

3D Cadastres Best Practices, Chapter 3: 3D Cadastral Information Modelling

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SUMMARY

In this chapter we address various aspects of 3D Cadastral Information Modelling. Of course, this is closely related to the legal framework and initial registration as presented in the first two chapters. Cadastral data models, such as the Land Administration Domain Model, which include 3D support, have been developed for legal information modelling and management purposes without providing correspondence to the object's physical counterparts. Building Information Models and virtual 3D topographic/ city models (e.g. LandXML, InfraGML, CityGML, IndoorGML) can be used to describe the physical reality. The main focus of such models is on the physical and functional characteristics of urban structures (Aien et al, 2015). However, by definition, those two aspects need to be interrelated; i.e. a tunnel, a building, a mine, etc. always have both a legal status and boundaries as well as a physical description; while it is evident that their integration would maximise their utility and flexibility to support different applications. A model driven architecture approach, including the formalization of constraints is preferred. In the model driven architecture design approach as proposed by the Object Management Group the information model, often expressed in the form of a UML class diagram is the core of the development. This so-called Platform Independent Model (PIM, as presented in the current chapter) is then transformed into Platform Specific Model (PSM). This could be a relational database schema for a spatial DBMS (as will be discussed in the next chapter), or XML schema for a data exchange format or the structure of maps, forms and tables as used in the graphic user interface of a spatial application. Constraints have proved effective in providing the solutions needed to avoid errors and enable maintenance of data quality; thus the need to specify and implement them. This chapter explores possibilities of linking 3D legal right, restriction, responsibilities spaces, modelled with the Land Administration Domain Model (ISO 19152), with physical reality of 3D objects (described via CityGML, IFC, InfraGML, etc).

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1. INTRODUCTION

When considering the complete development life cycle of rural and, in particular, urban areas, related activities should all support 3D representations and not just the cadastral registration of the 3D spatial units associated with the correct RRRs (rights, restrictions, responsibilities) and parties (van Oosterom, 2011). The exact naming of these activities differs from country to country, and their order of execution may differ. However, in some form or another, the following steps performed by various public and private actors, which are all somehow related to 3D cadastral registration, are recognized:

- Develop and register zoning plans in 3D.
- Register (public law) restrictions in 3D.
- Design new spatial units/objects in 3D.
- Acquire appropriate land/space in 3D.
- Request and provide (after appropriate checks) permits in 3D.
- Obtain and register financing (mortgage) for future objects in 3D.
- Survey and measure spatial units/objects (after construction) in 3D.
- Submit associated rights (RRR)/parties and their spatial units in 3D.
- Validate and check submitted data (and register if accepted) in 3D.
- Store and analyze the spatial units in 3D.
- Disseminate, visualize and use the spatial units in 3D.

Several of the activities and their information flows need to be structurally upgraded from 2D to 3D representations. Because this chain of activities requires good information flows between the various actors, it is crucial that the meaning of this information is well defined—an important role for standardization. Very relevant are ISO 19152 (LADM) and ISO 19156 (Observations and Measurements), and highly related and partially overlapping is the scope of the new OGC's Land Development – Standards Working Group (LD-SWG), with more of a focus on civil engineering information, e.g., InfraGML (aligned with LADM). This phenomenon is especially true for 3D cadastre registration because it is being tested and practiced in an increasing number of countries. For example, for buildings (above/below/on the surface or constructions such as tunnels and bridges), and (utility) networks, this overlap is clear. LADM is focusing on the spatial/legal side, which could be complemented by civil engineering physical (model) extensions. It is important to reuse existing standards as a foundation and to continue from that point to ensure interoperability in the domain in our developing environment!

We start by giving an overview of the modelling requirements, i.e. defining, the scope (in section 2) of the 3D Cadastral Information Model. Next, we present an overview of the relevant standardized information models in Section 3. This could be considered as composed of a range of standards starting with pure cadastre/land administration standards, gradually moving towards standards for topography. The Land Administration Domain Model (LADM, ISO 19152) plays a key role. Similar to the 2D situation, topography is commonly used for reference or orientation purposes to make clear the actual location and size of the parcels. Topography and cadastral information does not have to be maintained by the same organization and/or in the same system, they can be combined when needed via the Spatial Data Infrastructure (SDI). In the case of 3D, the link between cadastral information and topography seems to be even tighter. Very often 3D legal spaces with RRRs attached are created near actual or planned constructions, such as buildings, roads, tunnels, bridges, utilities, etc.

Quite a number of countries are active in developing 3D Cadastral Information Models, based on standards as much as possible, but applied to the needs of the country. A selection of these 3D (LADM) country profiles is given in Section 4: Russia, Malaysia, Greece, Israel and Poland. The last section of this chapter analyses the gap between what is currently available (standards, country profiles) and the current and future requirements.

2. MODELLING REQUIREMENTS

In this section, various types of modelling requirement for 3D Cadastral information are introduced. The core requirement is that various types of 3D parcels should be supported. Additionally, the temporal dimension must be included, allowing representation of multiple versions of the same spatial object, and the link with 3D topography. It is further explained why it is important to have constraints explicitly included in the model and why it is critical to have standard-based modelling.

2.1 Types of 3D parcels

An initial categorization of 3D Parcels was given in Thompson et al. (2015) and forms the starting point for the further investigations into suitable corresponding database representations exchange format, and data capture encodings. The following categories were introduced, now listed in the order of growing complexity:

1. 2D spatial unit (actually prism of 3D space): defined by a 2 dimensional shape.
2. Building format spatial unit: defined by the extents of an existing or planned structure (e.g. apartment).
3. Semi-open spatial unit: defined by 2D shape with upper or lower surface.
4. Polygonal slice spatial unit: defined by 2D shape with upper and lower surface.
5. Single-valued stepped spatial unit: defined by only horizontal and vertical boundaries (among others the facestring from 2D space) and single valued¹.
6. Multi-valued stepped spatial unit: as above but now multi valued.
7. General 3D spatial unit: defined also by boundaries other than horizontal and vertical.

¹ The volume is called single valued if there is no pair of points within the spatial unit with the same (x,y) coordinates which have a point from outside the spatial unit between them.

The category of General 3D spatial units can be further refined: 2-manifold boundaries required or not, partly open/completely closed volume, planar/curved boundaries, multi-valued single/multi-volume, etc. (Thompson and van Oosterom 2012).

The problem of mixing 2D land parcel definitions with the range of 3D parcels in a corporate database and exchange format encodings is one of the most basic issues to be solved in creating a modern approach to Cadastral modelling. Various approaches have been suggested in Thompson et al. (2015):

1. Keep the 3D parcels in a separate database from the rest of the 2D database.
2. Simply store footprints only, with no reference to 3D definitions at all.
3. Keep a representation all parcels in the main database in 2D form only (with the 3D parcels represented by “footprints”). The full 3D definition of the 3D spatial units is kept in another form (in CAD or pdf format) and may be obtained from a document archive.
4. Store all parcels in the same database, with 3D parcels being approximated by a “slice” (a polygon with a horizontal top and bottom surfaces) which contains the parcel (but may be a loose fit).
5. Convert all parcels to 3D form and store in a single database.
6. Integrate 2D parcels and 3D parcels in the same database and make sure they fit well together.

Beyond simple mapping applications, a basic requirement to be satisfied by a corporate database is to answer the query “*given a spatial unit, what are its adjoiners?*” Of the above methods only methods 5 and 6 can satisfy this query directly. The others either cannot respond at all, or will give incorrect answers (Thompson et al., 2016). Thompson (2015) published the finding that levels of encoding can co-exist within the same cadastral database and that 2D and 3D parcels can be mixed.

Digital Terrain Model and Digital Surface Model can be superimposed with spatial units and ‘intersections’ with existing 2D spatial units can be created. Those intersections can be considered as spatial units by themselves (for example by defining ‘the above ground portion of spatial unit ...’).

2.2 4D time

Next to the spatial (3D) aspect of rights and restrictions, the temporal aspect, the fourth dimension of interests in real estate, is an important aspect of cadastral registration (van Oosterom et al, 2006). Rights, responsibilities and restrictions clearly have a temporal element. A further category of examples of the need for 4D cadastral information is when a record of history is required on a particular property, or when historic information on land use development in a certain region is needed to support future land policy – this is the real-world time aspect. The final category is where a history of the database content is needed – this is the system time aspect (van Oosterom, Maessen, and Quak, 2002).

The principle of an efficient management of object life cycle was elaborated on in Seifert et al. (2016), where the data model requires a unique identifier for each object, together with a designated time stamp for creation and deletion of that object. However, when an object is

deleted during an updating process, the object will not be physically removed from the data base. Only the thematic relevance has ended, not the existence of the object as a historic record. A “deleted” object is then considered the as historical information which can be easily distinguished from the actual information. Sometimes there are changes to an object which do not require the deletion of the object (e.g. the name of a person changes). In that case also the different versions of an object can be stored. Since every object carries life cycle information, the storage of historical objects and versions of objects is not limited to any specific object type. This approach supports the temporal dimension independent from the spatial dimensions, by adding separate versioning or time-range attributes.

It is clear that time has always played an important role in cadastral systems, but so far this temporal aspect has been treated quite independently from the spatial (2D or 3D) aspect. The current cadastral systems deal with both 3D situations and temporal 4D aspects on an ad hoc basis within existing cadastral procedures. Because this information is not registered in a uniform way, insight in all relevant aspects (who has which rights at a certain moment, for what space and for what period(s)) is frequently a problem. The basis of a cadastre has not been set up on a 4D space-time partition model. Time is not (yet) integrated in the data types of the topology/geometry. It is currently treated as a separate attribute (tmin/tmax everywhere and timeSpec in RRR). One could imagine full spatio-temporal Cadastral Object representations for the definition of moving object with RRRs attached; e.g. to define grazing rights moving/changing-location over seasons (2D and time) or a Marine cadastre with moving/changing fishing rights in the ocean (3D and time). A more integrated approach of the temporal and spatial aspects is wanted. Deep integrated treatment of space and time in one internal 4D data type representation has clear benefits for the future realization of a 4D cadastre (van Oosterom et al, 2006):

1. optimal efficient 4D searching (specifying both space and time in same query) can only be realized if a 4D data type (and index/clustering) is used, otherwise the DBMS (query plan) has to select first on space and then on time (or the reverse order). However, note that even 2D index/cluster is most likely sufficient for reasonable performance – as the 3rd dimension and time are less selective. So, this is not a strong argument for adoption of 4D data types;
2. with true 4D data types, parent-child relationships between parcels (the lineage) are neighbour queries in a topological structure (neighbours for which at least the time attribute changes), which is potentially more efficient than a spatio-temporal overlay as needed in the non-integrated approach; see Figure 1 (left): Parcel P3 has parent parcel P1 and children parcels P4 and P5;
3. 4D analysis: 'Overlap' appears in, for example, land consolidation procedures; here an 'old' and 'new' parcellations exist temporally in parallel. Another example is the question: do two moving cattle rights have spatio-temporal overlap/touch (Figure 1 right)? If stored and represented in the database by a 4D data type, this is just a simple query. If stored as separated attributes, this is not a trivial query to answer;
4. but most important, if we do want the full (4D) partition (of 3D space+time, with no overlaps, no gaps) as our foundation for a 4D Cadastre, having true 4D geometry and topology (with space and time integrated) is the most solid foundation.

