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Publication date
2018

Document Version
Final published version

Published in
Proceedings of the 7th Land Administration Domain Model Workshop

Citation (APA)
Thompson, R., Oosterom, P. V., Cemellini, B., & Vries, M. D. (2018). Developing an LADM Compliant Dissemination and Visualization System for 3D Spatial Units. In C. Lemmen, P. van Oosterom, & E. Fendel (Eds.), *Proceedings of the 7th Land Administration Domain Model Workshop* (pp. 103-124). International Federation of Surveyors (FIG).

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Developing an LADM Compliant Dissemination and Visualization System for 3D Spatial Units

Rod THOMPSON, Australia, Peter van OOSTEROM, Barbara CEMELLINI and Marian de VRIES, the Netherlands

Key words: 3D Cadastre, 3D Visualization, 3D Spatial Data, Data Capture

SUMMARY

This paper describes research into the visualization of mixed 2D and 3D Cadastre. A schema has been developed to accommodate this data, with provision for a time component. This paper describes the schema, the visualization requirements, and the provision of LADM-compatible views of the data for the purpose of developing these tools, and for the further research into the schema itself. A significant volume of 2D+t Cadastral data, which also contained 2D+t representations of 3D parcels, is currently incorporated in the Cadastral Database of Queensland. A moderate number of 3D building units, and a smaller number of volumetric parcels have been hand-encoded using bespoke software, and added to this database. The mixture has been displayed in KML through Google Earth. Examples of the database schemas, the encoding practices, LADM-compatible views, and the encoded 2 and 3 dimensional spatial units are included.

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1. INTRODUCTION

The state of Queensland, Australia has maintained a land administration system, based on Torrens System of registration (Queensland Government 2009). As modern practices in land use have developed, the administrative system has developed with them, accommodating different definitions of property. Thus, the early Cadastre was a register of simple areas of land, this has been augmented with 3D unit rights, timeshare, and volumes of space defined by metes and bounds. The state maintains a database, known as the Digital Cadastral Database (DCDB), which contains a record of all spatial units, but this is reduced in scope to carrying only 2D representations.

In Queensland many thousands of 3D parcels, both building unit format (more than 200 000) and volumetric format (3 000), have been submitted over the past decades (Thompson, Van Oosterom et al, 2015). The footprints of these 3D Spatial Units have been extracted from the survey plans and included in the DCDB. Despite this rather long history and experience, there are a number of remaining challenges. In this paper we focus on the dissemination and visualization of the 3D Cadastral parcels. In other jurisdictions several other (prototype) systems have been developed and presented (Pouliot, Ellul et al, 2018), however great challenges remain with respect to interaction and visualization of large numbers of 3D parcels, relating these to the existing 2D parcels, the earth surface, and 3D reference objects (physical building, bridges, tunnels, infrastructure, etc.). The existing data model of the Queensland DCDB is not described using the concepts and terminology of ISO's Land Administration Domain Model (ISO-TC211 2012). Further the model does not support 3D parcels and reference objects (earth surface, topographic objects). We are therefore developing an extension of the DCDB to support 3D parcels as used in the Queensland legislations, regulations and existing systems (DNRM 2013, DNRM 2016), incl. the DCDB and collection of submitted survey plans. Next, for a selected study area with all relevant types of 3D Cadastral parcels occurring, both building format and volumetric format parcel (above and below the earth surface, and covering both land and water areas), we are converting the information of the survey plan documents (pdf or tiff) into 3D geometry as collections of polyhedron faces. These activities consist of a mix of manual interpretation of the survey plans and using a dedicated (Java) program as support to generate the correct faces of the polyhedron. Currently only planar faces are supported, but curved surfaces do occur (e.g. cylinder patches) and they need to be supported also in the near future (most likely via approximations). The case study area is in central Brisbane on Kangaroo Point and is adjacent to the Story Bridge over the Brisbane River (Figure 1). The polyhedron faces are loaded in a prototype version of the extended DCDB (stored in PostgreSQL/PostGIS) and combined with other 2D and 3D spatial data. This now makes it possible to ensure that a collection of 3D parcels is not overlapping. So far, this is still the 'internal side' of the 3D Cadastre in

Queensland. The next step is dissemination and visualizing the 3D parcels. When disseminating data, it is important to use standard terminology and concepts. Therefore, the ISO 19152 (LADM) standard was used. Persons not familiar with the Queensland terminology can thus understand the content.
Note – this paper will preferentially use the language of the Land Administration Domain Model (LADM) (ISO-TC211 2012), but the terminology used within the DNRM (Department of Natural Resources and Mines) will occasionally be needed. thus:
– A spatial unit (LA_SpatialUnit) is internally referred to as a "parcel";
– A basic administrative unit (LA_BAUnit) as a "lot".

