The Modelling of Spatial Units (Parcels) in the Land Administration Domain Model (LADM)

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Key words: spatial units, parcels, LADM, spatial representations, cadastral systems, land administration systems

SUMMARY

The Land Administration Domain Model (LADM) is under development within the Technical Committee 211 (TC211) of the International Organisation for Standardization (ISO) and identified as ISO 19152. Within the LADM classical cadastral concepts as “parcel” and “boundary” have been extended to be able to include spatial representations of overlapping tenures or claims and also multidimensional objects (3D and 2D/3D, combined with temporal dimensions). Furthermore, a series of new representations are possible apart from topologically well structured parcels (here called *spatial units*). Text based, sketch based, point based, line-based, polygon based, or topological based representations of spatial units are possible. The topological spatial units are defined by a consistent topological structure (with no gaps, overlaps or intersections), which is in contrast with a set of polygons, where a consistent topological structure is not guaranteed. A line-based spatial unit is represented by a collection of lines which may be collected from different sources or surveys. A point-based spatial unit contains only the coordinates of the unit’s reference point. A text based spatial unit is not represented by coordinates, but has a spatial unit description in words, e.g. the metes and bounds system (a spatial unit description in terms of distance, direction, and landmarks). All these spatial units may have a 3D representation, and a provision is made for a mixture of 2D and 3D spatial units to co-exist. A *level* is a collection of spatial units with a geometric or thematic coherence. The concept of level is related to the notion of “legal independence” from ‘Cadastre 2014’. This 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.

The paper explores the LADM spatial component, which is further based on ISO standards, combined with new concepts as “boundary face string” and partially unbounded primitives. Spatial profiles and the different spatial representations are used to demonstrate the flexibility of spatial representations of this domain model; for formal and non formal land administrations systems alike. The first trial implementation of the Queensland (Australia) Digital Cadastral Database (DCDB) for 2D parcel encoding using the line-based spatial profile will be discussed in detail, together with the polygon based spatial profile for the spatial units of the Portuguese land administration.

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1. INTRODUCTION

This paper explores the spatial component of the Land Administration Domain Model (LADM).

In the beginning of 2008 FIG submitted a proposal to develop an International Standard for the Land Administration (LA) domain to the Technical Committee 211 (TC 211) on Geographic Information of the International Organization for Standardization (ISO/TC211, 2010). The proposal received a positive vote from the TC211 member countries and a project team started to work on the development of the standard. The proposal was based on many years of discussion on this subject within FIG and from the input of several workshops and from many experts in this field worldwide. A predecessor of the LADM was presented at the FIG Congress in Munich in October 2006 (Lemmen and Van Oosterom, 2006).

The International Standard intends to provide an abstract, conceptual schema with five basic packages related to (1) parties (people and organizations); (2) rights, responsibilities, and restrictions (ownership rights); (3) spatial units (parcels, buildings and networks); (4) spatial sources (surveying); and (5) spatial representations (geometry and topology). It enables the combining of land administration information from different sources in a coherent manner. The LADM can include informal and customary rights. It should be noted that there can be no interference with (national) land administration laws.

Within TC 211 many issues and comments have been discussed during several meetings held with a project team composed of 21 delegates from 17 countries. The authors have been strongly involved in the development of this standard. A significant contribution to the development of the standard has been provided by the research communities of the Faculty of Geo-Information Science and Earth Observation of the University of Twente (ITC) and Delft University of Technology, The Netherlands.

There was a positive vote for LADM at the 29th Plenary Meeting of ISO/TC 211 in Quebec City (Canada) in November 2009 on forwarding the LADM (aka ISO 19152) as a Draft International Standard (DIS). An Editing Committee is working now on the DIS, which is expected to be available in 2010. The final International Standard is expected in 2011.

FIG expects this standard to be accepted and supported by a wide community. It can then form the basis for software development and for data exchange of land information. In this way the LADM can contribute in the development of flexible land administration systems.

2. CORE CLASSES OF LADM

During the development of the LADM the three core classes “Person”, “Right” and “Parcel” (or “RealEstateObject”) have always been included, with the remark that the terminology has been changed, not the meaning. The class name “Person” has been changed into “Party”, the class name “Right” has been changed into “RRR” (for Rights, Restrictions and Responsibilities) and the class name “Parcel” into “Spatial Unit”. The core classes were derived from (Henssen, 1995) and from FIGs “Cadastre 2014” (Kaufmann and Steudler, 1998). This means that land ownership of parcels in traditional cadastres has been extended in LADM to include and administer all spatial units, which have some social, legal or economic relevance – which makes LADM a more generic model (similar with “Cadastre 2014”).

In the orginal LADM class diagram the classes “Person” and “Parcel” (or “RealEstateObject”) were associated, with class “RRR” as an association class. The orginal model is represented in Figure 1.

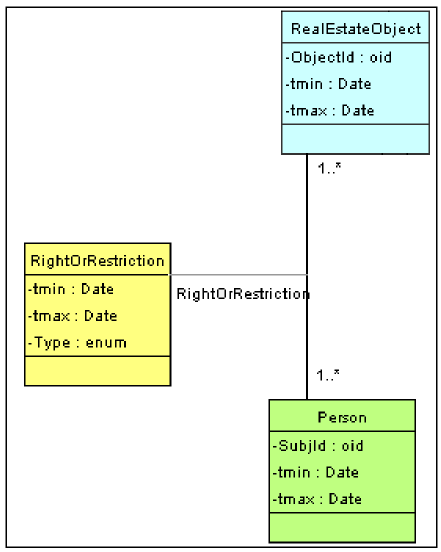

Figure 1. “Person” and “RealEstateObject” with an association class “RightOrRestriction” (Van Oosterom et al, 2004)

The association class “RightOrRestriction” was replaced by *two* associations: (1) between class “Parcel” and class “RightOrRestriction”, and (2) between class “Person” and class “RightOrRestriction”; see Figure 2. The main reason for this design decision was to make it possible that, for a unique combination of a specific “Person” with a specific “RegisterObject” multiple RRR instances can be associated (e.g. one expressing ownership and one expressing a certain responsibility), which was not possible in the construction with the association class “RightOrRestriction” (Van Oosterom et al, 2006).

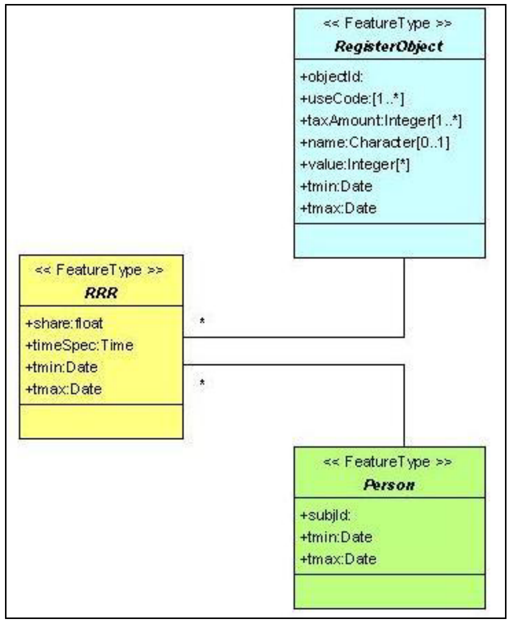

Figure 2. Separate associations between the LADM core classes (Lemmen and Van Oosterom, 2006)

Then, during the discussions in the ISO Technical Commission 211 it was agreed that there was a need for a so called “Basic Administrative Unit”, located between the classes LA_RRR and LA_SpatialUnit. This allows for the introduction of the so called “Basic Property Unit”. A “Basic Property Unit” is in the definition in (UN/ECE, 1996) “*the extent of the land that is one unit of ownership is referred to as the basic property unit (BPU). It may consist of one or more adjacent or geographically separate parcels. A farm, for example, may have a number of fields that are in different locations but together they constitute one BPU. Likewise, a house may have a garage on a separate piece of land.*

The Basic Property Unit is called Basic Administrative Unit (abbreviated as “baunit”) in the LADM. This is a more generic term, LADM is not only about freehold and leasehold but also about other types of people – land relationships; e.g. customary and informal types of land use. This resulted in four core classes (LA_Party, LA_RRR, LA_BAUnit and LA_SpatialUnit); see Figure 3. The related definitions are introduced in (Lemmen et al, 2010). This allows for a separate introduction in LADM of the “legal/administrative part” (the registers) and of the “spatial part” (the cadastral map) at different moments in time; e.g. first the registers, then the map.