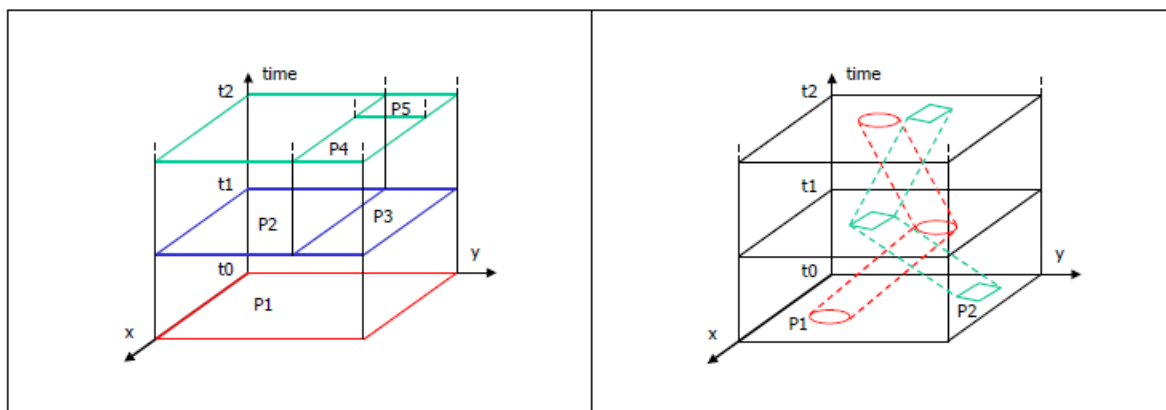


Figure 1. Integrated treatment of space (2D) and time: left the subdivision of parcels and right the representation of moving cattle

2.3 Represent multiple versions of the same point

In land administration and surveying the ‘same point’ is often represented in multiple ways. However, these different representations must be modelled properly and linked. Examples of these cases include: a point as included on a design (BIM/IFC – Building Information Model/Industry Foundation Classes), after/during construction the same point can be surveyed multiple times (with slightly different coordinates); a point converted from a local coordinate reference system to the national grid; a newly surveyed point fitted in existing cadastral mapping (van Oosterom et al, 2011).

Besides linking the various representation, the class representing the ‘point’ must include the attributes such as: point identifier; estimated accuracy; interpolation role (this is the role of point in the structure of a straight line or a curve, e.g. end, isolated, mid, mid_arc, or start); monumentation (this is the type of monumentation in the field, e.g. beacon, cornerstone, marker, not_marked); original location (the calculated coordinates from original observations); point type (e.g. geodetic control points, or points with or without source documents); production method; and finally zero or more transformations (and transformed location, so that the transformed location defines a new version of the point). Transformations include for example affine transformations but also mathematical computations such as least square adjustments.

2.4 Spatial Data Infrastructure links to 3D topography and BIM

It is important to remember the relationship between the concepts of ‘legal’ and ‘physical’ objects in 2D (Döner et al, 2011). In 2D, a parcel is a legal object indicating the extent of property rights (ownership, leasehold, easement, limited real rights such as emphyteusis in civil law) of which the boundaries are not always visible features of the terrain. Only when overlaying the parcel boundaries maintained in the cadastral database with topography (i.e. representation of physical objects), the real estate objects can be fully visualised. In a full 3D

cadastre, a volumetric parcel is also a conceptual (legal) object, not necessarily visible in reality, and only indirectly related to physical objects. Therefore, it can also be used for other purposes than the registration of ownership of 3D physical objects, for example, to register the ownership of a safety zone for a tunnel or to register the ownership of some space to assure future view from a building. In most cases in 2D, parcels are related to physical objects because the ownership of a piece of land implies ownership of all physical objects that are attached to it, if located within the parcel boundaries. In the same way, the ownership of a 3D parcel implies the ownership of all physical objects that are located within the space, for example tunnel or utility network. This explains the need for 3D topographic data in the context of 3D Cadastre. Currently the cities are producing the city models according to the CityGML. Such data could be then potentially reused for 3D cadastre purposes.

For example, Building Information Models (BIM) are used to update the cadastre in Costa Rica (Van Oosterom et al., 2014). Behnam et al. (2016) present usage of BIM as a feasible approach for managing land and property information in high-rise administration. They propose an extension to the BIM standard to show the potential capability of using BIM for modeling 3D ownership rights. Note: architectural drawings have long been used to represent apartment complexes in cadastral systems. It is frequently the case that the implementation of the design in reality differs from the design itself. This may require re-surveys after the design is constructed.

For any developments that require spatial data, often the fusion of diverse spatial datasets is unavoidable. For instance, in developing a 3D cadastral database serving various purposes, data may need to be sourced from different spatial datasets such as: building design models in BIM format, topographic and built environment information in CityGML, and cadastral legal boundaries in LandXML (Soon et al., 2014). Note: it is common that there are differences in the geometry in different sources because of different data acquisition methods and different scales. A BIM designed object has a scale 1:1. It may fit to reality but maybe not to the cadastral map. If the cadastral map is locally adjusted there may be overlaps with surrounding parcels. In the context of cadastral requirements, the CityGML does not contain any features describing the legal information about spatial objects (Gózdź et al., 2014). As also stated in Gózdź et al. (2014), the Land Administration Domain Model also constitutes a generic expandable domain model, designed to be connected in a SDI setting to data from other domain models and other standards (e.g. CityGML, INSPIRE Data Specifications).

The link between LA_SpatialUnit and ExtPhysicalBuildingUnit (as represented according to CityGML, IndoorGML or BIM/IFC) is an important topic to explore further; e.g. which LoD (Level of Detail) is being referred to (see Figure 2). Obviously, when a single building contains multiple spatial units, then indoor is needed (LoD4 in CityGML or preferably IndoorGML or BIM/IFC representations). Note that the link between the LA_SpatialUnit and ExtPhysicalBuildingUnit (or ExtPhysicalUtilityNetwork) does not have direct legal implication. However, if the corresponding 3D spaces are very different, then someone should take action. Actual reusing of (3D) topographic objects as boundaries of legal spaces could be a dangerous step (if physical object should move or change, then also legal spaces might be affected unintentionally), so care is needed (Thompson et al., 2016).



Figure 2. The five LODs of CityGML 2.0. The geometric detail and semantic complexity increase, ending with LOD4 containing indoor features (Biljecki et al., 2016)

Not only the geometrical aspect, but also the semantic aspect of data sources should also be considered. Building data in BIM/IFC, CityGML and LandXML are produced based on different knowledge domains (design, physical and legal). This causes conceptual and terminological differences between data sources if these data sources are to be integrated (Soon et. al. (2014)).

Rönsdorf et al. (2014) demonstrated how the OGC CityGML standard can be used to provide an encoding for 3D land administration information. The basic principles of the integration by mapping key feature classes in both standards are shown. Further they conclude that the same approach will be applicable for country or region specific profiles of ISO 19152 and encourage practical experimentation with this.

The possibilities of applying CityGML for cadastral purposes are elaborated in Gózdź et al. (2014) with particular attention to the 3D representation of buildings. A proposal for the CityGML-LADM Application Domain Extension (ADE) is presented, drawing particular attention to the buildings, both addressing their physical aspects and their legal counterparts. Technical realization of the issue has been executed at the conceptual level by integration the CityGML OGC Standard and the International Standard ISO 19152. Practical implementation of the CityGML-LADM ADE model has demonstrated the benefits of providing relations between spatial objects from legal and physical world. The insight into the third dimension of physical objects helps to understand the location and size of the legal spaces as well as it is relevant in the context of developing the multipurpose cadastral systems.

Ying et al. (2014) provide a framework and workflow for the conversion from CityGML data to 3D Cadastral unit with the test of city data of CityGML LOD3.

Roschlaub and Batscheider (2016) used 3D City Database (3DCityDB²) to store the 3D buildings (at LOD2 level), created as a combination of 2D digital building ground plans derived from the official digital cadastral map; and LIDAR (Light Detection And Ranging) data. 3D City Database is a free 3D geo database to store, represent, and manage virtual 3D city models on top of a standard spatial relational database. The database model contains semantically rich, hierarchically structured, multi-scale urban objects facilitating complex GIS modeling and analysis tasks. With a database scheme the user has the possibility to create a CityGML conformant data model in the database. Seifert et al. (2016) add that these data participate in

² <http://www.3dcitydb.org/3dcitydb/3dcitydbhomepage> (accessed on 21 August 2016)

the existing national and international spatial data infrastructure (SDI), for example through simple export to the defined INSPIRE topics (e.g. Buildings).

2.5 Constraints supported

In the introduction the importance of constraints within the Model Driven Architecture (MDA) was emphasized. Now we have a look at the geometric aspect of this. A methodology of modelling 3D geo-constraints has been proposed (Xu et al, 2016) and can be used as a generic approach for all spatial-related constraints specifications in four stages:

1. Natural Language
2. Geometric/Topological Abstractions
3. UML/OCL Formulations
4. Model Driven Architecture (MDA)
 - a. Database PL/SQL Code
 - b. Exchange Format XML
 - c. Graphic User Interface ArcGIS

Natural language is a simple way to specify a constraint statement relating to spatial objects, but it is subjective to the individuals and therefore a more objective specification is necessary. A logical next step is making drawings of the objects (mostly the ‘nouns’ in a sentence) in order to illustrate the shape of the objects. After that, the objects interactions (mostly the ‘verbs’) can be explained better by formal descriptions of topological relationships, e.g. Egenhofer 9 intersection matrices (9IM) (Egenhofer 1989). Constraint statements thus become more specific and clear to others, and not subject to multiple interpretations. In order to let machines understand the constraints and automate the model translation, a further specification should be made considering MDA. UML/OCL as a modelling aid/tool therefore is the clear choice at this stage. Under the support of various tools/software, the constraints implementation in the database (e.g. PL/SQL code), data exchange (e.g. XML schema), graphic user interface (e.g. ArcGIS) or any other domains, can be automated. Here we focus on the constraint implementation in the database. With a small modification the generated code can be used in database triggers, which realises the implementation of constraints checking.

2.6 Standardization

Information models should, whenever possible, be based on agreements and standards. In this manner it is possible to better understand and reuse each other’s data in our networked society. Also standardization brings together the knowledge of experts from around the world. Using a standardized information model also imports the expert knowledge. Standards enable interoperability

ISO

ISO is an independent, non-governmental international organization with a membership of 163 national standards bodies³. Through its members, it brings together experts to share knowledge

³ <http://www.iso.org/iso/home/about.htm> (accessed on 19 August 2016)

and develop voluntary, consensus-based, market relevant International Standards that support innovation and provide solutions to global challenges.