In representing the Cadastre digitally, the current DCDB is as follows:
– 2D spatial units are recorded as polygons with line styles. A subset of them (known as "base parcels") are constrained to form a complete, non-overlapping coverage;
– 2D secondary interests (e.g. easements) are recorded as polygons which overlap base parcels;
– Spatial units defined by the building walls are recorded as attributes (unit number, and floor area only) within the base parcel (i.e. no graphical representation is present). The building footprint is recorded as a polygon within the base parcel;
– Volumetric spatial units are "flattened" into a 2D polygon, which overlaps the base parcel(s).

But, note that the "2D" DCDB has a time component, using a variant of the "Versioned Object" pattern, and maintains a history (since about 1990). Thus, it can be better described as 2D+t.

Following this introduction (Section 1), a summary of the requirements of a successful visualization system is given (Section 2). This is followed by a description of the data capture undertaken (Section 3), and the schema as implemented (Section 4). The progress so far (Section 0), conclusions and future research (Section 6) follow.

2. IDENTIFIED REQUIREMENTS

These requirements are identified in, and more details are available in an associated paper (Cemellini, Thompson et al, 2018). Two types of requirements are identified: 3D cadastral data visualization requirements (functional/platform independent in Subsection 2.1) and requirements for the web viewer (as this is the target dissemination platform; see Subsection 2.2).

2.1 Requirements for 3D visualization of cadastral data

In order to define what is the best way to visualize 3D cadastral data it is important to analyze the existing literature and define a list of requirements. Both the issues related to 3D visualization and 3D cadastre will be taken into account. In this subsection, the requirements regarding 3D visualization of cadastre are listed:
– Navigation tools and view controls;
– Integrating topography and reference objects;

– Transparency;
– Object selection;
– Object search;
– Wireframe display;
– Explode view;
– Sliding;
– Cross-section view;
– Visualization cues;
– 3D measurement tools;
– 3D buffer;
– Display partly unbounded objects and ‘complex’ geometries.

2.2 Requirements for the web viewer

In addition to the functionalities related to 3D visualization, the web viewer requirements must be considered too. One of the main aims of cadastre is to make information available to everybody and the web is a powerful tool which can make this happen. Consequently, the choice of the most appropriate web platform is crucial. Having a good 3D visualization would be useless if the platform in which the data is visualized is not suitable for that purpose. Choosing the proper web based platform for the dissemination of 3D cadastre is not an easy task. Most of the following functionalities should be present:

– Platform and browser independence;
– Handling massive data and caching/tiling between server and client;
– Layers control;
– Database support;
– Support different models (vector/polyhedral, raster/voxel, point clouds);
– Support of basic 3D topographic visualization;
– Support for geo-referencing;
– Ensure spatial validity (3D vector topology);
– Underground View.;Open source platform;
– Possibility for the platform to be extended;
– 2D overview map (orientation).

3. DATA CAPTURE

In order to further investigate the dissemination and visualization of 3D Cadastral parcels, it was decided that this needs to be in the context of a mixed 2D/3D DCDB. It is not considered acceptable that a different (and separately maintained) DCDB should exist for the 3D spatial units. For research purposes, a significant subset of the current DCDB (which is stored in an Ingres database), has been loaded into PostgreSQL/PostGIS (more than 3 000 000 parcels). For the prototype database, the basic tables of the current DCDB (in Ingres), have been converted to PostGIS, with no change in logical structure. The spatial primitives of PostGIS have been used in preference to the locally developed methods used in DNRM (developed in the mid 1990’s), but the semantics are unchanged. The main addition for the prototype is a table of faces, used to represent the boundaries of the 3D spatial units (parcels). In order to give a good selection of 3D spatial units, a number of parcels in suburb the Kangaroo Point

have been manually encoded. This area as shown in Figure 1 was chosen, because, while not in the most dense part of the city, it has a good representation of different classes of 3D object:

– Building format units (See Section 3.1);
– A major underground road tunnel, registered via volumetric format survey plans (in part running under building format units) (See Section 3.2);
– Other volumetric format parcels (not defined by buildings) (Section 3.2);
– Watercourse and land spatial units;
– 3D parcels which have changed within the DCDB history period (Section 3.3).