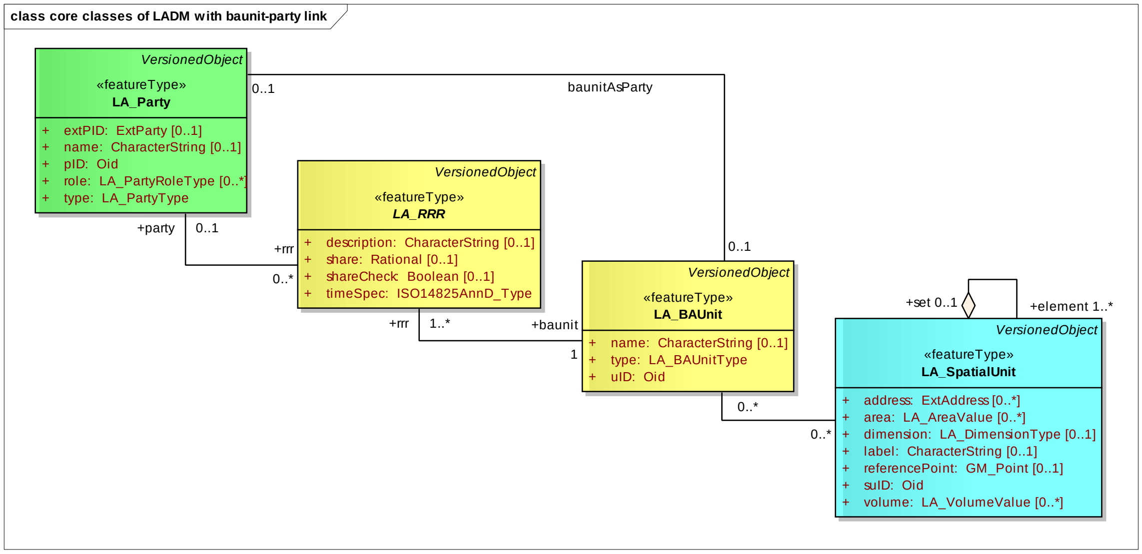

Figure 3. The four core classes of LADM (ISO/TC211, 2009)

3. SPATIAL UNITS

The main class of the spatial units package of LADM is class LA_SpatialUnit (with LA_Parcel as *alias*), with 2D or 3D spatial units as instances. Spatial units are refined into two specializations:

1. Building units (in class LA_LegalSpaceBuildingUnit), and
2. Networks (in class LA_LegalSpaceNetwork).

See Figure 4.

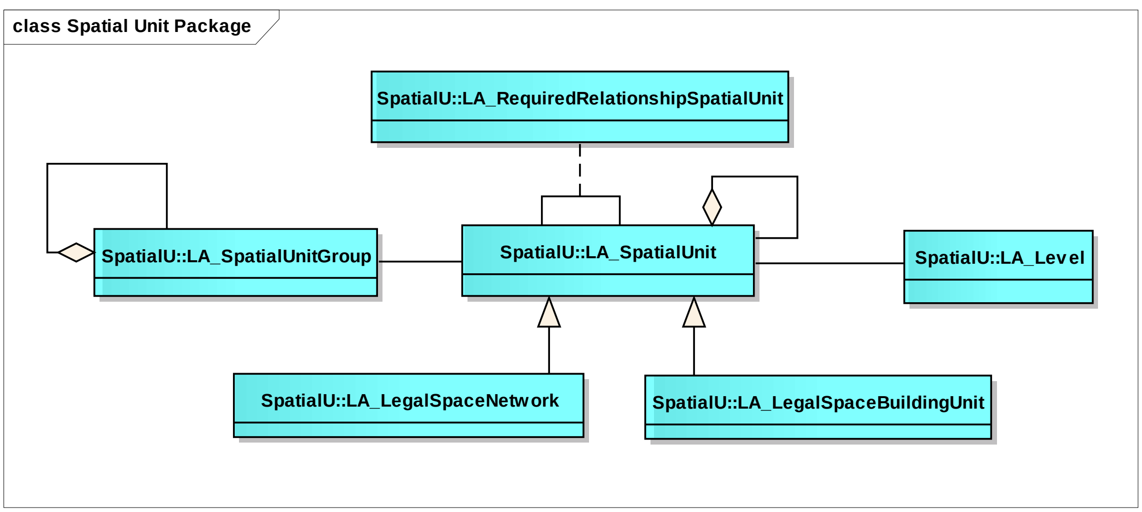

Figure 4. Classes of Spatial Unit Package and associations between them (ISO/TC211, 2009)

Spatial units may be grouped into "spatial unit groups", for example, a municipality, or a planning area. A spatial unit group may be a grouping of other spatial unit groups. In implementations of LADM, this may be related to spatial unit identifiers; when a spatial unit identifier (id) is composed out of hierarchical zones, e.g. country id, followed by department id, followed by county id, followed by municipality id, etc. Spatial unit groups, possibly together with basic administrative units, may also be planning areas, e.g. for the implementation of land reforms, land consolidations, land readjustments, or farming plans.

A "level" is a collection of spatial units with a geometrical, topological or thematic coherence. This concept is important for organising the spatial units in LADM, and it is introduced in Section 4.

LADM supports different types of spatial units:

- a "sketch based" spatial unit is used when a sketch (a quick draw of a group of spatial units) is available; e.g. sketch maps (Törhönen and Goodwin,1998), and photographs, in the absence of any better identification
- a "text based" spatial unit is used when the definition of the spatial unit is entirely by descriptive text. This includes the "bounds and metes" descriptions. Metes and bounds is a system or method of describing real property (in contrast to personal property). The system has been used in England for many centuries, and is still used there in the definition of general boundaries. By custom, it was applied in the original thirteen colonies that became the United States, and in many other land jurisdictions based on English common law (Cribbet et al, 2002). A typical description for a small parcel of land would be: *"beginning with a corner at the intersection of two stone walls near an apple tree on the north side of Muddy Creek road one mile above the junction of Muddy and Indian Creeks, north for 150 rods to the end of the stone wall bordering the road, then northwest along a line to a large standing rock on the corner of John Smith's place, thence west 150 rods to the corner of a barn near a large oak tree, thence south to Muddy Creek road, thence down the side of the creek road to the starting point."* (quoted from: http://en.wikipedia.org/wiki/Metes_and_bounds). There can be observations like distances and bearings (by compass) in a local system. This means there is no cadastral map.
- a "point based" spatial unit is used when the only information about the location are the coordinates of a single point within its area (or volume). Jackson (1996), with references to several other authors, speaks about the "midpoint concept". In this concept the position of a land right is recorded, not its boundaries. Lester and Teversham (1995) refer to the concept as follows: "*a single coordinate of the centre of the dwelling unit could positively identify that unit, and this may be sufficient for basic recording purposes where the limits of the land holding are for the time being unimportant*". This concept is supported in LADM by "point based" spatial units. Fourie and Van Gysen (1995) place the midpoint survey *at an early stage in a system of progressive title improvement, ending in a standard freehold system*. This is exactly what LADM supports in providing different options for the representations of spatial units
- a "line-based" (aka "unstructured" or "spaghetti") spatial unit is used when the representation is allowed to have inconsistencies, such as hanging lines and incomplete boundaries. This may happen if data are collected over time with different data acquisition methods. Referring to Figure 5 it can be seen that, although the linework is of different quality and lineage, and in fact does not join in places (the circled points), a

large number of the parcels are well defined. In fact, to a human user, the pattern of subdivision is clear. Further, adjacent parcels can be determined by inspection of the figure. The other side of this issue is that each piece of linework is uniquely identifiable, and can be marked with a quality statement. Using this statement, a set of criteria can be developed to allow many of the issues of hanging lines and mismatches to be resolved. Different 'levels' (Section 4) may be used for different qualities.

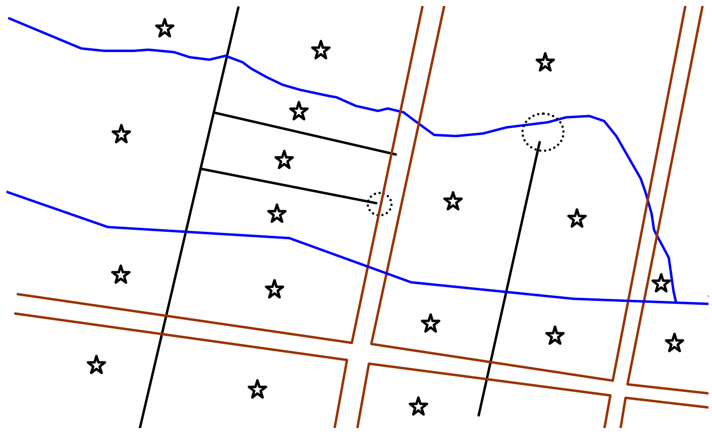

Figure 5. Line-based spatial units

- a "polygon based"spatial unit is used when each spatial unit is recorded as a separate entity. This is applied in many GIS systems. There is no topological connection between neighbouring spatial units (and no boundaries shared), and so constraints enforcing a complete coverage must be applied by the sending and receiving software
- a "topology based" spatial unit is used when spatial units share boundary representations. A topological based spatial unit is encoded by reference to its boundaries, with the common boundary between two adjacent spatial unit's being stored once only. Thus there is a topological connection between neighbours.