The ISO 19100 is a series of standards for defining, describing, and managing geographic information. This standard defines the architectural framework of the ISO 19100 series of standards and sets forth the principles by which this standardization takes place. Standardization of geographic information can best be served by a set of standards that integrates a detailed description of the concepts of geographic information with the concepts of information technology. A goal of this standardization effort is to facilitate interoperability of geographic information systems, including interoperability in distributed computing environments. The ISO 19100 series of geographic information standards establishes a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth. This standard specifies methods, tools and services for management of geographic information, including the definition, acquisition, analysis, access, presentation, and transfer of such data in digital/electronic form between different users, systems and locations.

The overall objectives of ISO/TC 211 are (ISO/TC 211, 2009):

- increase the understanding and usage of geographic information;
- increase the availability, access, integration, and sharing of geographic information;
- promote the efficient, effective, and economic use of digital geographic information and associated hardware and software systems;
- contribute to a unified approach to ecological and humanitarian problems.

OGC

The Open Geospatial Consortium (OGC) is a non-profit organization that deals with the development of standards for modelling real-world objects. These standards deal with conceptual schemes for describing and manipulating the spatial characteristics of geographic features. The specification defines three important areas, namely (Khuan et al., 2008):

- Data types: the need to have data types that represent real world object is obvious. Different kinds of data types and different kinds of objects could be modelled within DBMS.
- Functions/operations: there must be functions and operators to support the management of multi-dimensional objects that work for spatial analysis in DBMS.
- Spatial index: the main purpose is to deal with spatial searching (query), and sometimes it is implemented in different spatial operators to speed up the query process.

Cooperation between ISO and OGC

By 1995 ISO/TC 211, developing international standards for spatial data and the OGC, developing computer interface specifications, became highly visible and prominent players on the international geographic agenda. Later ISO/TC 211 and the OGC formed a joint coordination group to leverage mutual development and minimize technical overlap. The OGC is submitting their specifications for ISO standardization via ISO/TC 211. Achieving more interoperability requires a proactive coordination of spatial standards at both the abstract and implementation levels. Proactive cooperation among spatial standards activities of ISO/TC 211

and the OGC should also help to use available resources more efficiently by minimizing technical overlap wherever this occurs. Such coordination and cooperation should lead to more market-relevant spatial standards, and could serve as a useful roadmap for all interested parties (ISO/TC 211, 2009).

INSPIRE

The European Union promotes the Infrastructure for Spatial Information in the European Community Directive (2007/2/EC) for a wide range of applications. The Directive sets the legal framework for the establishment of the Infrastructure for Spatial Information in the European Community (INSPIRE). A major task of the INSPIRE programme is to enable interoperability and, when feasible, harmonisation of spatial data sets and services within Europe. Each Member State has to create and maintain a series of spatial data that is organized into three annexes. To ensure that the spatial data infrastructures of Member States are compatible and usable by the Community in a transboundary context, the Directive requires that common implementation Rules are adopted in a number of specific areas (Metadata, Data Specifications, Network Services, Data and Service Sharing and Monitoring and Reporting). INSPIRE is based on selected ISO/TC211 and OGC standards, and complemented among others with detailed data specifications for 34 themes as listed in the three annexes.

3. STANDARDIZED INFORMATION MODELS

3.1 ISO 19152 LADM

LADM is one of the first spatial domain standards within ISO TC 211. There is a need for domain specific standardisation to capture the semantics of the land administration domain on top of the agreed foundation of basic standards for geometry, temporal aspects, metadata, and observations and measurements from the field. This is required for communication between professionals, for system design, system development and system implementation purposes and for purposes of data exchange and data quality management. Such a standard will enable Geographical Information Systems (GIS) and database providers and/or open source communities to develop products and applications. And in turn this will enable land registry and cadastral organisations to use these components to develop, implement and maintain systems in an even more efficient way. LADM provides a shared ontology, defining a terminology for land administration. It provides a flexible conceptual schema with three basic packages: parties, rights (and restrictions/responsibilities) and spatial units. LADM supports the development of application software for land administration, and facilitates data exchange with and from distributed land administration systems (Van Oosterom and Lemmen, 2015). In LADM, 2D and 3D representations of spatial units use boundary face strings and boundary faces as key concepts (see Figures 3 and 4).

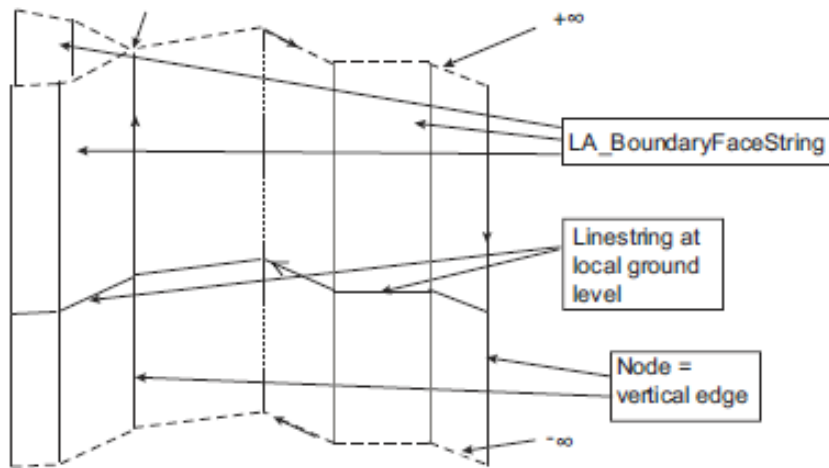


Figure 3. Boundary face string concepts (ISO, 2012)

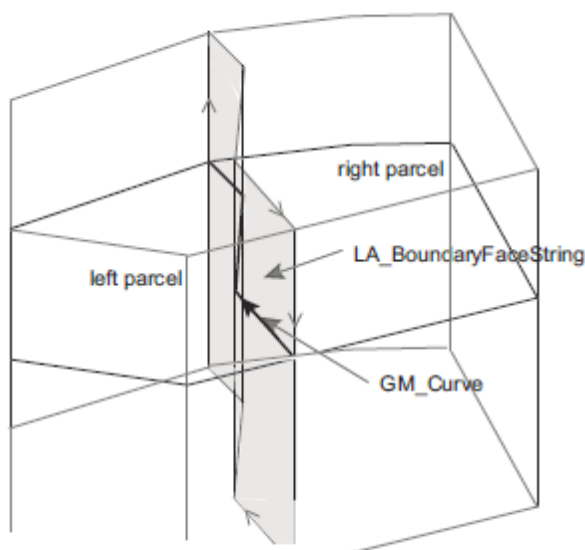


Figure 4. Spatial units defined by boundary face strings (ISO, 2012).

3.2 LADM OWL ontology

The World Wide Web Consortium (W3C) is an international community where Member organizations, a full-time staff, and the public work together to develop Web standards. W3C publishes documents that define Web technologies. These documents follow a process designed

to promote consensus, fairness, public accountability, and quality. At the end of this process, W3C publishes Recommendations, which are considered Web standards⁴.

The W3C Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be exploited by computer programs, e.g., to verify the consistency of that knowledge or to make implicit knowledge explicit. OWL documents, known as ontologies, can be published in the World Wide Web and may refer to or be referred from other OWL ontologies. The current version of OWL, also referred to as “OWL 2” is an extension and revision of the 2004 version of OWL⁵.

The current ISO 19152 - Land Administration Domain Model (LADM) standard (ISO, 2012), being modelled in Unified Modeling Language (UML) with additional explanatory natural text and tables, will facilitate the software development and database design for the proper implementation of land administration systems. The use of UML supports generating a database schema or exchange format (Soon et al., 2014). To support reasoning and inference, Soon (2013) has formalized LADM in OWL. LADM OWL ontology also supports automated integration of land administration information (Boskovic, et al., 2010; Sladić, et al., 2013).

To use the LADM OWL ontology for automated integration of land administration information, Soon et al. (2014) proposed to augment the LADM OWL ontology with the concept of ‘Physical Space Building Unit’ (see Figure 5). In addition, as a physical building sometimes can have more than one legal boundary (for example through strata subdivision) a relation is defined as *hasLegalSpace* between ‘Physical Space Building Unit’ and ‘Legal Space Building Unit’. The relation *hasLegalSpace* is an ObjectProperty in the LADM OWL ontology. The same also applies to utility network where a new concept ‘Physical Space Utility Network’ is added. The relation *hasLegalSpace* also links ‘Physical Space Utility Network’ with ‘Legal Space Utility Network’ (Soon et al., 2014).

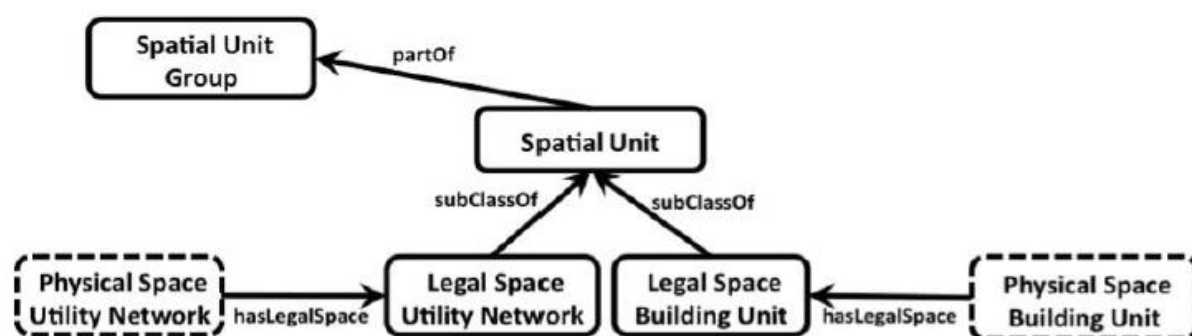


Figure 5. Extension to the LADM OWL ontology with the concept ‘Physical Space Utility Network’ and ‘Physical Space Building Unit’ (highlighted in dash-lined boxes) and with a new relation *hasLegalSpace* (Soon et al., 2014)

⁴ <https://www.w3.org> (accessed on 19 August 2016)

⁵ <https://www.w3.org/OWL> (accessed on 19 August 2016)

The addition of new concepts ('Physical Space Building Unit' and 'Physical Space Utility Network') in the LADM, OWL ontology helps to integrate information about building from CityGML and LandXML as discussed in detail by Soon et al. (2014).

3.3 INSPIRE Data specifications on cadastral parcels⁶

Land Administration is a broad topic with many applications, which provide a basic infrastructure for implementing land related policies and land management strategies to ensure social equity, economic growth and environmental protection (Williamson et al., 2010). The European Union, acknowledging that LA can contribute to sustainable development and thus environmental policy, included 'Cadastral Parcels' in INSPIRE.

Cadastral parcels (INSPIRE TWG-CP, 2009) are described in Annex I of INSPIRE Directive and are thus considered as reference data. The data specifications focus only on the geometrical aspects of cadastral parcels while information about ownership and other rights are outside its scope. The temporal alignment in the development of LADM and INSPIRE's 'Cadastral Parcels' (CP), led to the development of compatible definitions and common concepts in both models (ISO 2012). The LADM-based model version of CP is included both in the ISO19152 publication (Annex G) and in the Data Specifications of CP (Annex C). However, their differences are immediately noticeable as the latter focusses on the geometric aspect, not taking into consideration the rights, restrictions and responsibilities applied to it.

