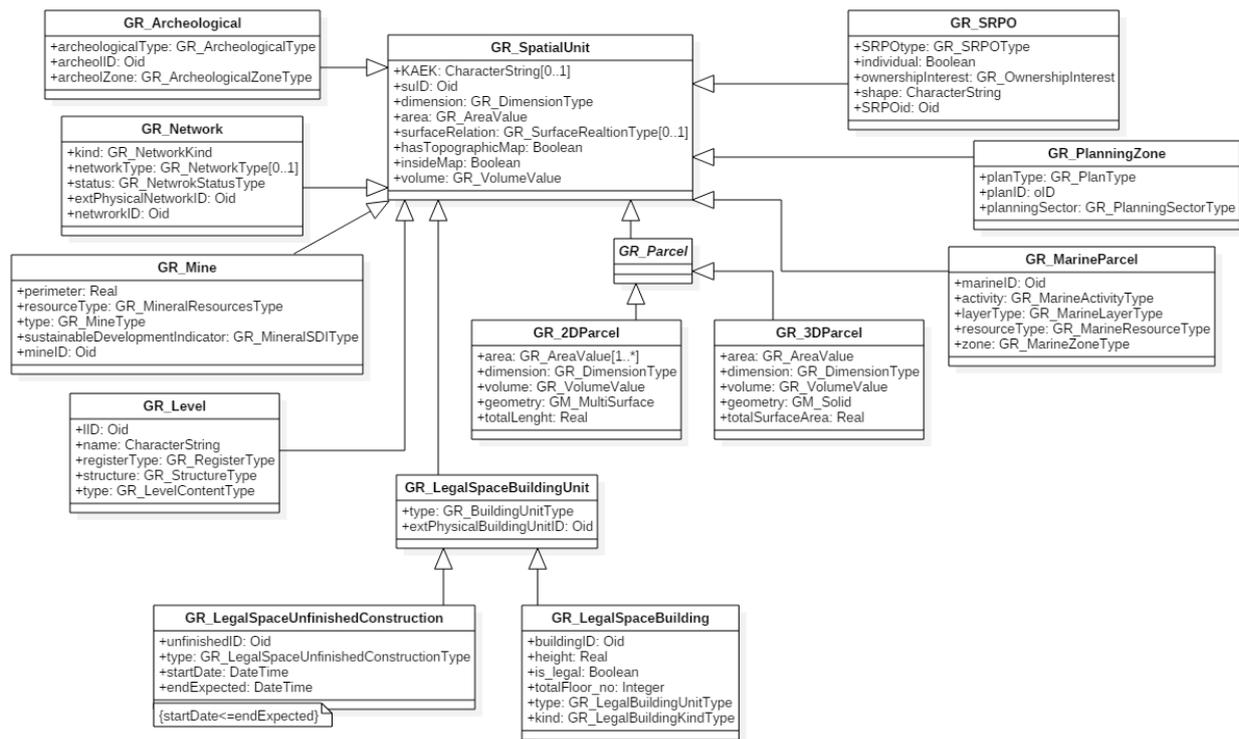


Figure 2. Overview of the specialisations of GR_SpatialUnit class that form the “levels” of the Greek LADM country profile (Kalogianni, 2015)

4. CATEGORISATION OF 3D SPATIAL UNITS’ TYPES

The level of geometric encoding as defined in the current edition of LADM (ISO19152, 2012) provides a framework for categorisation of spatial units recorded in a cadastre or other land administration organisations, ranging from “text based” spatial unit to the “topology based” encoding (both 2D and 3D). The initial classification of 3D spatial units was influenced by use cases of Queensland, Australia, as provided by Thompson et al. (2015) and forms the starting point for further investigation. In the context of this paper this taxonomy is further analysed and based on that, UML class diagrams will be modelled, corresponding database representations will be generated, various encodings and application schemas will be tested for their technical specification.

The defined spatial units’ categories (FIG, 2018b, Dimopoulou et al., 2018; Thompson et al., 2016) are listed below in an order of growing complexity:

- I. 2D spatial unit: (Figure 4A) completely defined by the 2D location of points along its boundary (5 spatial profiles have been developed and are included in Annex E of ISO 19152 LADM, - Section 5.1). 2D spatial units are the most common in most jurisdictions and they actually implying 3D spatial units which have no explicitly

defined bounded surfaces, as they actually define a prism, column of space above and below the land surface (Stoter and van Oosterom, 2006). For storage, visualisation and administrative purposes, they are the simplest cases, however, in a 3D visualisation, they may be problematic, being un-closed above and below;