2D and 3D or mixed representations of spatial units are also possible (Lemmen et al, 2009).

4. LEVELS

A "level" is a collection of spatial units with a geometrical, topological or thematic coherence. A level may be organized on the basis of the geometrical or topological structure of the spatial units, and is used for the implementation of the notion of "legal independence" from "Cadastre 2014". For example, a level with rights, or a level with restrictions. Another approach is a level structure for urban areas, rural areas, or mining areas.

To apply the principle of "legal independence", when building a land administration system, it is necessary to investigate the laws in a jurisdiction and to identify those with an effect on land. The different spatial units may be arranged according to the laws by which they are defined. This structure allows the immediate adaptation of the land administration to the development of the legislation. It is not necessary to rearrange the information. New legal topics can simply be added by including a further (information) level. If a law is cancelled, the respective information level can be removed without reorganizing the other levels.

In this way it is also possible to deal with facts which are not formally written down in a law. Such informal and customary rights exist where tribes or clans are obeying unwritten rules. These tribes or clans may have living, hunting and fishing rights within a defined territory from which the boundaries are known, but not documented formally. The rightful claimants are certainly able to localize the outlines of their rights and the respective spatial unit can be included into the land administration system. A form of "occupation rights" exist in informal settlements in many areas of the world. Even when the occupation of the land may be contrary to the formal law, the rights of the involved settlers are informally defined by an unwritten code. The boundaries resulting from these informal arrangements can be localized and documented. So this principle can show overlapping rights and serve to formalize the situation, to regulate transactions, to monitor and to improve ambiguous situations. Indigenous rights normally overlap with a formal ownership system. The rights and the boundaries where they are in effect are well known and can be documented (Augustinus et al, 2006; Lemmen et al, 2007).

In this way, in relation to the principle of "legal independance", there can be one level representing spatial units, reflecting the formal rights as described in e.g. the civil code. This may include freehold, leasehold and servitutes. If spatial units are based on local legislations (e.g. a municipal regulation) there can be another level for this. This may be valid for all municipalities in a territory. Further levels can be related to regulations developed by other governmental institutions.

A further division may be based on the legal tasks of urban- and rural cadastres which exist in many countries. There can also be forest cadastre, railway cadastre, or utility cadastre. There may be a need to represent a taxation and legal cadastre – which can be separate organisations.

A final division is in allocating levels for types of spatial units: text based, sketch based, point based, line-based, polygon based, or topology based. The principle of legal independence; the type of land administration (urban, rural, etc) and different types of spatial units can be combined in one level structure. This allows for integrating data delivered by different organisations, with different legal mandates and for integrating data based on different spatial units as a basis for *progressive title improvement, ending in a standard freehold system*. This can also be applied in relation to the quality of spatial data related to different qualities: from no map at all to a high quality structured map.

5. OVERVIEW SPATIAL PROFILES

The Spatial Representation and Survey subpackages of LADM allow a large number of possible representations of spatial units in 2D, 3D, or mixed (integrated 2D and 3D); see Figure 6. As explained in Section 3, the LADM supports text, point, (unstructured) line, polygon and topology based spatial representations. Combining these five spatial representations with the three options for the dimension of the representation results in 15 combinations. In a specific "country profile" it is possible to use different levels (see Section 4), with different spatial representations; e.g. for the "normal parcel" level 2D topology-based spatial representation can be used, while for the "legal spaces building" level a 3D polygon (that is, polyhedron in 3D) based solution is used. For one specific type of spatial representation, there are often just a limited number of classes and attributes needed. A "spatial profile" shows the needed classes and attributes.

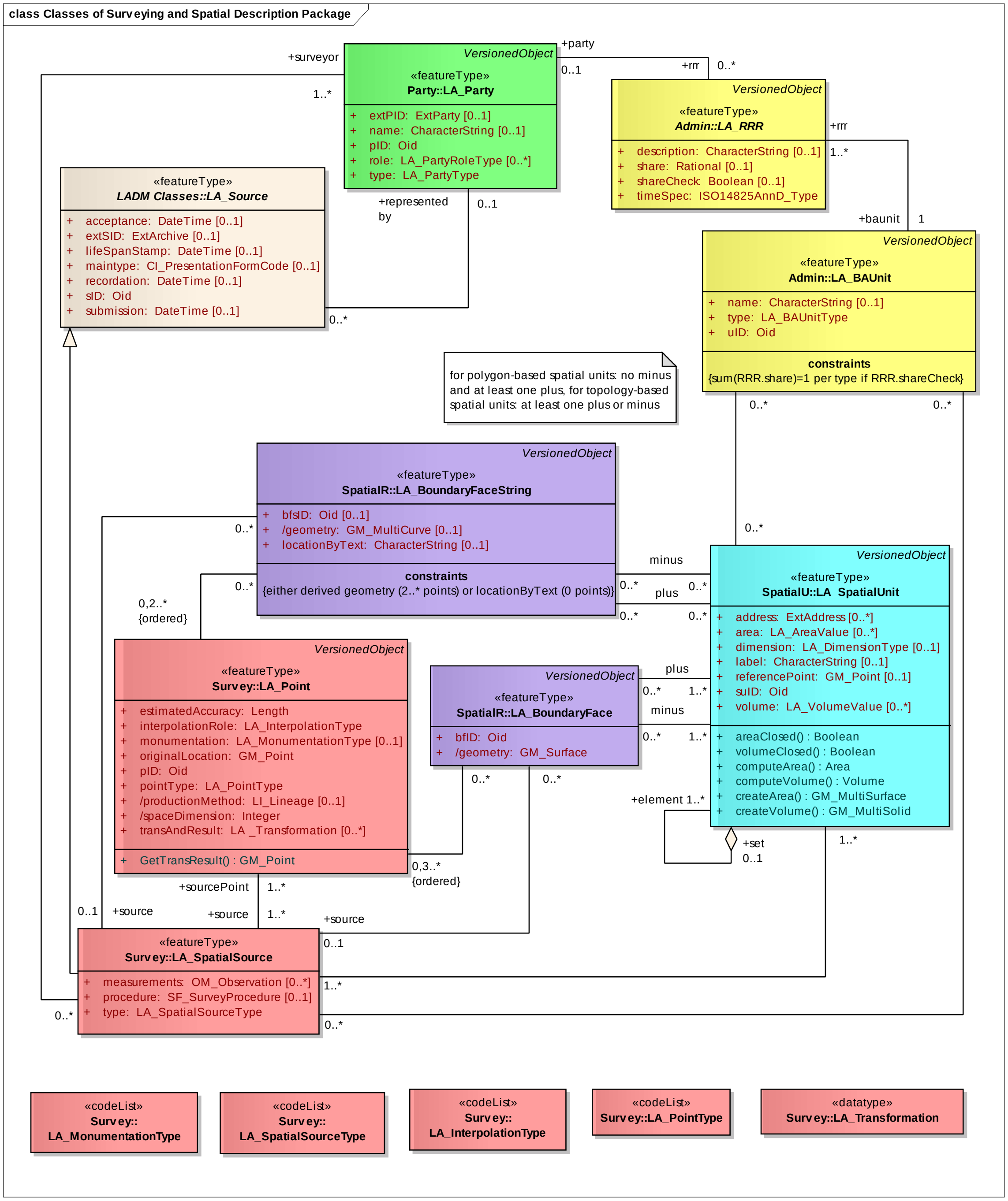

Figure 6. Spatial representation of spatial units (ISO/TC211, 2009)

Out of the 15 possible combinations, the current version of LADM specifies six spatial profiles (see Annex E in ISO/TC211, 2009): 2D Point based, 2D Text based, 2D Unstructured (line-based) (see Figure 7 top), 2D Polygon based, 2D Topological based, and 3D Topological based (see Figure 7 bottom).