The application schema of cadastral parcels consists of four entities; see Figure 6. The core – and always available – entity of the cadastral parcels schema is the 'Cadastral Parcel'. The other three entities are 'Cadastral Zoning' (the intermediary areas used to divide the national territory into cadastral parcels), 'Cadastral Boundary' (part of the outline of a cadastral parcel) and 'Basic Property Unit' (the basic unit of properties which may consist of one or more parcels). Each entity consists of three kinds of attributes: the obligatory, the voidable and the information about time (also voidable). The voidable characteristics in the INSPIRE context are "those properties of a spatial object that may not be present in some spatial datasets, even though they may be present or applicable in the real world".

The "Cadastral Boundary" class will be available from the member state only if information about the absolute positional accuracy information is recorded for the boundary. Furthermore, 'Basic Property Units' will be used by countries where cadastral references concern basic property units. The INSPIRE 'Cadastral Parcel' model is basically a subset of LADM with specific choices for representing parcels (Annex G of ISO 19152). However, in this case, other themes of the INSPIRE seem to be very much related to the LADM. For example, 'Addresses' is considered an external class in LADM and it is expected that there exists a detailed model (data specification) and registration to which can be referred. Within an SDI setting, the various registrations can refer to each other. This is also true for buildings and administrative units. For example, in the INSPIRE themes, the municipalities are considered part of the 'Administrative Units' theme and therefore they are not repeated in 'Cadastral Zoning'. It is expected that the related datasets are harmonised with each other.

⁶ This section is largely based on Psomadaki et al. (2016).

Besides not covering RRRs and Parties, other aspects outside the scope of INSPIRE's CP are the survey (spatial source) information and 3D representations (just 2D is supported). Only INSPIRE's data specification for buildings do support 3D representations.

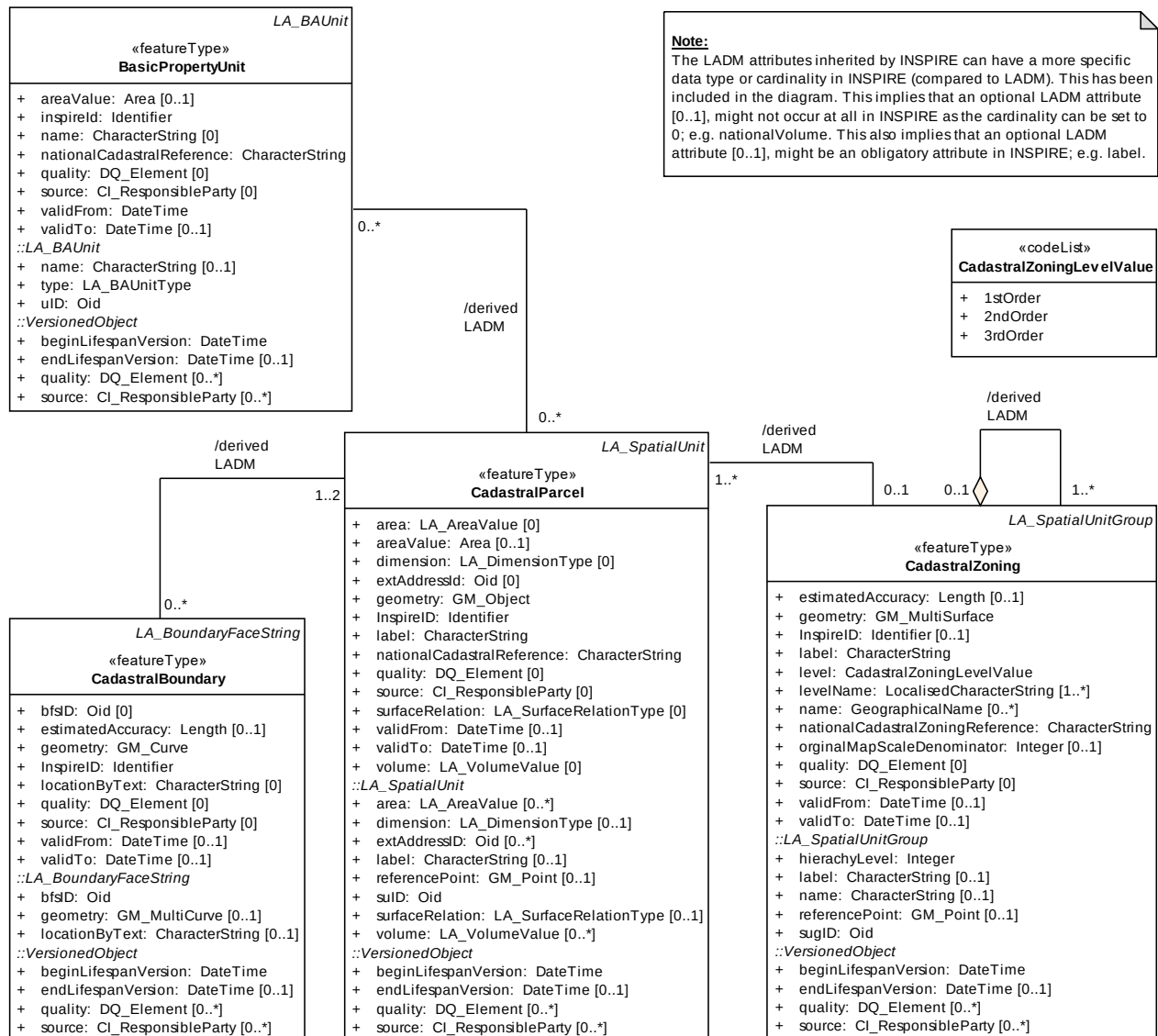


Figure 6 The INSPIRE cadastral parcel model based on the LADM (from Annex G, ISO 19152)

3.4 GML

GML is an XML grammar defined by OGC to express geographical features (ISO, 2007). GML serves as a modeling language for geographic systems as well as an open interchange format for geographic transactions on the Internet. As with most XML based grammars, there are two parts to the grammar – the schema that describes the document and the instance document that contains the actual data. A GML document is described using a GML Schema. This allows

users and developers to describe generic geographic data sets that contain points, lines and polygons. However, the developers of GML envision communities working to define community-specific application schemas that are specialized extensions of GML. Using application schemas, users can refer to roads, highways, and bridges instead of points, lines and polygons.

Aien et al. (2014) convert the logical data model of the 3D Cadastral Data Model (3DCDM) to a physical data model. The physical data model of the 3DCDM has been developed as an application scheme of the GML (in version 3.2.1). For this purpose, eleven XML schemes were developed: 3DCDM Root, LegalPropertyObject, InterestHolder, Survey, CadastralPoints, Building, Land, Tunnel, UtilityNetwork, PhysicalPropertyObject, and Terrain.

3.5 CityGML

There are many formats for the storage and visualization of spatial data, however they are usually focused only on a description of geometry. In contrast, the CityGML which provides a geographic information model for urban landscapes, not only represents the shape and graphical appearance of the 3D city objects, but also addresses the representation of the semantic and thematic properties, taxonomies and aggregations (Gózdź et al., 2014).

Open Geospatial Consortium has defined CityGML (City Geography Markup Language) for modeling 3D city models. The current version of CityGML is 2.0 and contains modules like ‘Relief’, ‘Building’, ‘City Furniture’, ‘Water Body’, ‘Bridge’, ‘Tunnel’, ‘Vegetation’, ‘Land Use’, and ‘Transportation’. CityGML defines classes, attributes and relations for topographic features with aspects of geometrical, topological, semantic and appearance. Different level of details can be captured from LOD 0 to LOD 4. LOD 0 represents the earth surface (i.e. the terrain) be it as Digital Terrain Model (DTM) or Digital Surface Model (DSM). LOD 1 represents topographic and constructed features as simple 3D blocks (i.e. no texturing or appearance). LOD 2 shows topographic features with texturing and refined top structure. In the case of a building, for example, instead of a flat roof surface in LOD 1, LOD 2 models the actual shape of a rooftop. LOD 3 models more detailed topographic features and includes other external installations – for example windows and doors. LOD 4 includes internal installation modeling (van den Brink et. al., 2012).

In the ‘Building’ module of CityGML, ‘Abstract Building’ is an important class, which has two subclasses called ‘Building’ and ‘Building Part’. The attributes for the ‘Abstract Building’ class include ‘Class’, ‘Function’, ‘Usage’, ‘RoofType’, ‘MeasuredHeight’, etc. The ‘Abstract Building’ class also has geometries, which support the level of details from LOD 0 to LOD 4. As ‘Abstract Building class’ specializations, ‘Building’ and ‘Building Part’ inherit all attributes and relations of ‘Abstract Building’ (Soon et al., 2014). The CityGML schema can be extended to have additional modules such as ‘Cadastre’ using the Application Domain Extension (ADE) (Stoter et al., (2011); van den Brink et al., (2012); Gózdź et al., 2014).

3.6 LandXML/InfraGML

There are currently two transport specifications in discussion for the interchange of survey plan data: 1: LandXML which is currently in use in New Zealand and being implemented in Australia and Singapore; and 2: InfraGML which is being developed by the OGC as a BIM

interchange specification and as successor of LandXML for survey data (Thompson et al., 2016). LandXML can also be used for capturing other types of engineering data, such as pipe networks and roadways (Soon et al., 2014). Soon et al. (2014) extend LandXML to model 3D parcels and introduce the Nested Parcels Approach, which makes use of the element of PntList3D of LandXML, to store 3D coordinates.

In addition to LandXML, the expression in InfraGML (currently in development by the Open Geospatial Consortium) (Scarponcini 2013; OGC 2016) should be considered for the integrated footprint (LA_BoundaryFaceString) and face (LA_BoundaryFace) volumetric encoding of spatial units (Thompson et al., 2016).

Apart from the transport of survey data there may be a need for transport of parameters related to transformations applied to sets of (2D or 3D) points. This may be needed if separate software (in separate hardware – eg survey instruments) is used for adjustments of observations. This type of adjustments is also needed in a 3D environment.

Integrating data from different sources means integrating data with different object versions to new objects in a new or existing environment – this had impact on the organisation of data exchange.

3.7 IndoorGML

IndoorGML was adopted as an OGC standard in December 2014 (Lee et al 2014, Li, 2016). IndoorGML is intended to support development of indoor navigation systems, by providing description of indoor space and GML syntax for encoding geoinformation (geometry, network or path) for indoor navigation. In this respect IndoorGML is application-oriented standard and differs from generic 3D standards such as CityGML, KML, and IFC. It is based on subdivision of the interior space. The obtained cells are described with the geometry, semantics and topology that are important for indoor navigation. In this respect, IndoorGML can be seen as a complementary standard to CityGML, KML, and IFC to support location based services for indoor navigation. IndoorGML defines the following information about indoor space: navigation context and constraints, space subdivisions and types of connectivity between spaces, geometric and semantic properties of spaces and navigation networks (logical and metric), and their relationships.