II. 3D spatial unit: defined by a set of bounding faces, which are themselves defined by a set of 3D points and an interpretation. The following subcategories are defined for the 3D spatial unit:

- *Semi-open spatial unit*: (Figure 4B) defined by a 2D shape with one horizontal surface (upper or lower surface) – e.g. “to the depth of ...metres”. Semi-open spatial units are also common and very simple to store and to visualise in a 2D sense; a 2D spatial units with a height limitation attribute. In a 3D visualisation, they have the same issue as the 2D spatial units – being un-closed at the upper or lower surface. Specifically, for an individual spatial unit of this category the information required is:

- The extents of the 2D shape;
- The definition of a horizontal surface (upper or lower);
- The definition of the surface relation (unit is above or below the land surface).

- *Polygonal slice spatial unit*: (Figure 4C) defined by 2D shape with horizontal bounded surfaces (upper and lower surface), it is the most common form of closed 3D spatial unit. Individually, the units that lie in this category are easy to visualise and store. Specifically, for an individual spatial unit of this category the only information required is:

- The extents of the 2D shape;
- The definition of the top horizontal surface;
- The definition of the bottom horizontal surface;

The two above-mentioned categories (semi-open spatial unit and polygonal slice spatial unit) present similarities mainly in storage, however they differ in visualisation and management. For both of them, there are subcategories depending on the nature of the surface definitions. Each surface may be defined as:

- Above/below an elevation: the surface is defined by a horizontal flat plane at a height above/below a datum.
- Above/below a surface parallel to the local ground surface, and a defined distance above/below it.

- *Single-valued stepped spatial unit*: (Figure 3C and Figure 4D) defined by only horizontal and vertical boundaries, but non self-overlapping in z (i.e. at any location x, y there is only a single range of z values that belong to spatial units). In Figure 4D, all the information needed to understand the geometry is available in a 2D drawing;

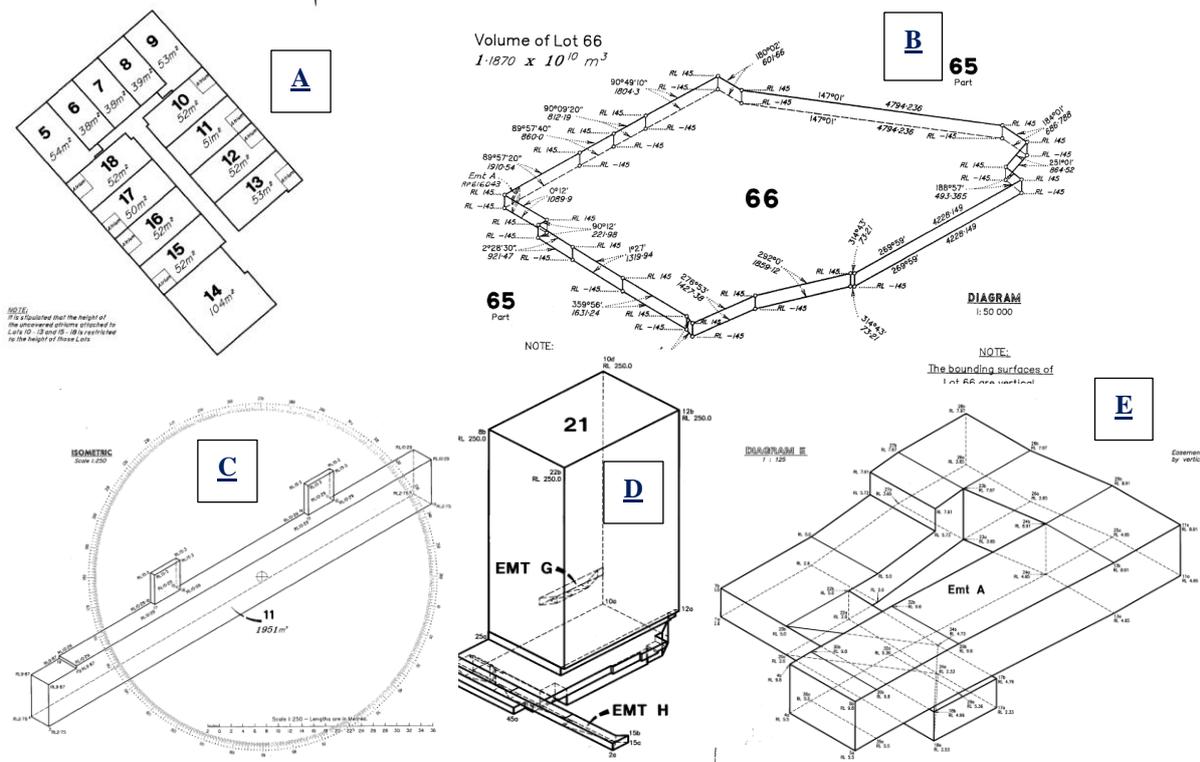


Figure 3. Subcategories of spatial unit geometries: A. Building Format spatial units; B. Simple Slice; C. Single-valued stepped spatial unit; D. Multi-valued stepped slice ("EMT G" forms a "cave"); E. General 3D spatial unit