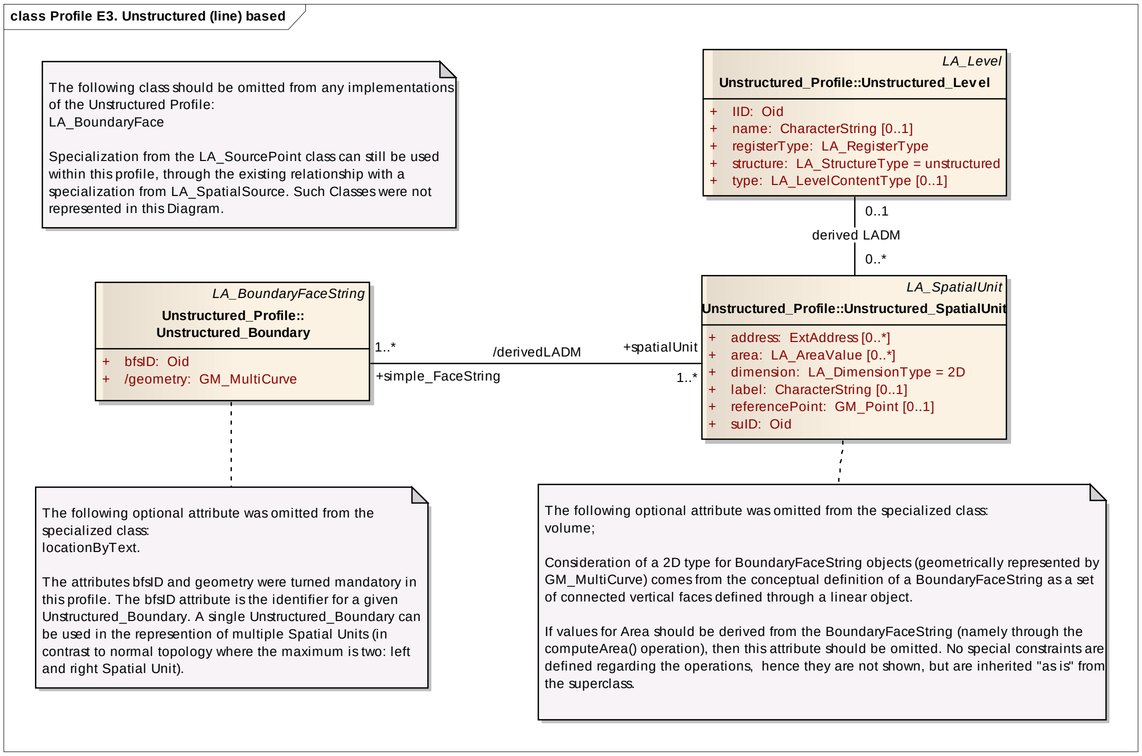

Figure 7. 2D Unstructured (line-based) spatial profile (ISO/TC211, 2009)

6. UNSTRUCTURED (LINE-BASED) SPATIAL PROFILE (with some examples from the Queensland DCDB)

This section will discuss in further detail, first the trial implementation for the Queensland Digital Cadastral Database (DCDB) 2D parcel encoding using the "2D Unstructured (line-based) spatial profile" (Section 6.1) and various operations (Section 6.2). Next the extensions that allow a mixture of 2D and 3D cadastre is presented (Section 6.3). The relative easy editing of the data according to the "2D unstructured (line-based)" spatial profile is discussed; see Section 6.4. A set of proof of concept Java classes and Informix tables have been created, showing that the approach is workable, and giving an indication of the issues that will arise if the matter is pursued; see Section 6.5. The critical benefit of this representation is that it allows the development of a Digital Cadastral Database (DCDB) with many, if not most, of the valuable functionality of such a database, without having to wait until an expensive and time-consuming data validation process has been completed. Rather than waiting until pristine data has been prepared, many of the benefits can be had immediately. In essence, a collection of linework of differing quality and lineage can be used to define a cadastre, and create a cadastral database. This database can be used to assist with the administration of the land while allowing improvement of the quality of the information.

Experience has shown that the move towards 3D cadastre is widespread throughout the world, and does not wait for the existence of a 3D cadastral database (Stoter and Van Oosterom, 2006), so it is advantageous that an approach such as this is available which potentially makes the necessary infrastructure available more rapidly than would otherwise be the case.

6.1 The Model for 2D Spatial Units

This very simple structure is an excerpt from the LADM. It allows the storage of cadastral parcels (the spatial units) in terms of the “centroid” (the referencePoint), and the linework that separates and defines the parcels (as LA_BoundaryFaceString entries). Referring back to Figure 5 it can be seen that the linework may be of different/imperfect quality (not always joining). In order to encode 2D parcels in the line-based form, each identifiable line is represented as a LA_BoundaryFaceString. Each parcel centroid is used to generate a LA_SpatialUnit record, which is then connected to the LA_BoundaryFaceString records that define it.

In the following, it must be stated that this is not a suggestion that the Queensland DCDB be converted into this form. It currently is topologically sound, and does not need this sort of treatment. The use of Queensland cadastral data is merely a matter of convenience and availability of data. A significant number of 2D parcels (about 6000) were extracted from the DCDB and converted to this form. In addition, two 3D parcels were hand-encoded. These have been used in the following to illustrate some of the issues.

Figure 8. A Parcel defined by four face strings

[Figure 8](#) shows the definition of a single parcel (a simple rectangle, marked by the pin and the text 25023/65). It is defined by part of a road boundary (pink) and three property boundaries (blue). Note that the road boundary line runs around the whole block, and is part of the definition of many parcels. This re-use of the definition of an item of linework leads to a reduction of the amount of redundancy in the database, but also defines an object that can be used to record the metadata of that linework (as distinct from the parcel metadata).

Note also that a face string may be more than one part of the definition of a single parcel. For example, in Figure 9 (above), and shown pictorially and schematically in Figure 9 (below), the target parcel (25036/81) is defined by five linestrings (numbered 1 to 5), with the (pink, arrowed) road boundary being present three times.

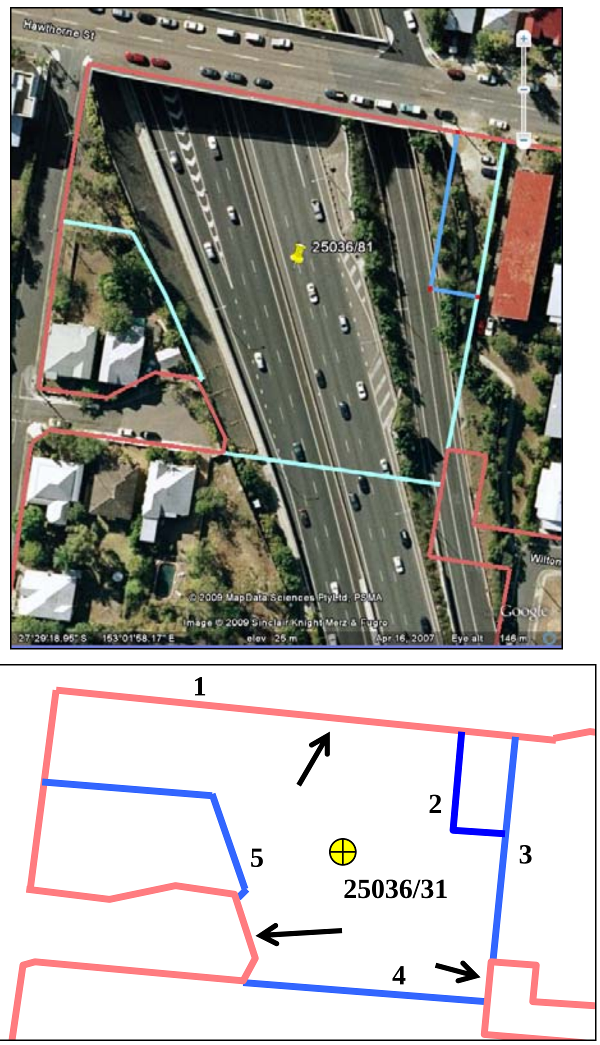

Figure 9. *Above*: a single face string participating more than once in the definition of a parcel; *Below*: Schematic of view

A further reduction in redundancy is obtained by the sharing of linework between base and non-base parcels. In Figure 10 the main parcel (25030/286) is defined by the pink and light blue lines. There is an easement (25030/278) which is delimited by the yellow line, and shares its other boundaries (pink and blue lines) with the main parcel. There is also a tunnel (25030/287) below the surface, shown here (in 2D) delimited by white lines, and the pink and blue lines of the main parcel. Although the road boundary is part of the definition of these three parcels, (and many others), it is stored once only.

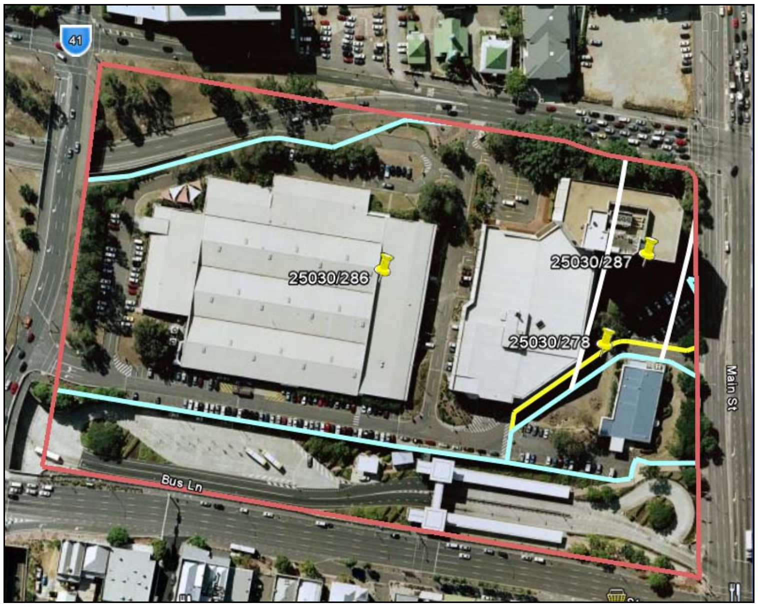

Figure 10. Non base parcels using base linework

6.2 Various Algorithms

Fill Window: This is a very simple algorithm. All face strings within the given window are retrieved, and plotted. Then all spatial units with reference points within the window are retrieved and plotted. This is very fast, retrieves no redundant data, and produces a basic "cadastral map", or web map service etc. It could be argued that this is the fastest possible data storage mechanism for this operation.