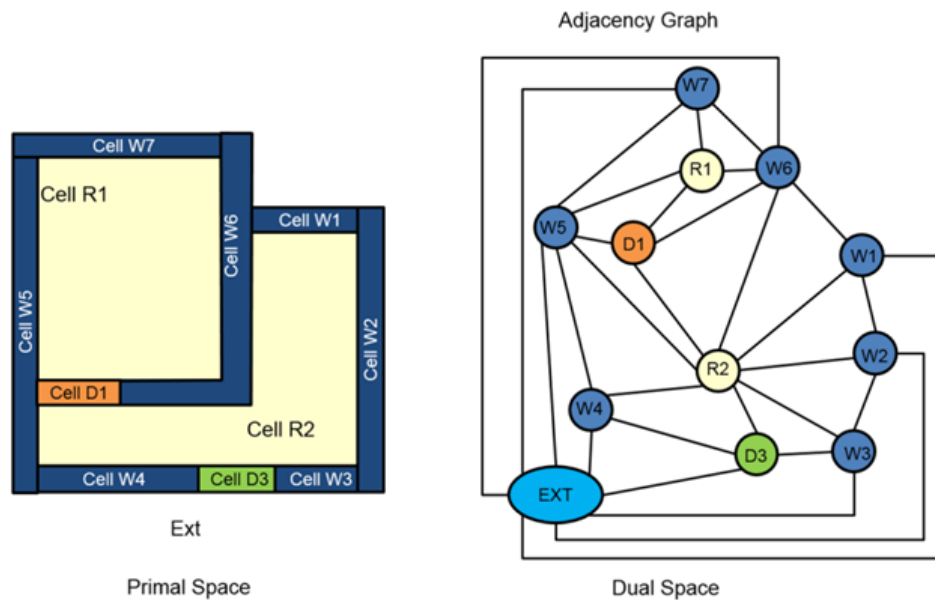


Figure 7. Example of spaces in a building: a) non-navigable (in blue) and navigable (in yellow, orange and green) b) derived network

The notion of space or ‘cell’ is the most important concept in IndoorGML (Figure 6). A building or groups of buildings are subdivided into non-overlapping cells. The cells are further classified into navigable or non-navigable. The adjacency network is then to be derived by applying Poincaré duality, i.e. each cell in the 3D space (named also primal space) is mapped in a node in 2D space (dual space) and the adjacency between the spaces represents the edges. For the purpose of navigation, non-navigable spaces are not of interest and have to be excluded from the adjacency network (not illustrated in Figure 7b). Considering the remaining links and the semantics of the spaces (i.e. which spaces are doors), the navigation/connectivity network is derived. An important characteristic of the IndoorGML is that cells do not need to be bordered by physical features. Cells can be defined as aggregation of features or a physical space can be subdivided into smaller units. It is also possible to neglect the size of some physical features, e.g. doors, windows. As visible on Figure 7, the doors are represented as spaces, but the standard allows to consider them as borders (i.e. ‘thin doors’) between two spaces. In that case there are no door nodes in the navigation network.

IndoorGML allows multiple space subdivisions per building (Figure 8). A space subdivision can be derived from the topography of the building, the function of spaces, the security restrictions, but can be also with respect to coverage of sensors such as wifi or RFID (Radio-frequency identification) or the legal (LADM RRRs) status of spaces. Different spaces are to be organized according the Multi-Layered Space Model (Becker et al 2008).

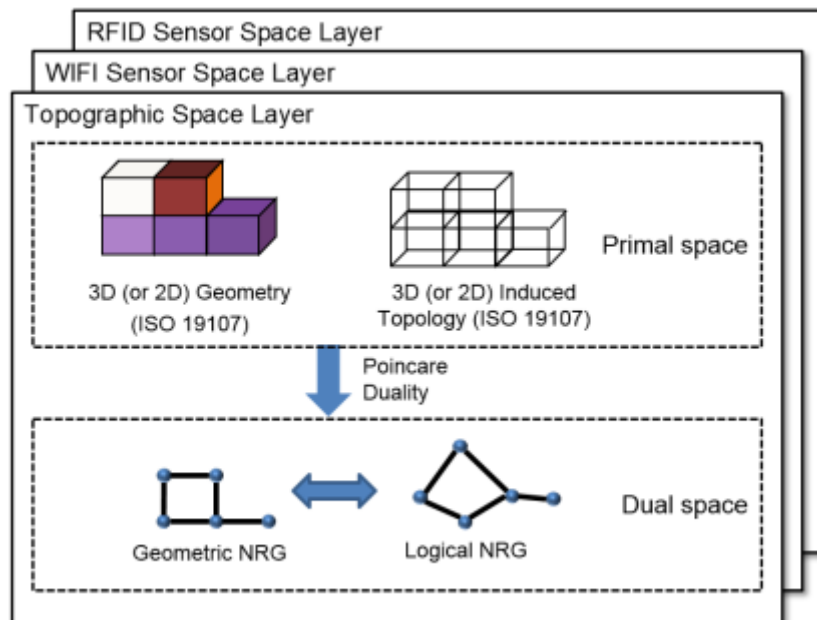


Figure 8. Multi-Layered combination of alternative spaces (Lee et al 2014)

Space modelling with respect to its legal use is specifically interesting for IndoorGML. Restrictions, rights and responsibilities on a part of a floor or a building can influence the accessibility and can significantly change the set of cells that can be used to derive a network. Many office buildings share common entrance and registration areas and they share the responsibilities for the maintenance of the common area. Shopping malls may also share access to different departments and sections but they also have clearly defined area which are given for use only to them. In many public buildings, restricted or security areas are clearly identified by requiring security cards and/or security doors. Such RRR are rarely identified with physical boundaries and are usually difficult to model.

3.8 BIM/IFC

ISO 16739:2013 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries, specifies a conceptual data schema and an exchange file format for Building Information Model (BIM) data (ISO, 2013).

Under development is ISO/AWI 19166 Geographic information -- BIM to GIS conceptual mapping (B2GM)⁷. This international standard defines the conceptual framework and mechanisms for the mapping of information elements from BIM to GIS to access the needed information based on specific user requirements. The conceptual framework for this mapping is defined with the following three mechanisms:

- BIM to GIS Element Mapping (B2G EM);
- BIM to GIS LOD (Level of Detail) Mapping (B2G LM);
- BIM to GIS Perspective Definition (B2G PD).

⁷ http://www.iso.org/iso/catalogue_detail.htm?csnumber=32584 (accessed on 19 August 2016)

The conceptual mapping mechanism defined in this international standard uses existing international standards such as Geography Markup Language (GML), CityGML (OGC standard) and Industry Foundation Classes (IFC).

3.9 Linking IndoorGML and LADM⁸

In this section we investigate the possible synergy between two different but related standards: OGC's IndoorGML and ISO TC211's LADM. Both (can) deal with 3D spaces with properties, constraints and associations attached and both can operate with abstract notations of space. But there are also differences, e.g. LADM is just a conceptual model, while IndoorGML is also an actual XML schema (technical model), which can be used directly for data exchange and storage. Also, the scope is different; e.g. IndoorGML focuses on indoor spaces, while LADM addresses all spaces (in principle a complete subdivision of the countries territory, including outdoor, water, surface and subsurface spaces). LADM models legal and administrative concepts such as use and ownership rights of spaces related to certain parties. IndoorGML puts emphasis on connectivity of spaces related to the navigability as one of the main use cases. These characteristics make the two standards quite complementary and this motivates our exploration in the combination of both.

The spaces defined by LADM are the results of legal/administrative rights, restrictions and responsibilities (as the largest possible spaces, homogeneous with respect to these RRRs). The space subdivision of IndoorGML is based on navigable areas and their connectivity. IndoorGML also recognizes other spaces, called abstract spaces. This section will compare the space characterizing of the two models and will explore options to combine the models. Many indoor applications deal with abstract spaces, i.e. spaces which do not have well-defined physical borders (such as walls, ceiling and floors), to identify a function, use or right on the space. For example, a room can be further subdivided into several sub-spaces indicating 'information corner', and 'working area', or a 'security area'. Figure 9 illustrates such examples. Such functional areas need to be identified and usually this is done by applying geometric or semantic approaches for partitioning of space (Bandi. and Thalmann, 1998, Becker et al 2008, Goetz and Zipf, 2011, Khan and Kolbe 2012, Afyouni et al 2012, Brown et al 2013, Zlatanova et al 2013, Kruminaite and Zlatanova, 2014). Although the importance of such spaces is recognized, their modelling is still insufficiently explored, especially in the context of human perception and human navigation (Fallah et al, 2013). By contrast, the LADM may need to represent a completely inaccessible volume of rock through which a tunnel may be constructed in the future.

⁸ This section is based on (Zlatanova et al, 2016) and (Abdullah et al, 2017)

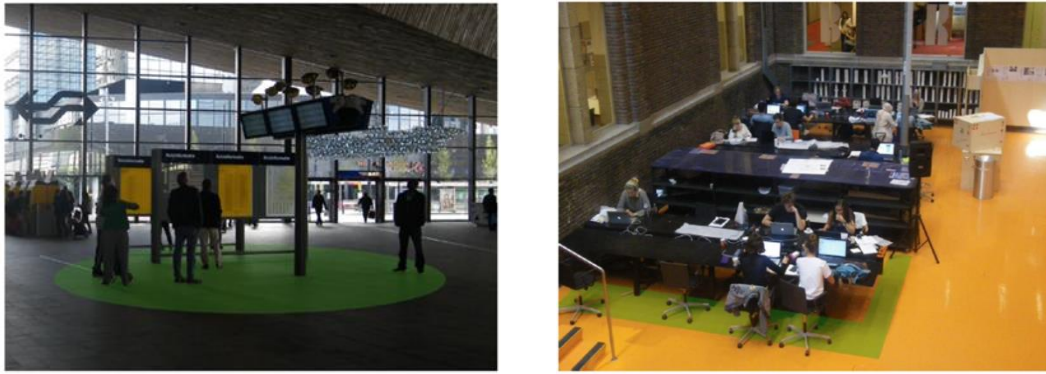


Figure 9. Examples of functional areas (in green): information corner and working area (Kruminaite and Zlatanova, 2014)

Modelling is always within a certain domain and scope, despite the fact that many concepts are linked to other external concepts. In the past, the conceptual models of LADM and European Union's Land Parcel Identification System (LPIS) have been linked (Inan et al, 2010) as it makes sense to combine the information of cadastral parcels (LADM) to agricultural parcels (LPIS). LPIS mainly concerns 'outdoor' parcels. For the (extended) indoor environment it does make sense to combine the conceptual models of IndoorGML and LADM. With this, information from these two domains can be used together in a meaningful manner. Actual use cases include:

- Airports – common spaces accessible for all visitors, check in area, passport control, waiting/shopping areas, boarding gates, transit areas and so on.
- Hospitals – common access areas, examination sections, areas for hospitalized persons, surgery, laboratories, storage of medical equipment, etc.
- Museums - exhibition halls, storage halls, administration areas, security areas.