- *Multi-valued stepped spatial unit:* (Figure 3D) defined by a set of boundary faces, all of which are all either horizontal or vertical, without a restriction of the volume to being single valued in z. This allows volumes with "caves" or "tunnels" in the wall.;
- *General 3D spatial unit:* (Figure 3E) it is the "catch-all" category of spatial units, which fail to fit in one of the above categories. It is defined in part by boundaries other than horizontal and vertical and thus at its definition at least one boundary should be defined by one non-horizontal, or non-vertical face. This category may result to a further categorization of this class as the following boundaries lie in this category: 2-manifold, planar/curved boundaries, open/closed volume, single/multi-volume. It should be considered whether the sub-categories that will be created would be mutual exclusive, or would they be independent aspects and generate multiple categories form their possible combinations.
- *Building/construction format spatial unit:* (Figure 3A) legally defined by the extents of an existing or planned structure that contains/will contain the unit. This is an important categorisation from the point of view of counting spatial units (being the most common category of 3D spatial units in Queensland, Australia, which was the area of interest at the previous research on taxonomy. In the case that some jurisdictions decide not to record the geometry at this category, then it can be a 3D spatial unit with a "text-based" description, while for the rest that do describe the geometry, this category behaves like other 3D spatial units (usually polygon slice).

The decision to record or not the geometry is purely local and could be applied to any type of spatial unit.

- *Any of these 3D Spatial Units can give rise to a Balance spatial unit:* It can be of any complexity as above but represents the remainder of a 2D spatial unit (i.e. prism) when all the 3D spatial units defined within it have been excised. The remainder (inner 3D region) could be of any complexity, but there are two variants of what this construct means:
 - The volume may be a primary interest excised from the 2D spatial unit (to avoid overlap);
 - The volume may define a secondary interest (e.g. lease, where overlap is allowed), therefore leaving the base spatial unit as a standard 2D spatial unit.

In the case where 3D spatial units are modelled by a 3D geometry collection (polyhedra), within a 2D surface parcel, then the "Balance space unit" is the unit which comes as a result from prism - (minus) polyhedron. If the whole 3D domain is modelled as space partition using a 3D topology structure, then the "Balance space unit" will be a prism on the outside, with holes or caves made by the 3D geometries. This category is intended to enable the estimation of the number of spatial units of a particular complexity and is useful in discussing data modelling and visualisation issues.

“Multi-valued stepped spatial unit”, “General 3D spatial unit” and “Balance spatial unit” are the classes that require more sophisticated storage and visualisation than the other categories., It is noted that those three categories cover a small minority of the spatial units in real world, which means that, although they need to be accommodated, classified and modelled, it is not so important that their storage and maintenance is as highly optimised as in the more common categories (e.g. polygonal slice and semi-open). All three classification aspects- real-world spatial unit type, geometric representation, encoding level- are more or less orthogonal (in theory all combinations are possible), but in practice they are also very much related.