The "As Polygon" Operation: This is rather more complex, but still reasonably fast. In effect, the hanging ends of the face strings that define the parcel must be cut off and discarded. The algorithm is a cut down "parcelling algorithm". The intersection points between the face strings are calculated, and the face strings traced (in the correct direction), taking the hardest right turn at each intersection. When a closed loop is located, it must be tested to ensure that it contains the reference point of the spatial unit. Figure 11 shows the linework that would be trimmed and traced to form the polygon representation of Figure 9. This processing may be fairly complex, but it is merely a set of well known 2D algorithms that are available in optimised form. In addition, most cadastral parcels consist of very few face strings (typically 4), so the operations will be fast.

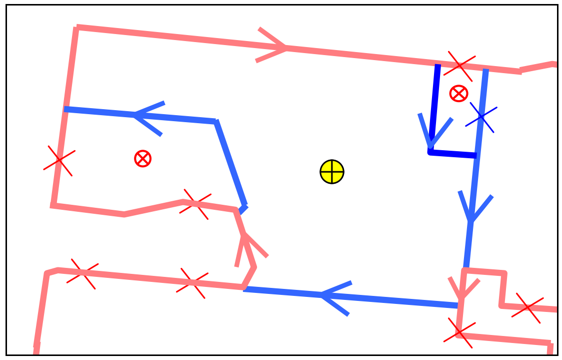

Figure 11. Tracing the linework to construct a parcel polygon

Select Parcel by Reference Point: This is the simple "point and click" operation. Selection by clicking near the reference point is just a case of finding the nearest points, and deciding which is required. The parcel as polygon algorithm above can then be used to trim back the linework.

Select Parcel(s) by Linework: A spatial search of the LA_BoundaryFaceString table will return the line(s) that are close to the cursor position. From the line(s) a set of parcels can be retrieved, and the parcel as polygon routine used to determine which ones are appropriate to the query.

Select Parcel by Included Point: This is the search that returns the base parcel that covers the point. It does not need to be near the centroid or the linework. The nearest (on any nearby) centroid is located, and the parcel lines retrieved as a polygon. A line is drawn joining the retrieved centroid and the search point, and traversed until the correct parcel is found (see Figure 12). This may seem complex, but in the majority of cases the correct centroid will be chosen first time, and in most other cases, the directly adjoining parcel will be chosen.

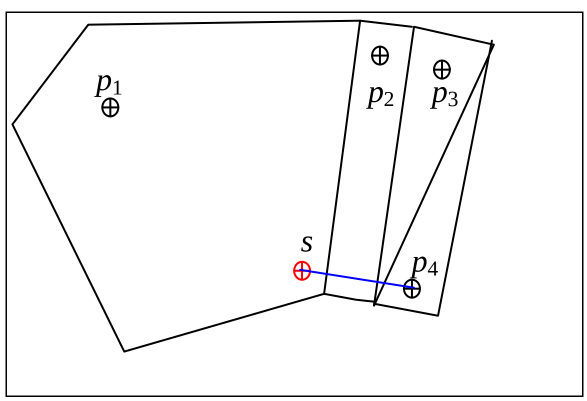

Figure 12. Finding the parcel covering points

Non-Base Parcels: In this structure, non-base parcels can share the linework of the base parcels (thus improving ease of update, and saving redundancy), but unlike the base parcels, they do not form a complete non-intersecting coverage. This means that the neighbor and

"Parcel by included point" algorithms above cannot work reliably. For example, in Figure 13, using topological tracing across lines, easement e_1 will be detected as adjoining parcel p_1, but e_2 will not (not having any line in common). Also, e_3 overlaps p_1, but has no lines in common. This can be accommodated by a linkage between the easement LA_SpatialUnit record and the base parcel(s) that it covers, or by a spatial index on the non-base parcels.

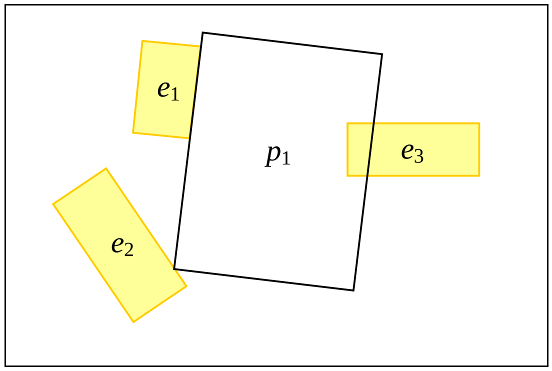

Figure 13. Relationship of easements to a base parcel

6.3 3D Parcels

A very effective storage and transfer mechanism is possible with this approach where 2 and 3D parcels are mixed in a cadastre. The 3D parcels can be represented by a mixture of faces and face strings; see Figure 6. In the same way as the face strings, faces can be linked to (and participate in the definition of) a number of spatial units. For example, Figure 14 shows a mixture of 2D and 3D parcels in side view. Parcel D is a simple 2D parcel, defined by face strings on all sides, but with no defined top and bottom. E was originally 2D parcel, which has been converted to 3D by the excision of part of parcel F. Parcel E is also open above and below. Parcels B, C and F are true 3D parcels.

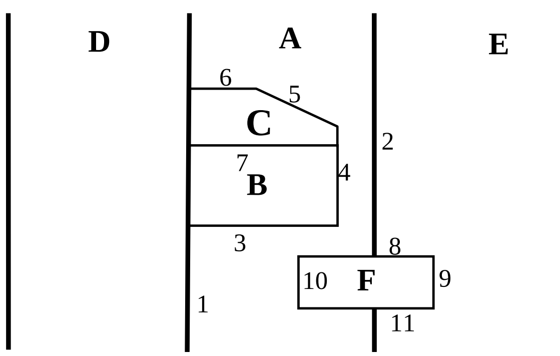

Figure 14. Side view of mixed 2D and 3D cadastral parcels

In the structure being proposed here, parcel F is defined by a set of LA_BoundaryFace records (8, 9, 10 and 11 in Figure 14), but parcels B and C are defined by a mixture of LA_BoundaryFace records (3 to 7) and an LA_BoundaryFaceString record (1 in Figure 14).

In order to explore the issues associated with the mixture of 2D and 3D parcels using the line-based paradigm, two parcels were hand encoded, and included in the database along with the 2D parcels extracted from the Queensland DCDB. These parcels comprise a bus way, which is partially above and below ground level (identified as Lot 4 on plan SP149278 – see Figure 15), and a segment of an underground road tunnel which runs below it (identified as Lot 160 on SP184385 – see Figure 16). These are shown together in Figure 17.

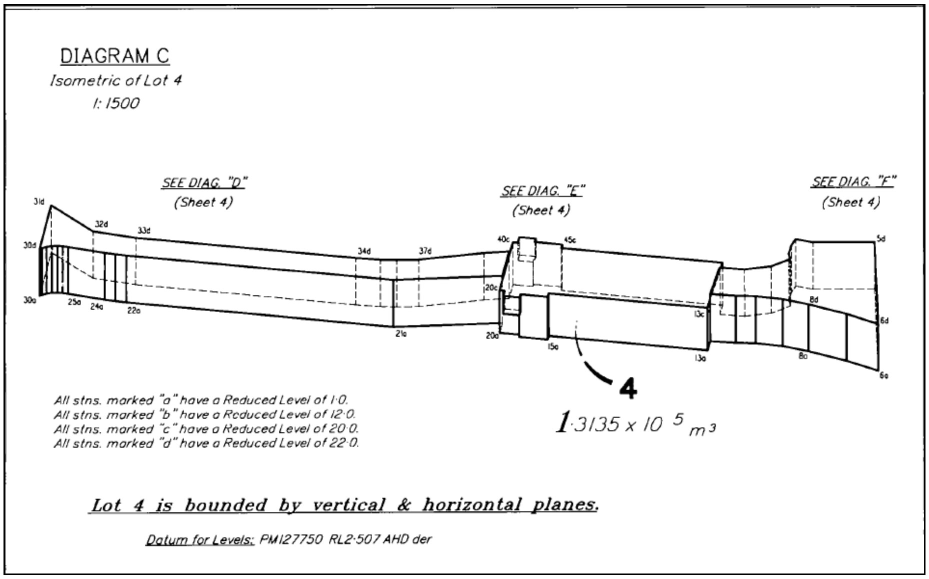

Figure 15. A volumetric parcel (bus way) which is above and below local ground surface level (Lot 4 on SP149278)