Summary – Combined use of LADM and IndoorGML models

The two standards have been developed for different purposes (navigation vs. land administration) and have different scope (indoor vs. indoor/outdoor, above/below surface). The two standards have many differences and similarities. The main similarities between the two models are:

- Both models (can) deal with semantically annotated 3D spaces, which have properties.
- Both models operate with abstract spaces. Abstract spaces in IndoorGML can be defined on the basis of user or environment properties. Abstract spaces in LADM are based on legal regulations. Similarly, IndoorGML allows subdivision and aggregations of spaces such as accessibility, security, etc. The same is true in LADM: legal spaces can be grouped in LA_BAUnit or LA_SpatialUnit and organized in a hierarchy.
- Both models have a notion of primal space with geometry and topology. The 3D partitioning of LADM can be seen as primal space. LADM maintains links to external classes of which some are mentioned in annex K of the standard: building units, utility networks. IndoorGML provides links to CityGML, IFC and KML.

- Both models can support several subdivisions of space. The mechanism in IndoorGML is by defining specific space layers. LADM abstract subdivisions are embedded in the conceptual schema (and called LA_Level).
- Both models maintain relationships between objects. LADM supports extensive set of relationships and constraints. Spatial relationships can be based on topology but could be also without topology (just geometry or even textual descriptions). IndoorGML does not have specific notions of constraints between objects, but rather topological relationships (i.e. adjacency and connectivity) is used to derive the dual space.

There are also a number of significant differences:

- LADM is only a conceptual schema, while IndoorGML has XML implementation.
- IndoorGML requires non-overlapping subdivision of spaces, LADM may have overlapping abstract spaces, but spatial units related to full ownership may not overlap with each other (these might overlap with a spatial unit defining a restriction; e.g. because of an environmental protection zone).
- IndoorGML maintains primal and dual space, while LADM has only primal space.
- LADM models legal and administrative concepts such as ownership rights of spaces related to certain (group) parties. IndoorGML might use such rights to specify subdivision, but no explicit Space Layer have been developed so far.

LADM could be applied to determine a framework for space subdivision. Thus, the topological primal spatial units do not have gaps or overlaps in the partition in LADM. The rights, restrictions and responsibilities and the administrative unit play a critical part during this process. We explore the combined use IndoorGML and LADM by creating a link that connects each navigable space of IndoorGML to the corresponding LA_SpatialUnit of LADM without adjusting IndoorGML and LADM. As a navigable space in IndoorGML can correspond to various spatial units of LADM (and vice versa), a many-to-many association is needed. In this way, it is possible to model or to subdivide the spatial units in LADM. Via LA_BAUnit the associated rights and parties can be obtained (for navigable spaces linked with a LA_SpatialUnit). Note that in order to be able to use one-to-one correspondence, each space of IndoorGML would need to be defined based on the constraints of the spatial unit of LADM, and vice versa. This is considered less convenient.

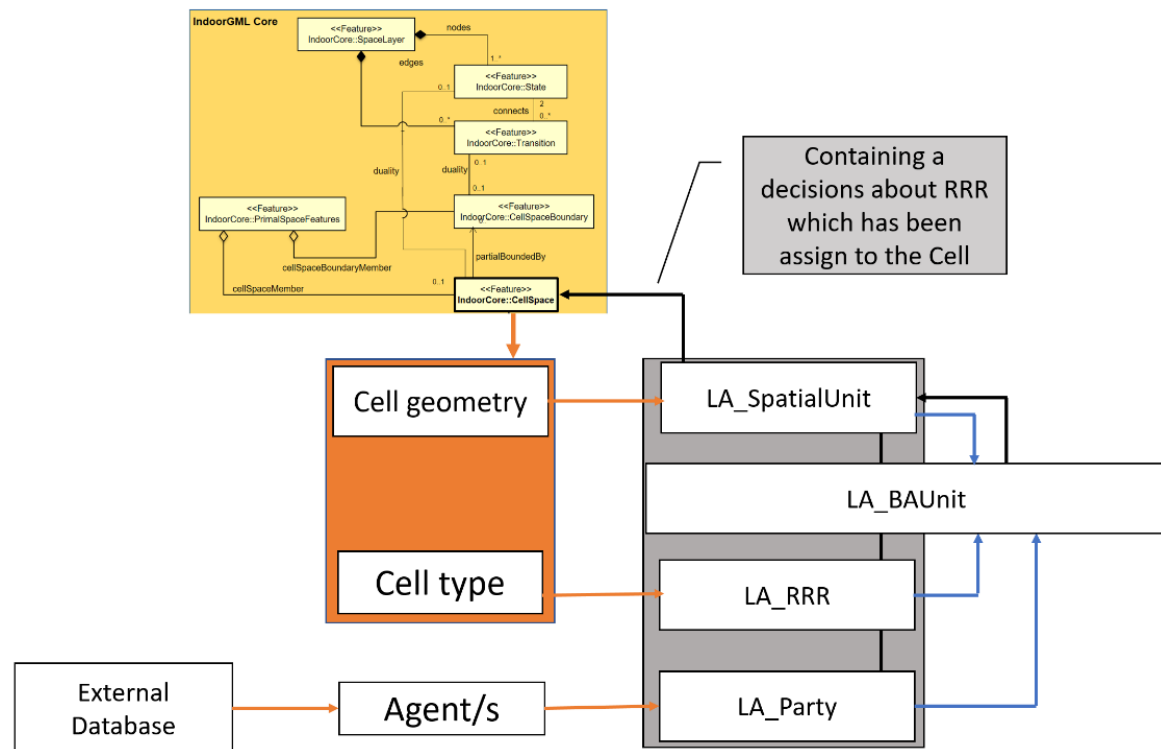


Figure 10. The integration process for IndoorGML and LADM

The rights, restrictions, and responsibilities affect the motion of users (use, manage, transfer, add, receive) in indoor spaces by regulating the access and use of space. Figure 10 represent a general overview of the integrated model of LADM, IndoorGML, and an external party database. IndoorGML associates spatial data that contains information about the geometry of the cells and the external database associates information about users. LADM associates the subdivision of the indoor space to IndoorGML based on the rights, restrictions, and responsibilities.

The major link between the spatial features of indoor space from the 'Cell Space' in the IndoorGML with the LA_SPatialUnit package in LADM is modelled as an association. The association provides the identification (Cell number) and the function of the cell. The spatial information of the cell collected by LA_SPatialUnit and the cell function information gathered by the LA_RRR which is a class of the Administrative package. The user's information in the external database is associated with the LA_Party package. The LA_BAUnit which is a class in the Administrative package will collect the Information to be registered based on the information of each package. Based on registration of information LA_BAUnit and LA_SPatialUnit associate the subdivision of space to the Cell space in IndoorGML.

4 3D LADM COUNTRY PROFILES

In the last few years several prototypes of 3D LADM based country profiles have been developed, for example: Russian Federation (Elizarova et al 2012), Poland (Gózdź and Pachelski 2014), Malaysia (Zulkifli et al., 2014; Zulkifli et al., 2015b), Israel (Felus et al., 2014), Greece (Kalogianni et al, 2016), Trinidad and Tobago (Griffith-Charles and Edwards, 2014) and Turkey (Alkan and Polat, 2016). The first five are elaborated on a bit more in the subsections below.

4.1 Russian Federation

At present, the system of state cadastre and real estate registration is based on the 2D representation of objects including land parcels, buildings and structures. However, the current approach does not cover all situations of the real 3D world (Elizarova et al 2012). Examples of such situations impeding cadastre and rights registration are: multilevel complexes, intersections of various objects in space, underground and elevated engineering networks, etc. The developed conceptual 3D-cadastre model is based on the ISO 19152 LADM. The model was adapted to the Russian environment and oriented to 5 types of property objects (land parcels, buildings, premises, structures and unfinished construction projects); see Figure 11. Coming from the 2D cadastre and registration system existing in Russia, the option of a polyhedral legal 3D cadastre based on the representation of 3D objects as polyhedrons (volumes limited by flat faces) was selected as a working model. Curved surfaces of such objects as pipelines and cables are approximated by multi-polylines with diameters. For technical implementation, a solution involving the existing 2D portal and linking it with a new 3D-Viewer was selected. This solution is the most lightly implementable and requires minimal changes, based on functionality supported by the existing 2D portal. For the development of the prototype and its testing on the cases, a package of data was acquired and processed according to requirements of the prototype, including:

- a topographic base map and a digital terrain model;
- cadastral data including boundaries and characteristics of cadastral blocks (groups of cadastral parcels) and land parcels;
- information on state registration of land parcels, buildings, premises and structures;
- technical documentation including technical passports with floor plans, etc.

In order to optimise the 3D cadastre prototype using floor plans and additional information, 3D models of buildings were developed reflecting volume characteristics of premises with the concurrent representation of respective right holders in different colours (see Figure 12).

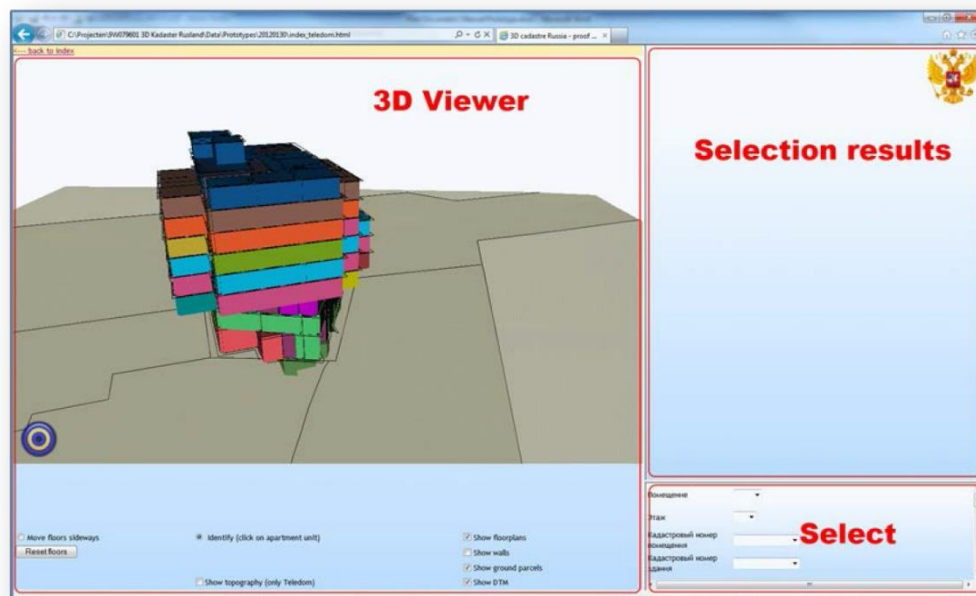


Figure 12. The web-based user-interface to interact and query 3D cadastral objects

4.2 Malaysia

A conceptual model as well as the associated technical model for the 2D and 3D objects have been proposed and developed for Malaysia (Zulkifli, Rahman, van Oosterom, 2014). For both private and public land, the main subdivision of land in Malaysia is based on lots. In many continental European countries, 'lot' would be called 'parcel', but 'parcel' has other meaning in Malaysian context. The lots can have 2D or 3D representations. The Strata Title Act and Strata Management Act are very important for a large part of the Land Administration in Malaysia, and this is especially true for many 3D related situations. The Malaysian LADM country profile includes support for these strata objects: building and building parts (all in 3D within a single lot), land parcel (with house no more than 4 stories within a single lot), accessory unit, and (limited) common property unit including support for provisional and multilayer/underground aspects. In addition, the Malaysian country profile also supports the legal spaces for utilities. By developing a Malaysian country profile based on the international standard ISO 19152, the possible confusion related to terminology (e.g lots, parcels, strata, 2D, 3D) has been resolved. This is not only important for Malaysia, but also useful for many other countries, that have the strata title system.