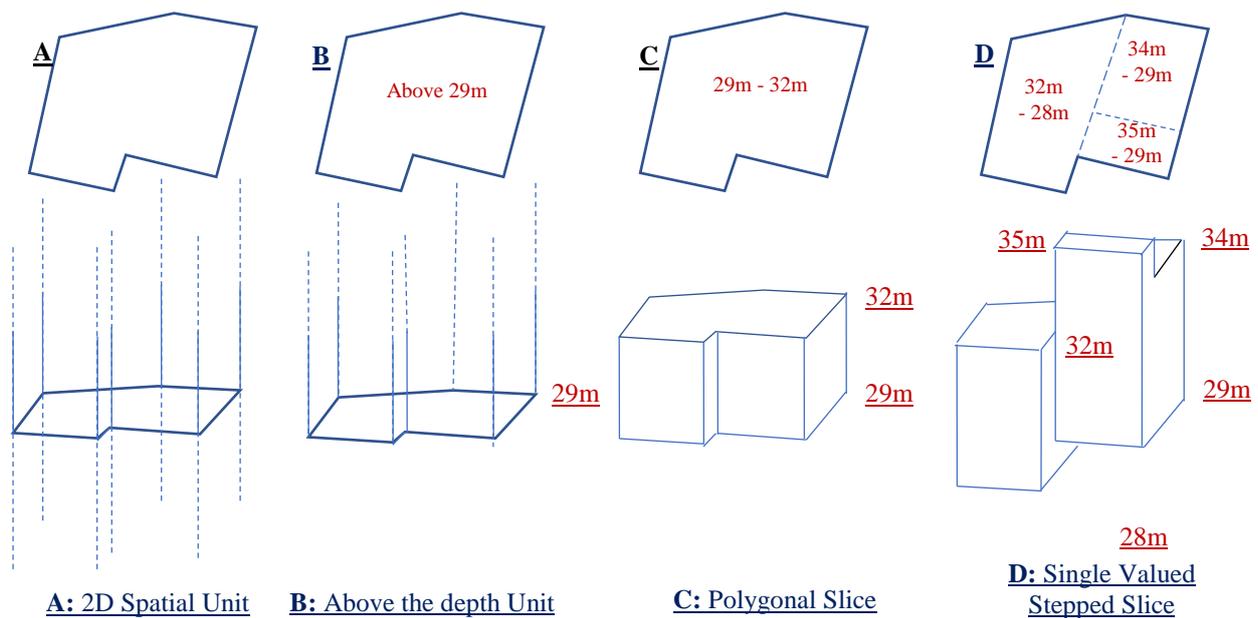


Figure 4. The simpler classifications can be represented in 2D and 3D rendition. Even the single valued stepped spatial unit (D) can be represented in a 2D drawing, showing all the necessary information

5. MODELLING PROPOSED FOR LADM II SPATIAL PROFILES

The LADM revision includes an extension and improvement of its initial scope, which comprises, among others, the improvement of current 3D support and consequently the design of additional 3D spatial profiles. The Spatial Unit Package and the Spatial Representation and Survey sub-packages of the current edition of LADM allow a number of possible representations of spatial units in 2D, 3D or mixed (integrated 2D and 3D). In this Section, a brief overview of the existing spatial profiles is presented (Sub-sections 5.1 and 5.2) and the proposed approach of modelling 3D spatial profiles is presented in Sub-section 5.3. For a specific spatial representation, usually a limited number of specific classes and attributes from LADM conceptual model are needed, which can be expressed through a spatial profile.

5.1 Existing LADM spatial profiles for 2D spatial units

For 2D spatial units five spatial representations are supported in the current Edition of LADM, which form the corresponding spatial profiles described with a small UML diagram (Annex E ISO 19152, 2012). The liminal spatial units (mixed 2D/3D) are introduced in Annex B of ISO 19152 (ISO 19152, 2012), however there are no spatial profiles for their representation.

The spatial profiles for 2D spatial units allow 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 ('2D point based' spatial units); representation with lines and incomplete boundaries ('2D unstructured line based' spatial units); representation with polygons, where spatial units are defined as separate entities and no topological relations apply ('2D polygon based' spatial

units) and representation when spatial units share boundary representations ('2D topological based' spatial units).

5.2 Existing LADM Spatial profile for 3D spatial units

At the current edition of LADM one spatial profile for 3D spatial units is supported (Annex E ISO 19152, 2012); the "3D Topological based" (Figure 5).

In terms of the 3D topology representation, a 3D boundary face has positive/negative information included in the association with a 3D spatial unit to indicate the orientation of the face, however the geometric 3D volumetric primitive (GM_Solid) is not indicated as this is the topological representation (Ying et al., 2015).