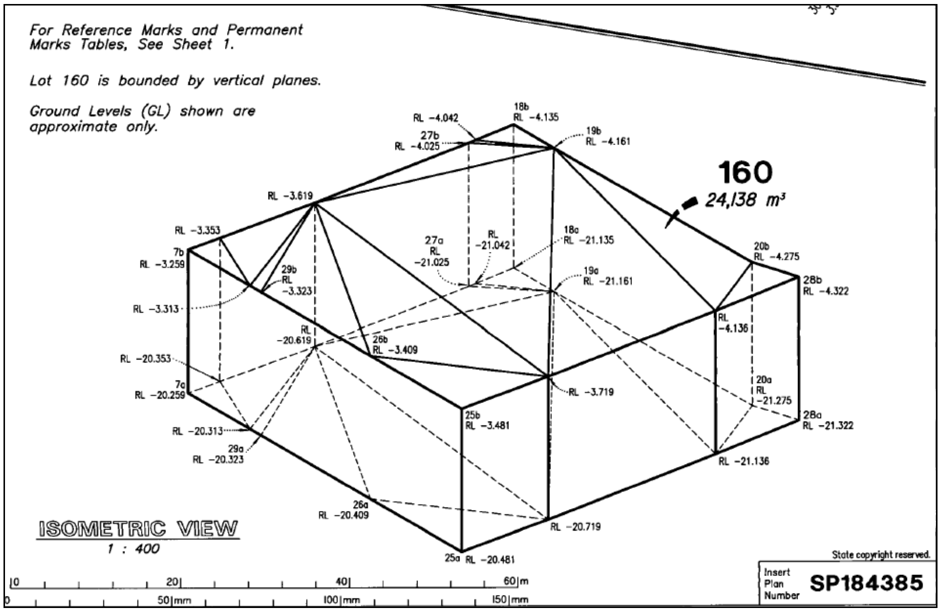

Figure 16. A section of underground road tunnel directly below Lot 4. The upper and lower surfaces are not horizontal. (Lot 160 on SP184384)

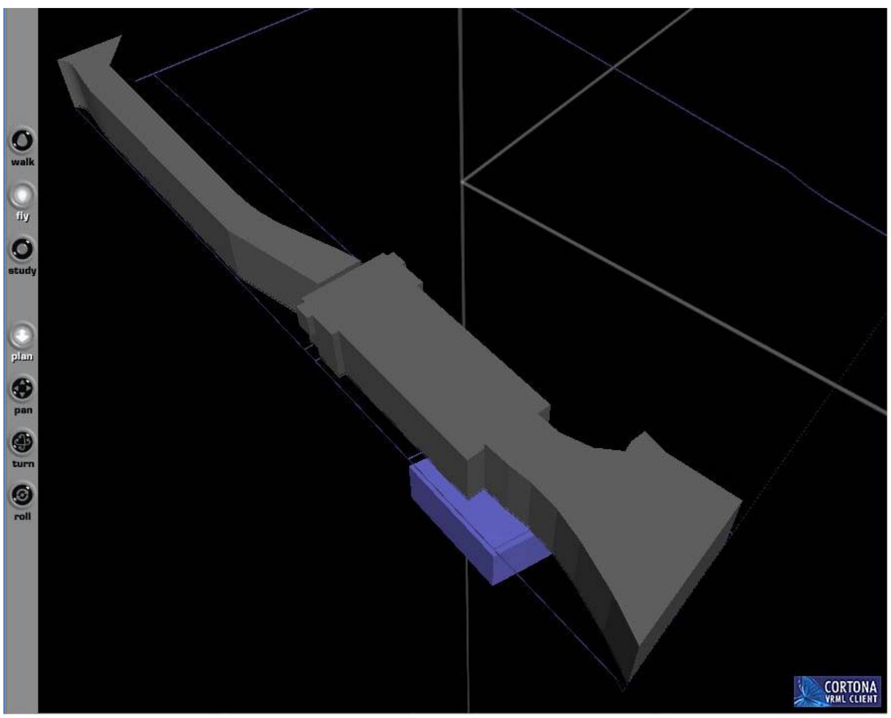

Figure 17. Lot 4 (grey) and Lot 160 (blue), displayed together using Cortona VRML viewer

The encoding of the 3D parcels as line-based spatial units made use of the face strings that were already in the database, and which define the base parcels. Note that this bus way can be seen in Figure 10 at the bottom of the frame. In Figure 18 the face strings are represented as low "fences" at z=0 so as not to obscure the rest of the picture. The face strings and faces for Lot 4 are grey and blue respectively, while those for Lot 160 are light green and cyan respectively.

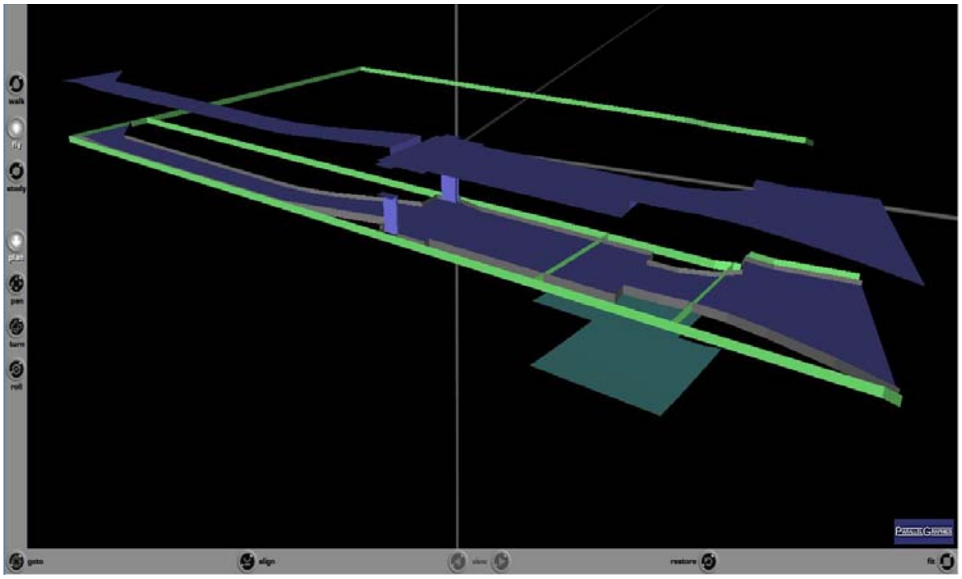

Figure 18. The two 3D parcels defined using a mixture of face strings (depicted as grey and light green vertical fences) and faces (depicted in blue and cyan)