Figure 13 illustrates the various types of strata objects in Malaysia. A parcel in relation to a subdivided building, means one of the individual units comprised therein (apartment or condominium), which is held under separate strata title. An accessory unit means a unit shown in a strata plan, which is used or intended to be used in conjunction with a parcel. A common property means so much of the lot as is not contained in any unit (including any accessory unit). A limited common property means common property designated for the exclusive use of the owners of one or more strata lots. A land parcel means a unit delineated within the lot (in which

is contained a building of not more than four storeys) which is held under a strata title and which may have shared basement, accessory unit and common property.

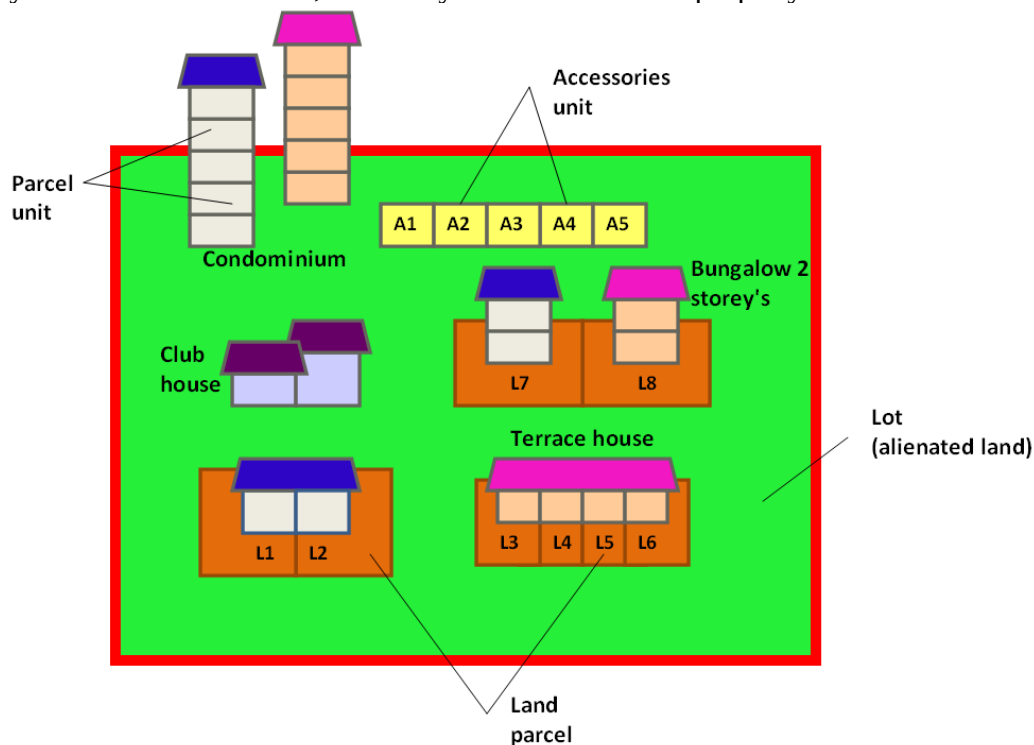


Figure 13. Various cadastral objects related to strata titles within a lot

All classes in the Malaysian country profile are based on the inheritance of the LADM classes - the 'MY_' is the prefix for the Malaysian country profile, covering both the spatial and administrative (legal) data modelling. To illustrate the inheritance from the LADM classes, the MY_classes have either in upper right corner the corresponding LA_class name in italics or have the explicit inheritance arrow shown in the diagram (see Figure 14).

The country profile that has been developed for the 3D spatial unit represents building, utility and lot. The building is represented by MY_Building class and utility represented by MY_Utility class. Both MY_Building and MY_Utility are subclasses of MY_Shared3DInfo (a specialization of LADM's LA_SpatialUnit), 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. Meanwhile, a 3D lot is represented by MY_Lot3D, which is a subclass of MY_GenericLot (which is in turn also a subclass of LA_SpatialUnit). MY_GenericLot has another subclass called MY_Lot2D. Both MY_Shared3DInfo and MY_GenericLot are abstract classes and do not have any instances. Figure 14 illustrates the associated spatial component (with strata classes in darker colour).

one transaction involving all surface parcels, each selling a part of their property, to create a single 3D subsurface parcel to which the right and party can be attached (for the tunnel).

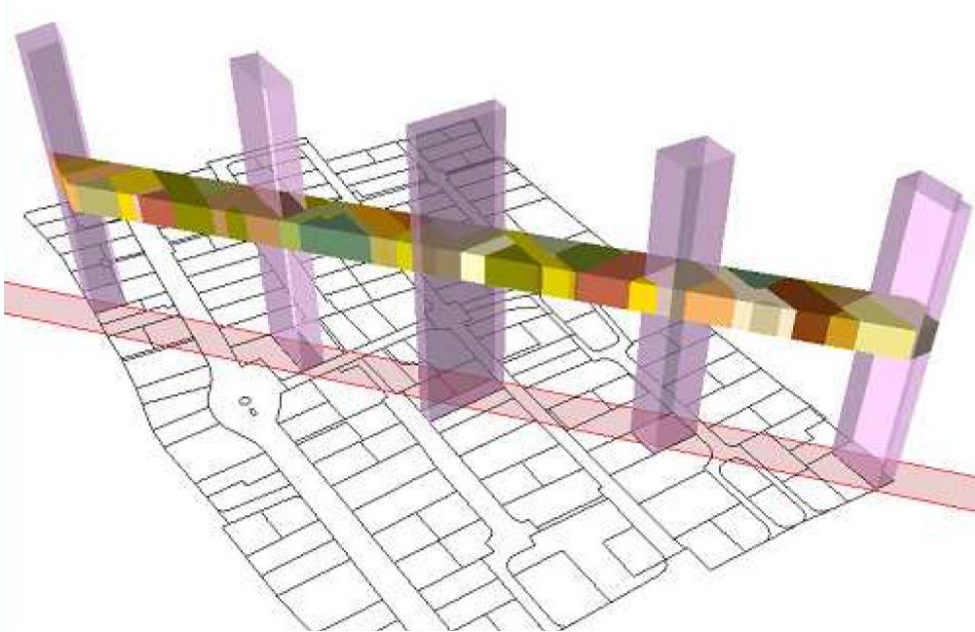


Figure 15. 3D Presentation of the spatial sub-parcels on the background of the existing land parcels. Source: (Shoshani, Benhamu, Goshen, Denekamp and Bar 2005)

Figure 16 shows a UML diagram of the current registration in the initial Israeli country profile as specialization of LADM. The prefix 'IL_' is used to indicate the fact that this is the Israel country profile. The following inheritance relationships are shown IL_Parcel (from LA_SpatialUnit), IL_ParcelArc (from LA_BoundaryFaceString), IL_ParcelNode (from LA_Point), IL_Gush (from LA_SpatialUnitGroup), and IL_Talar (from LA_SpatialSource). The first step towards 3D parcels is the introduction of the 3D IL_BoundaryFace (from LA_BoundaryFace).

(NSDI) of Greece. Within the model, an attempt is made to cover all Greek land administration related information, which are currently maintained by different organizations.

This means that apart from the registrations of the Hellenic Cadastre (HC), other objects are also categorized and registered in the proposed model aiming at the creation of a multipurpose land administration system for Greece. The different types of spatial units include areas with archaeological interest, buildings and unfinished constructions, utilities (legal spaces), 2D and 3D parcels, mines, planning zones, Special Real Property Objects (SRPO) usually found in Greek islands (anogia, yposkafa) and marine parcels. What makes the development of this model unique is the support of a wide range of spatial units, each of them having different requirements, several of them having a 3D aspect. The country profile also includes the content of various code lists, which are an important aspect of standardization.

According to ISO 19152, 2012, LA_Level and therefore, the Hellenic country profile specialization GR_Level is a collection of spatial units with a geometric or thematic coherence, an important concept for organizing the spatial units. For the proposed model, this structure allows for the flexible introduction of spatial data from different sources and accuracies, including utility networks, buildings and other 3D spatial units, such as mining claims, or construction works, etc. (see Figure 17).

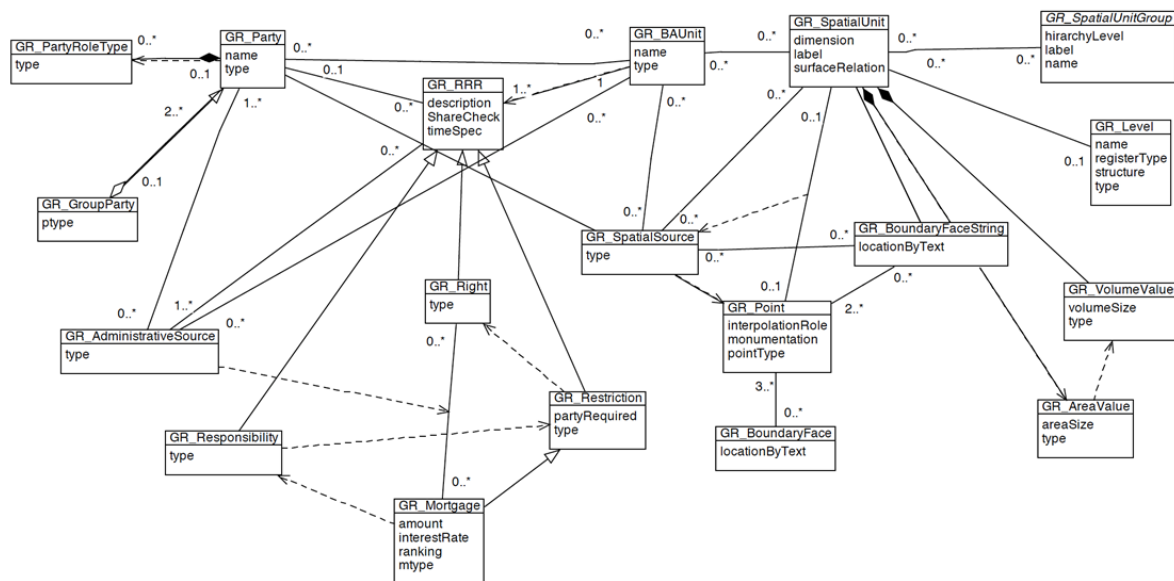


Figure 17. Proposed model graphically represented using UML INTERLIS Editor (Kalogianni E., 2016)

4.5 Poland

Gózdź and Pachelski (2014), Gózdź and van Oosterom (2015) introduced the 3D LADM based country profile, see Figure 18. They mention the fact that Polish cadastral system meets serious difficulty with providing information about the legal status of properties in case of 3D situations, when different property units are located above each other or even more complex structures, i.e. interlocking one another. For that reason, the presented Spatial Package is extended to new classes, e.g. PL_3DParcel.