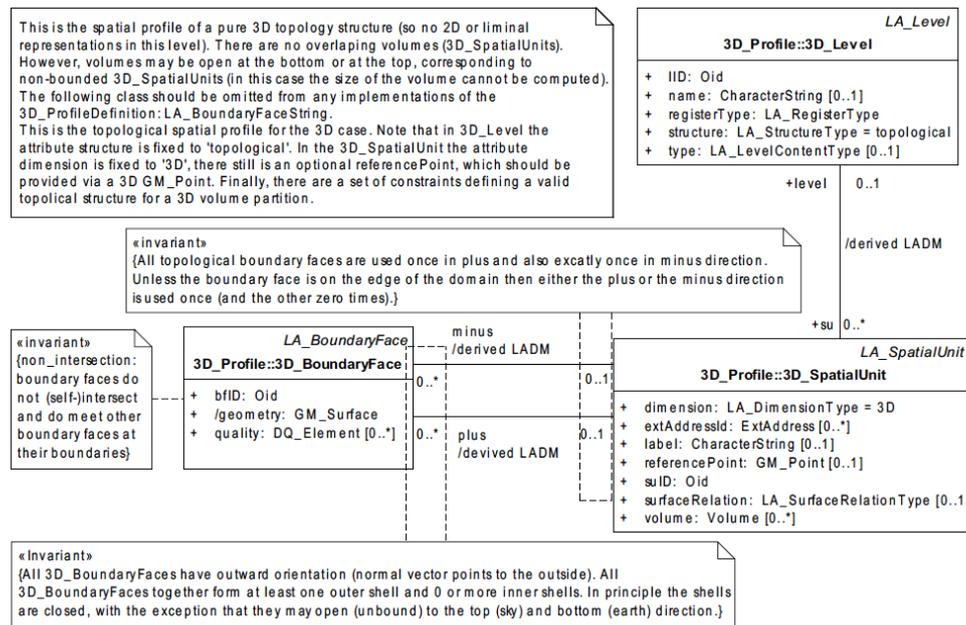


Figure 5. Existing 3D topology based spatial profile, Annex E - LADM ISO 19152 (ISO 19152, 2012)

5.3 Modelling approach of LADM II Spatial profiles for 3D spatial units

Based on characteristics of the categorisation of the spatial units (presented in Section 4), at the following paragraphs the approach for modelling spatial profiles for 3D spatial units is presented. It is proposed to implement the following principles to the categories of the taxonomy, adapted each time to their requirements.

5.3.1 "Footprint polygon"

As a foundation it is proposed to have a "footprint polygon" or a set of (vertical) face string for each spatial unit, as introduced by Thompson et al. (2017). In that way, a 3D spatial unit is represented by a footprint, which is then restricted by faces above and below the actual parcel. The concept of having a "footprint polygon":

- provides a simple 2D limitation on the extent of the unit;
- makes a simpler connection between 2D and 3D spatial units;

- in a non-topological storage structure, it can be stored as a polygon, thus allowing 2D indexing at the database;
- in a topological structure, the face string network can be stored as a 2D planar graph;
- in any case, a set of vertical boundaries for all spatial units opens the database to query and update (even) using 2D software.

5.3.2 Maximum and minimum z value

Each spatial unit to have an optional max and min Z attribute stored. Depending on the category the spatial unit will fall into, one of those values will be omitted. Storing those values allows for fast searching for potential overlaps in the database.

5.3.3 Absolute or relative height

An attribute defining the absolute height of the spatial unit is proposed to be included as an optional attribute at the spatial profiles. Moreover, a reference to a relative height will be included to describe 3D parcels.

5.3.4 Bounded surfaces

A spatial unit may not be fully bounded. Talking about 3D spatial units, they will normally have vertical faces and a top and/or bottom face(s). Thus, a set of faces that indicate the surfaces above and below the spatial unit (upper and lower surface) to be included in all the spatial profiles. Associated constraints will be imposed, and multiplicity will be appropriately defined.

5.3.5 Surface relation attribute

The indicator LA_SurfaceRelationType is used to define that the “upper surface is relative to ground” or the “lower surface is relative to ground”, as a spatial unit could be defined as “from 20 m below to 20m above local ground surface”.

5.3.6 Reference to a topographic object

A reference to the topographic object is proposed to be included at the spatial profile to specify one or more 3D boundary surfaces, through an association with the external registration.

5.3.7 Reference to another surface

Depending on the categorization they fit into, several spatial units are defined (partially or completely) referring to another surface. To realise this relationship, an association to this surface - whether it is the earth surface, another spatial unit, etc. - is proposed to be created.

5.4 Proposed spatial profile for “simple” 3D spatial units

The following UML class diagram (Figure 6) represents the proposed spatial profile for the “simple” 3D spatial units: polygonal slice and semi-open spatial units.

At the class Simple 3D_SpatialUnit, which is a specialization of LA_SpatialUnit, the value of dimension attribute is fixed to “3D”. Moreover, two attributes are added: upper_surface and

lower_surface defining the horizontal bounded surfaces. A constraint upper_surface > lower_surface is imposed to prevent the two surfaces to intersect and to be stored appropriately. What is more two attributes for the minimum and maximum Z are added.