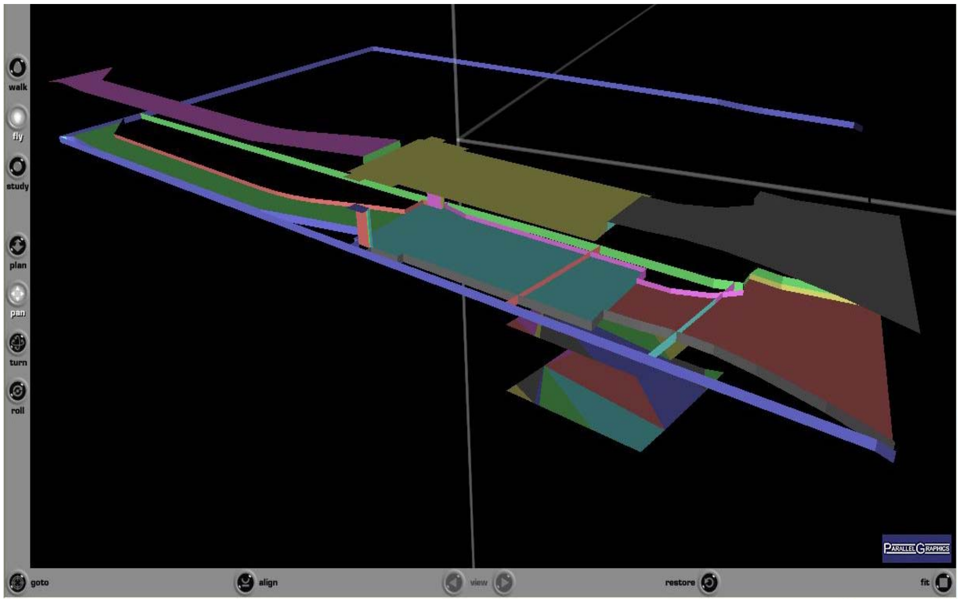

Figure 19. Individual faces and face strings highlighted

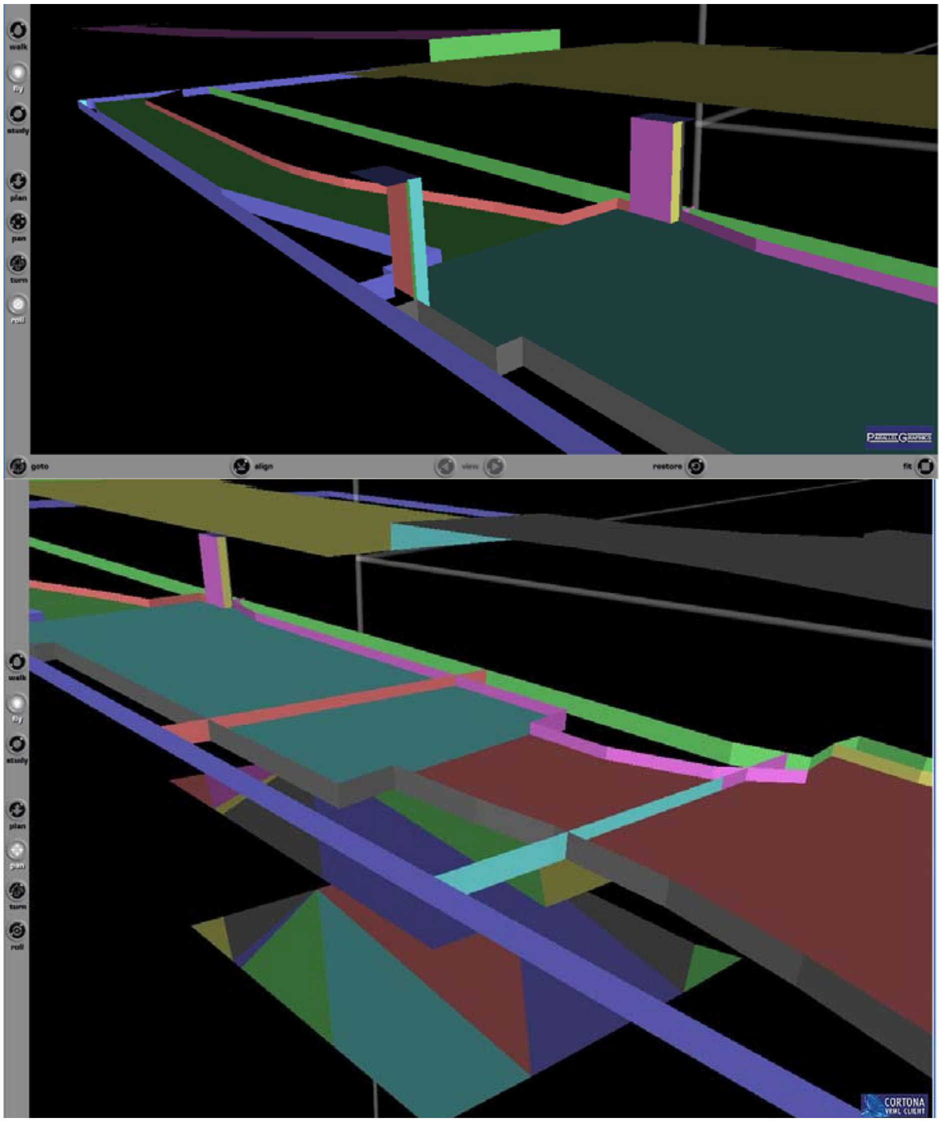

Figure 20. Detail from Figure 19

In Figure 19 and Figure 20, the same parcels are depicted, but with each face and face string in a different colour, in order to show the detail of the encoding. Note that the upper and lower surfaces of lot 160 (below ground) are triangulated as defined in the plan (Figure 16), but the upper and lower surfaces of lot 4 are planar polygons. Note also that faces are only needed in the definition of the parcels where the face strings do not complete the definition.

The "As Polyhedron" Operation

This allows the representation of a parcel as a complete polyhedron. Since it is not guaranteed that every parcel in the database can be converted to polyhedron form, provision must me made for this operation to result in an incomplete polyhedron. For example, parcel *A* in

Figure 14 cannot be represented as a closed polyhedron since it is open above and below. However, a collection of faces can be generated that can be visualised using a VRML viewer.

Each face is intersected with the set of face strings. This is effectively a 2D operation – just the footprint of each face is intersected with the linestring representing each face strings. Any points introduced into the faces must have a Z value calculated to preserve planarity.

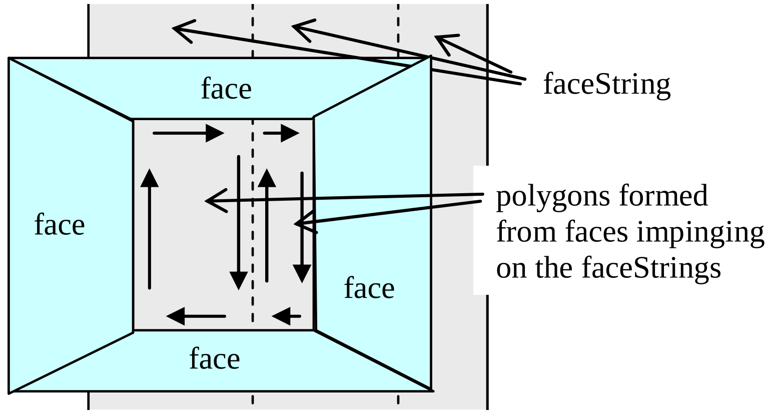

Figure 21. forming polygons from the intersection of faces with a face string. Note that the polygons are clockwise because this is viewed from inside the parcel.

As part of this operation, edges are marked on the individual faces of the face strings. The next step is to parcel these edges to produce true faces (see Figure 21). The final step is to assemble the faces into a polyhedron (Figure 22).

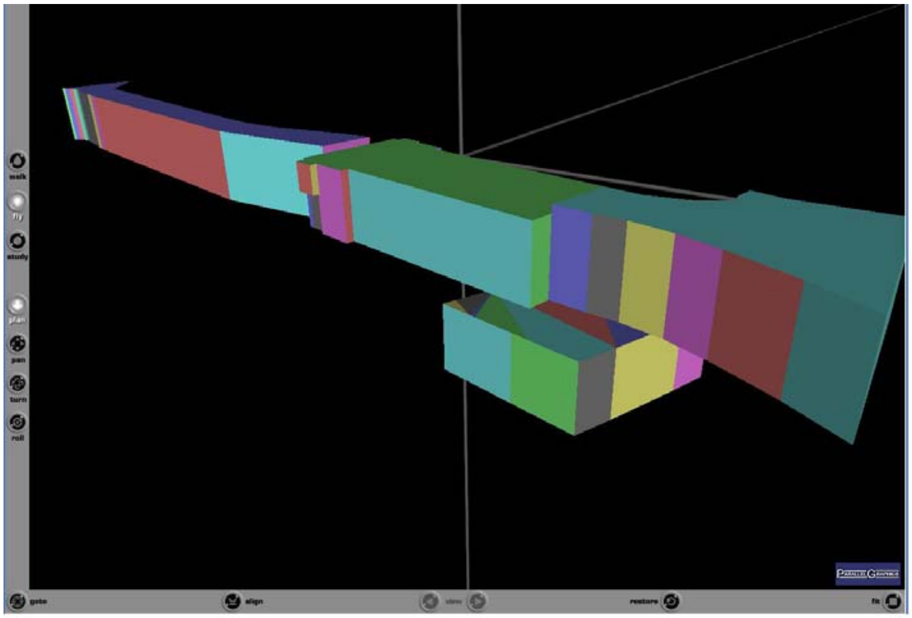

Figure 22 "Polygon Soup' form of the spatial unit

6.4 Editing

The structure is particularly suited to updating. The existing procedure for editing the DCDB in Queensland is to convert to this "spaghetti" form, allowing unfettered editing in the graphics package, and then parcelling back into polygon form. The same procedure can be used here, but omitting the polygon storage.

Some processing is needed to ensure validity of the base coverage – that there are no cases where there are two or more parcel reference points in the same parcel, and other similar issues. It is also necessary, if the alternative form is used, to regenerate the frontageOffset and frontageLength attributes.

6.5 Proof of Concept

A set of Java classes have been written that take the existing DCDB, and convert it to the proposed structure. The Informix tables that are populated are based on the ISO19152 structure and attribute names. About 6000 parcels were loaded into this structure, about 3000 being from an inner suburban/commercial area (Woolloongabba – see Figure 8 to Figure 10), and 3000 from a rural area with beachside townships (in the Tuan-Boonooroo area – see Figure 23).