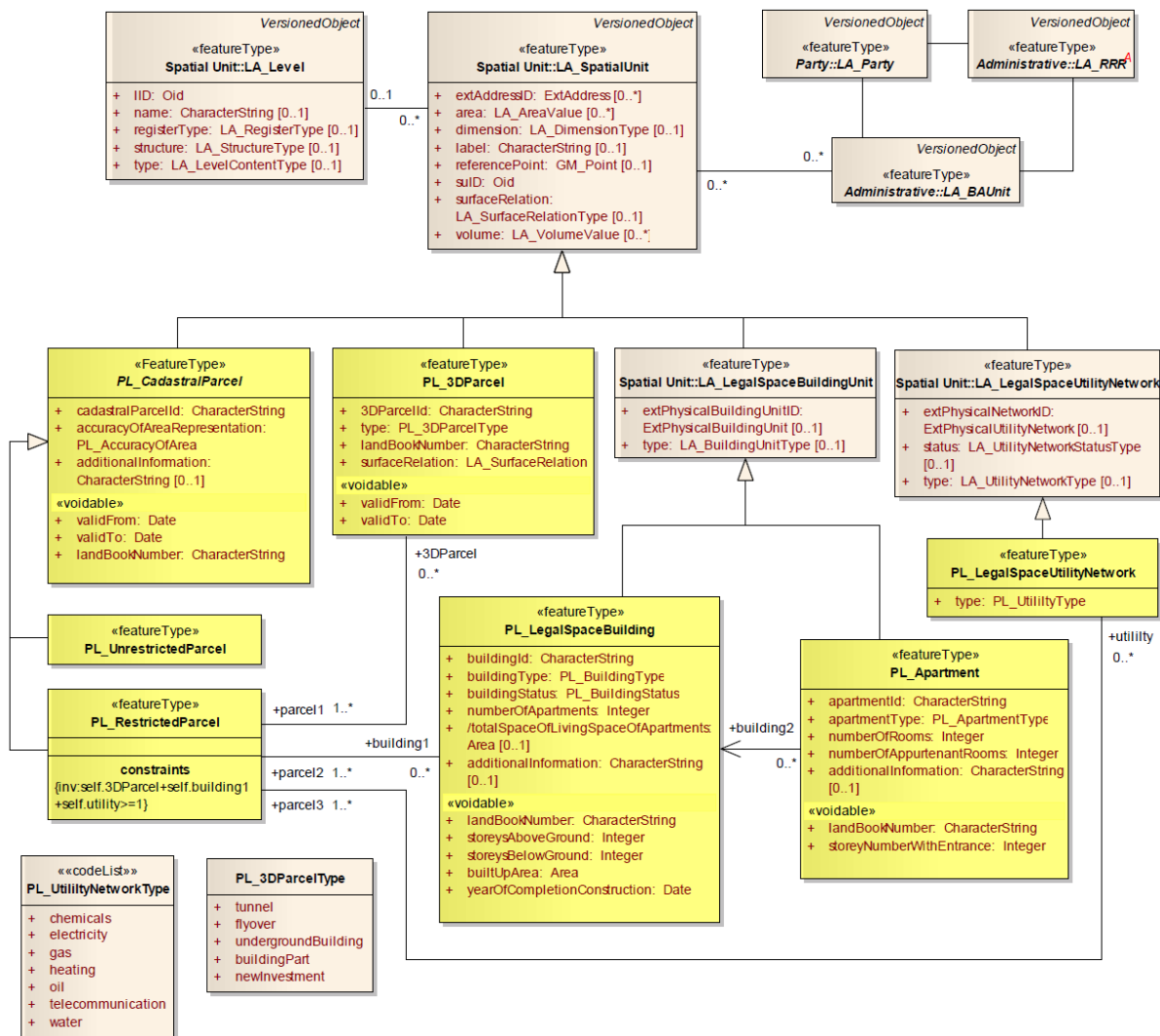


Figure 18. Spatial package of the Polish 3D LADM country profile (Gózdź and Pachelski, 2014)

5 CONCLUSION

In this concluding section, we revisited the various 3D Cadastral Information Modelling aspect, with focus on the gap between what is currently available and what is needed in an ideal situation. In the last subsection future work related to the upcoming revision of LADM is listed.

5.1 3D parcels

What are acceptable (valid) 3D cadastral object representations, and how to create their 3D geometries (even non-2-manifold geometries) are still challenges. The non-manifold 3D representations (self-touching in edge or node) are not well supported by current GIS, CAD, and DBMS software or by generic ISO standards such as ISO 19107 (Van Oosterom, 2013).

How to create and maintain valid 3D parcels is still a challenge in practice Ying et al. (2015). At least three aspects should be clearly developed in order to manage the 3D parcels correctly (Ying et al., 2015): (1) precise geometric models that describe the shapes and geographic locations of various 3D parcels based on flat faces; (2) volumetric or solid models that indicate boundary faces with orientation to present the corresponding 3D parcel objects; and (3) the topological relationships that encode the information about adjacencies between 3D parcels, using shared common faces/edges to preserve the consistency of the objects' geometries and support spatial query and management.

5.2 Interrelation CityGML – LADM ADE

An important trend which can be observed is the use of building information models/construction plans to update the cadastral database, as done in Costa Rica (Van Oosterom et al., 2014).

Further research will aim at investigating other possible alternatives of combining the LADM and CityGML standards (Gózdź et al., 2014) that is:

- embedding the selected CityGML classes into (broader) LADM framework,
- introducing a link between both domain models (in SDI setting) using references between object instances.

Unfortunately, it is not possible to indicate classes corresponding to LA_Party, LA_RRR and LA_BAUnit in CityGML, due to that fact there are many problems in the transformation of the model from conceptual to technical level. The results of this investigation suggest that introducing the semantic representation for land administration within CityGML will be advisable. That issue is included in the list of work packages that define the scope of next version of CityGML (Gózdź et al., 2014).

5.3 Ontology

For any developments that require spatial data, often the fusion of diverse spatial datasets is required. This becomes non-trivial when semantic heterogeneity occurs between schemas like CityGML and LandXML. Soon et al. (2014) introduced a semantics-based fusion framework to integrate CityGML and LandXML using the LADM OWL ontology previously developed. The LADM OWL ontology is augmented with the concepts of 'Physical Space Building Unit' and 'Physical Space Utility Network', which are related to 'Legal Space Building Unit' and 'Legal Space Utility Network' respectively through a new relation *hasLegalSpace*. Furthermore, they looked into how the extended LADM OWL ontology is linked with the CityGML schema and the Australian/Singaporean ePlan model (ICSM 2011) through the equivalent 'Class' relation. Syntactically, the equivalent 'Class' relation can be realized using the ExternalReference and DocFileRef elements of CityGML and LandXML respectively. The framework ultimately attempts to integrate not only the semantic models inherent in the schemas but also the geometries from CityGML and LandXML. Through this semantics based fusion, it is expected that a computer system will be able to do reasoning and inference in the OWL ontology. The computer system will also be able to retrieve the geometries of buildings' legal space or physical space, or both, through the ExternalReference and DocFileRef elements. The intention of the framework is to utilize the best of all worlds (i.e. CityGML, LandXML and

OWL) without affecting the existing schemas, which have been comprehensively developed for different applications.

5.4 Open data and smart cities initiatives

One of the new areas is the creation of the 2D and 3D registries in the context of open data and smart cities initiatives that are aimed at providing a platform for city data. The inclusion of geospatial and building data in this context is paramount and was highlighted by the British Standard Institutions City Data Survey Report⁹.

5.5 Compression and transfer of spatial data

3D models generally result in large data sets, which require special techniques for rapid visualisation and navigation (Breunig and Zlatanova, 2011). As the speed of geodata collection is still increasing, Janečka and Váša (2016) suggest that also the need for the effective geodata compression will be essential, for example to deliver the data to the final user/application via internet. They proposed a compression approach for geographical objects at various level of detail. For complex geographical objects, after the compression the amount of data is even lower than 4% of the original file size.

5.6 Future work related to the upcoming revision of LADM

Within ISO standards, which are actually being applied, are continued and subject to periodic revision, typically in a 6 year cycle. UN-GGIM Meeting of the Expert Group on Land Administration and Management was organized on 14-15 March 2017, Delft and the main conclusion was that indeed a LADM revision was needed in order to provide better tools to improve tenure security and better land and property rights for all. It was also noticed that it is a rather complex domain, with many stakeholders (ISO, FIG, OGC, UN-Habitat, UN-GGIM, World bank, GLTN (Global Land Tool Network), IHO, RICS,...). Further goals include: providing reliable LA Indicators for the Sustainable Development Goals (SDG), standard(s) supporting a Fit-for-Purpose approach, attention for implementations and tools (not just conceptual model), and inclusion of valuation information (which could might help to define/support Fit-for-Purpose approach). In order to prepare the LADM revision, a workshop was organized in 16-17 March 2017, with experts involved in the development of the initial version of LADM and representatives of all mentioned stakeholders. It is important to analyse and compare currently operational and proposed country profiles and their implementations of first version of LADM, ISO 19152:2012. The main, preliminary outcomes of the LADM 2017 workshop can be summarized as (van Oosterom 2017):

1. FIG makes New Work Item Proposal (NWIP) to ISO TC211
2. It is possible to start with an ISO Stage 0-project, given potential broad scope, including:
 - Fiscal/valuation extension module
 - More explicit semantics of code list values
 - Further modelling LADM's rights, restrictions, responsibilities (RRRs)
 - Further modelling of LADM's survey and spatial representation
 - SDG Indicators (aggregated values at different levels)

⁹ http://www.bsigroup.com/Documents/BSI_City Data Report_Singles FINAL.pdf (accessed on 23 August 2016).

- 3D/4D Cadastre
 - Spatial planning/zoning with legal implications
 - LADM in support of Marine Cadastre (esp. coastal zones)
 - More explicit relations with Building Information Modelling (BIM)
 - Other legal spaces: mining, archaeology, utilities,...
3. Multi-part standard, 2-4 years development. Some initial thoughts:
 - Part 0: Core (update current version LADM)
 - Part 1: Potential conceptual model extensions
 - Part 2: LADM Profiles (Methodology to define profiles, STDM, Sample country profiles)
 - Part 3: Application schema, technical models & encodings (considering existing markup languages (xxxML): CityGML, IndoorGML, InfraLand (InfraGML), LandXML, Own/new land administration markup languages → LAML, (Geo)BIM/IFC, INTERLIS, Linked data (RDF), GeoJSON,...)
 - Part 4: Process & workflow standardization
 - Sample implementation
 4. OGC Innovation Program (with the option that National Mapping and Cadastral Agencies (NMCA) support developed countries)
 5. GLTN support for developing countries
 6. In collaboration with many partners (more than list below)

The list above shows that the revision could have rather a wide scope and result in a complex process. The intention is that the next steps will be made during the 7th FIG Workshop on the Land Administration Domain Model, Zagreb, Croatia, 12-13 April 2018 (see <http://isoladm.org>).

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