An important aspect that is considered is that one of the surfaces may be the earth surface. For that reason, it has been modelled as “blueprint” for external class, as shown in Figure 6 and is related to relative z/height/depth types of representations and/or to 3D Parcel dissemination. The proposed code lists for the external class ExtEarthSurface are presented in Figure 7. Finally, the attribute surfaceRelation indicates if 3D Parcel is above, below or crossing earth surface.

At the Simple3D_Level class value of the attribute structure is fixed to “polygon”.

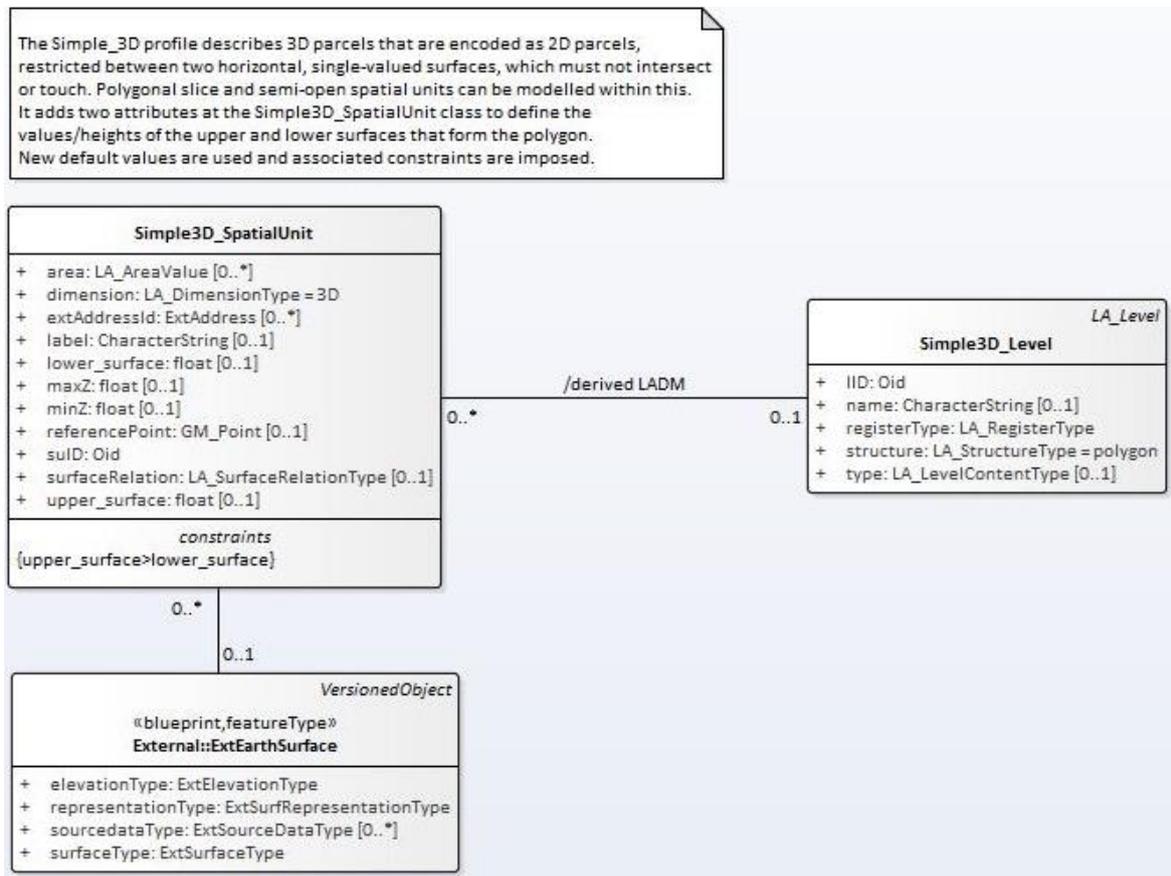


Figure 6. Proposed spatial profile for “simple” 3D spatial units

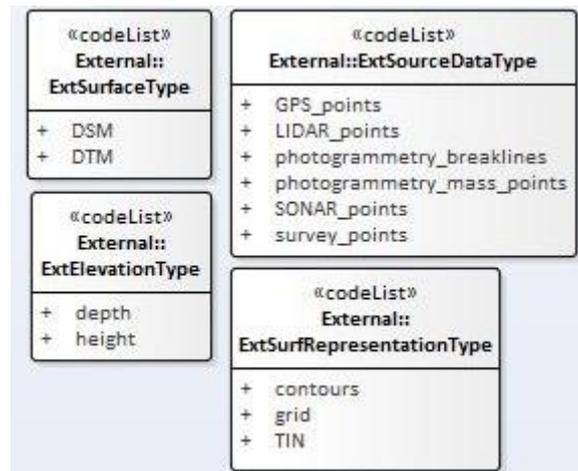


Figure 7. Proposed code lists for external blueprint class ExtEarthSurface

5.5 Proposed spatial profile for building/construction format spatial units

In the case of a building/construction format spatial unit (BFSU), where it is legally defined by the extents of an existing or planned structure that contains/will contain the unit, there are two ways to describe and spatially represent the spatial unit: by referring to a building format or by defining its actual shape by geometrical types. The actual geometric form of building/construction format spatial units is variable, mainly being polygonal slices, but all categories are possible.