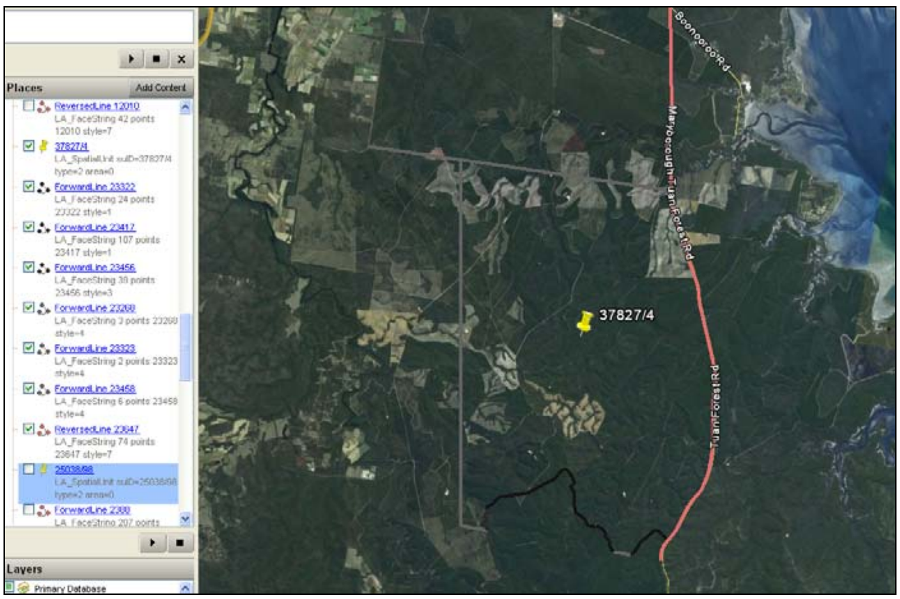

Figure 23. A rural land parcel in the Tuan-Boonooroo area defined by seven face strings

The time to convert was about 1000 parcels per minute, while access times (to present the spatial units in KML – to display using Google Earth) was about 1500 parcels per second. These indicate that the approach is more than acceptably fast.

The algorithm used joins the linework into as long and straight face strings as possible, and in the city or suburban areas, results in the road frontages closing to form "city/suburban blocks". This could be useful, because it provides an automatic (and unexpected) grouping of parcels. (See Figure 8 and Figure 10).

The face strings generated were then filtered, removing any points that are unnecessary (using a tunnel algorithm). This results in the final number of points being reduced to about half of the number of original parcel corners. There are approximately the same number of face string and spatial unit records loaded, and each is linked to on average about four of the other.

LA_BoundaryFaceString records have an average of about 6.4 points, with a maximum of 3240 and a minimum of 2. It may be useful to restrict this maximum. No statistics are possible in regard to 3D parcels, since only two were hand encoded. The Queensland DCDB only contains 3D parcels in terms of their 2D footprint at present.

7. POLYGON BASED SPATIAL PROFILE (with some examples from the Portuguese Land Administration)

This section briefly outlines the research that is being conducted over a Case Study of the Portuguese Land Administration, focused on the geometric (Cadastral Survey and Mapping) and legal (Land Registry) components of the Cadastre. Modelling of the Cadastral Domain has evolved significantly during the transition to the new millennium, and this is reflected in the information technology frameworks from the previous specifications (IGP, 1996), to the latest specifications which are UML based and ISO compliant (IGP, 2009).

One important change from the older to the current specifications is the focus on just two of the three forms of property: (1) private ownership and (2) local community ownership, omitting thus public domain ownership. Also, specialized classes from LA_SpatialUnit, namely the LA_LegalSpaceBuildingUnit, will not be acquired anymore, given the new specifications. The end result is the absence of a strict view of a planar partition, once there will be gaps over the country territory. Furthermore, consideration of transitional areas which are currently of an informal legal status, as the Deferred Cadastre or the Urban Areas of Illegal Genesis (AUGI, in Portuguese), will form areas that could overlap private Real Property parcels.

The proposal is then to consider the Polygon Based Spatial Profile from LADM (see Figure 24) as the geometry representation for the specific Portuguese spatial units. Within this profile, individual polygons are assembled by one or more GM_Multicurve geometry types. For implementation purposes, definitions contained in the Simple Features specifications (OGC, 2006) will be considered, because they are largely adopted in current spatial database systems.

This way, the constraints to be taken care of are the ones of each instance of the LA_BoundaryFaceString forms a Linear Ring, and that the boundary between adjacent polygons (which will be duplicated) do not create sliver polygons.

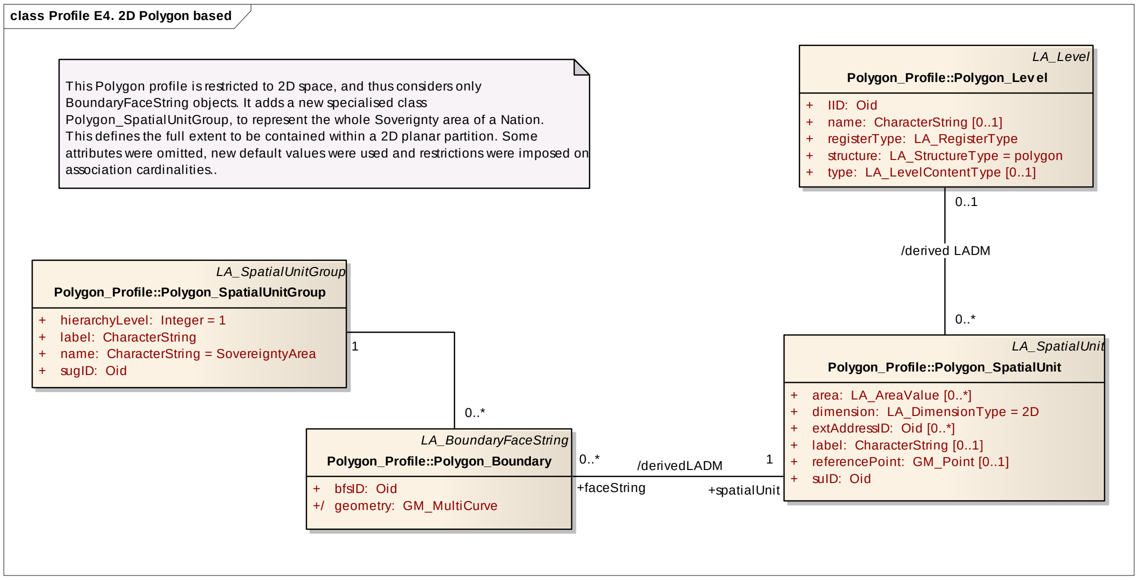

Figure 24. 2D Polygon base spatial profile (ISO/TC211, 2009)

Considering the LA_LevelContentType code types used in the LA_Level class, one could group the Portuguese specializations of the LA_SpatialUnit into two levels:

1. Base Level – comprises Real Property and Baldios (Communal Lands) parcels, which fundamentally do not overlap but will have gaps, or even holes within them. The code type will be "primaryRight", once is determined by the basic ownership right as a maximum real right.
2. EmptyAreas Level – thus called in the Portuguese specifications, they comprise both AUGI areas, which can overlap other spatial units on the Base Level, or the Deferred Cadastre areas, which, in spite being (potentially) private Real Property, do not have a full legal status due to a number of reasons.

The boundary and source point objects (respectively LA_BoundaryFaceString and LA_Point) are successively derived from a LA_SpatialSource, although the survey subpackage is presently absent from the specifications.

An implementation prototype will test the current capabilities of Model Driven Architecture in assisting the system analyst in obtaining an actual implementation on a Open Source Spatial Database, through a transformation chain from the Domain Model (LADM) to the Country Profile Model (LADM_PT) to a specific Object-Relational Implementation, that is, the Platform Specific Model.

8. CONCLUSIONS

This paper presented the range of options available in the LADM for representing spatial units. The LADM offers a very generic spatial representation model, as it has to be applicable world-wide, for a variety of spatial units (normal land parcels, legal spaces around buildings, legal spaces around networks/utilities). Further both 2D and 3D, and mixed 2D/3D representations are supported with various levels of accuracy: text-based, point-based, unstructured (line)-based, polygon-based or topology-based. In order to organize all these options from the generic LADM spatial representation model a number of spatial profiles are introduced. Two of these spatial profiles were further explored in this paper: unstructured (line-based) and polygon based spatial profiles and applied to data (models) from respectively Queensland (Australia) and Portugal.

The line-based structure of the Queensland Digital Cadastral Database would be a workable structure for the storage of cadastral data. It has some significant advantages, in allowing linework to be attributed and to be associated with metadata. Also 'long' parcel boundaries are not split/subdivided (with slight modifications due to the introduction of the intersection point as stored in the finite digital computer) due to a number of adjacent (touching) boundaries as what normally happens in a topology based approach. There could be some performance advantages in the structure, particularly where simple "window" enquiries are wanted.

Concerning the Model Driven (MDA) implementation of the Portuguese LADM, it would be possible to further update or upgrade the specific implementation from changes in design, including the spatial representation package, or even reflect changes in the Domain Model itself, although not all modifications can be translated *automatically* through the model.

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Obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, The Netherlands. In 1990 he received a PhD from Leiden University for this thesis 'Reactive Data Structures for GIS'. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague, The Netherlands as a computer scientist. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, were he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology (OTB institute) and head of the section 'GIS Technology'.

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