Thus, at the proposed profile both options are included by introducing new attributes. When the building/construction format spatial unit is defined by geometry types two attributes are added, similar to the profile for “simple” 3D spatial units: upper_surface and lower_surface defining the horizontal bounded surfaces. A constraint upper_surface > lower_surface is imposed to prevent the two surfaces to intersect and to be stored appropriately. At the class GeneralBoundary_SpatialUnit, which is a specialization of LA_SpatialUnit, the value of dimension attribute is fixed to “3D”.

The General Boundary Spatial Unit profile describes 3D parcels that are legally defined by the extents of an existing or planned structure that contains/will contain the unit. There are two ways to describe and spatially represent the spatial unit: by referring to a building format or by defining its actual shape by geometrical types. New attributes and default values are used and associated constraints are imposed.

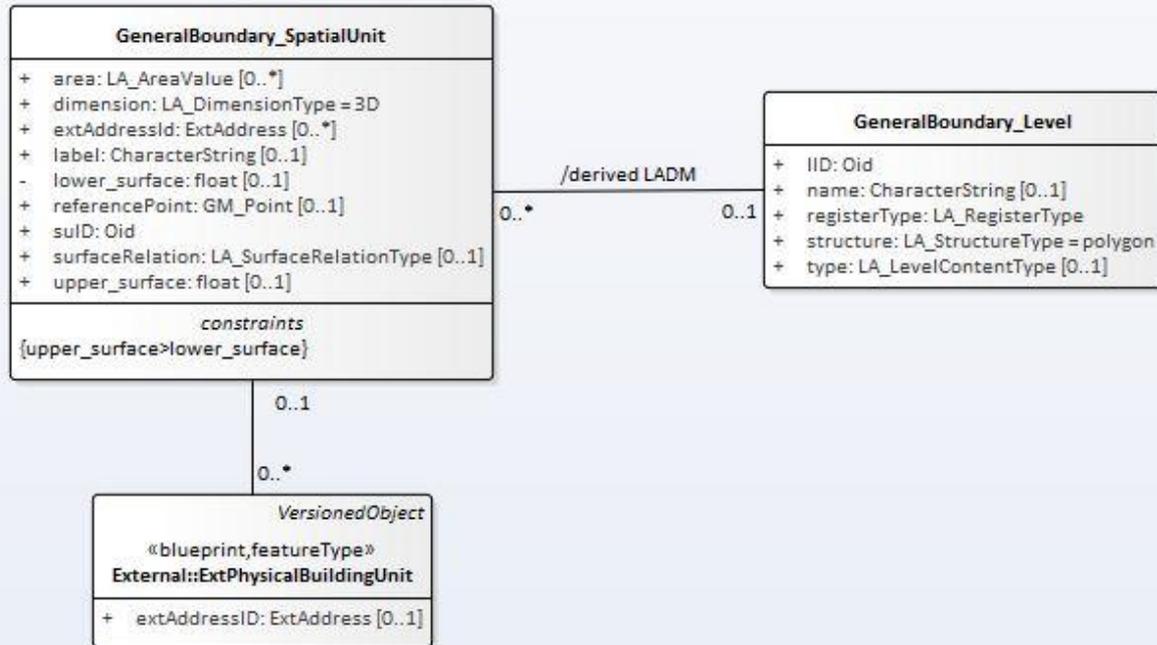


Figure 8. Proposed spatial profile for building/construction format spatial units

Moreover, to represent the reference to a building format, an association with an external class representing the building format is added. This external class needs further, refined modelling and as a future step it should be modelled considering approaches of integrating LADM with models encoding the fine detail of the units, as the recent research regarding integration of LADM with IFC classes, (Atazadeh et al., 2017; Oldfield et al., 2017); encoding information through surveying plans (described with LandXML); building module of CityGML through CityGML-LADM ADE (Gózdź et al., 2014) which should be defined depending on the LoD of the building, etc. In this scene, further modelling of existing ExtPhysicalBuildingUnit class should be investigated, in order to be used as an external class at the proposed spatial profile for the association with a building format spatial unit.

6. CONCLUSIONS AND FUTURE WORK

In May 2018 the New Working Item Proposal for Edition II of ISO 19152 has been submitted by FIG marking, officially, the starting point of the LADM revision. The multi-part future edition of the standard is expected to include extensions of the conceptual model, improvement of the current conceptual model, as well as process and workflow models.

Attention will be given at the 3D support of LADM in terms of modelling, storing, visualising and maintaining the spatial units, as well as at the future integration with technical standards and application schemas.

Adopting a holistic approach to treat land administration as a part of the whole chain of spatial development activities (surveying, designing, permitting, registering, maintaining, constructing) and not as an isolated domain is gaining ground as geographic data is widely used to support decision making, something that is also reflected in some of the world leaders' documents (UN Habitat/GLTN, 2017; The World Bank, 2018). Within this context, at the LADM I revision the interoperability with other standards to be pursued in order to facilitate the organisation, sharing, integration and reuse of information sources within the whole chain of spatial development activities.

Consequently, modelling and managing 3D spatial units as part of the spatial development chain and the BIM cycle brings potential benefits: data from one stage is reused in next one, data loss or mismatch is minimised, less mistakes/ misunderstandings occur, communication between stakeholders is enabled, etc.

Given this background, the paper presents a detailed analysis -in the context of LADM revision- of the initial categorisation of 3D spatial units that are usually found in cadastral jurisdictions, as provided by Thompson et al. (2015). The requirements of each category are analysed taking into consideration the ambition and scope of LADM revision. The categorisation of spatial units is definitive and verifiable and thus, any parcel can be placed in one and only category. Based on that, a modelling approach for the spatial units' categories is presented and two spatial profiles covering the simple 3D spatial units (polygonal slice and semi-open) and the building/construction spatial units are proposed in order to initiate a discussion on the modelling of 3D spatial profiles. This approach is based on the fact that although the complexity of volumetric spatial units is highly variable, the vast majority is composed of simple components.

To test the proposed approach and profile, as well as the profiles that will be designed, representative real-world use cases from the LADM profile for Greece, presented in Section 3 will be collected. Apart from the spatial profiles that will be designed it is important to investigate whether there is also need to create profiles for mixed 2D/3D representations (liminal spaces). The different types of liminal parcels that are investigated should be defined together with their requirements for spatial representation.

It is expected that presenting this modelling approach and the two spatial profiles will initiate a discussion on the modelling of spatial profiles in the context of LADM revision, considering the need to go beyond the conceptual model. Future actions include the investigation of different encoding models concerning the further detailed technical specification of LADM based on standards, such as: BIM/IFC, GML, CityGML, LandXML, InfraGML, IndoorGML, RDF/linked data, GeoJSON, INTERLIS. For each profile, the model(s) that can better support its implementation should be investigated. Possibly, there is no encoding that can adequately express the implementation of a spatial profile content (e.g. general 3D spatial units), or there is more than one encoding that fits some concepts. It is underlined that it is very important to establish a link between BIM and land administration in relation to spatial planning and lifecycles of constructions/ buildings, considering that in the future cadastral data may originate from design (e.g. BIM/IFC data).

What is more, INTERLIS object relational modelling language is now being updated and a draft INTERLIS 3 version is planned to be released by the end of 2018. LADM and

INTERLIS synergy has been tested the last years in many countries (Switzerland, Colombia, Greece) through various initiatives providing promising results. In the context of the LADM revision and the release of the new INTERLIS version, where 3D geometry primitives will be supported, the technical specification of some spatial profiles using INTERLIS should be investigated.

Moreover, as a future step more methods of volumetric representation that are used to create 3D objects, apart from current assumption of vector/boundary representation-based spatial units should be investigated. Specifically, data derived by architectural or other drawings leading to Constructive Solid Geometry or sweep representations should be observed, improving the link to CAD/BIM models. Additionally, it should be considered whether boundaries represented through voxels or point clouds, photos or pictometry can be supported. Similarly, for the curved boundaries there are many categories possible that should be identified, such as patches from cylinder, sphere, ellipsoid, NURBS, etc. Moreover, the “LA_BoundaryFace” class does not provide attributes to semantically distinguish various types of boundaries and it can be further explored based on the above-mentioned in the revision of the standard.

Last but not least, deep integration of space and time resulting in 4D geometry/topology should be further investigated and as a next step corresponding spatial profiles should be designed.

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