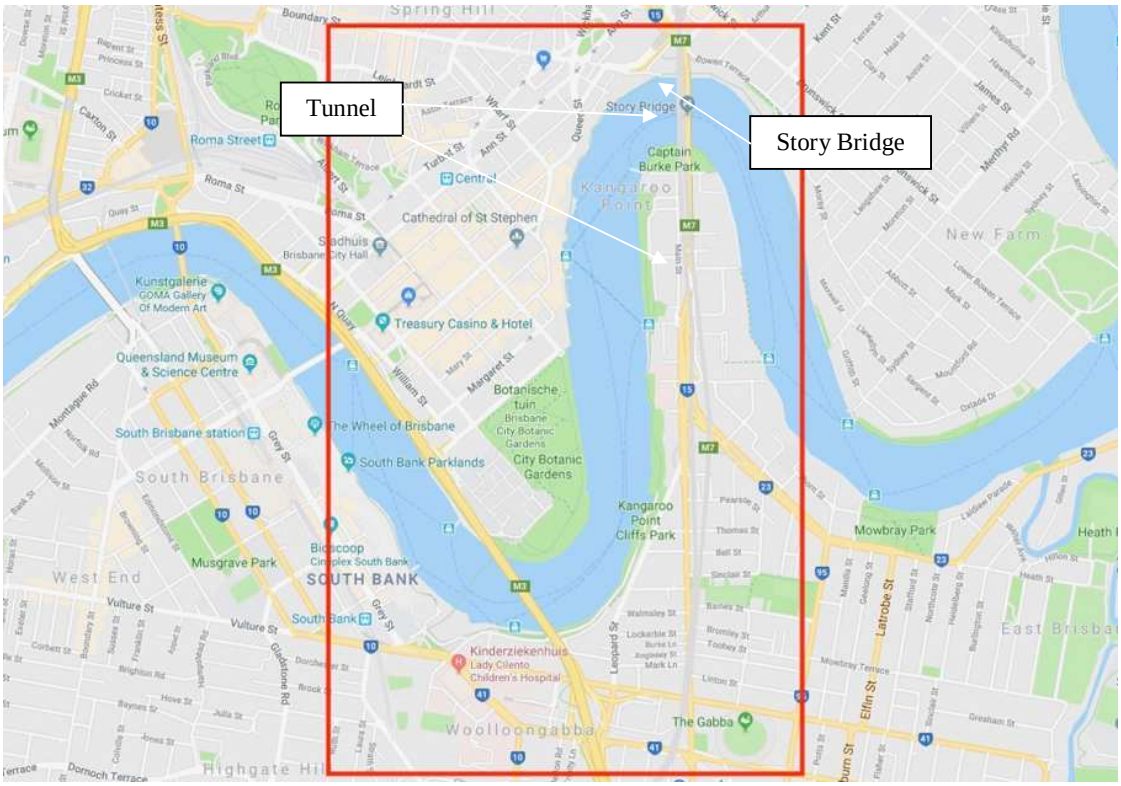


Figure 1. Bounding box of the Kangaroo Point, Brisbane area chosen

3.1 Encoding building format spatial units

These are defined by the building itself, typically by the walls (to the middle, or to the outside etc. of the wall). This means that the use of a Building Information Model (BIM), or an as-constructed building maintenance plan is a good ideal source for data (Aien, Rajabifard et al, 2011, Atazadeh, Kalantari et al, 2017), but only where such a model is available. Ideally, the data would be submitted electronically as a component of the plan of survey that is used in Queensland to register the properties (Khoo 2012, Karki, Thompson et al, 2013, Gulliver, Haanen et al, 2017, Thompson, van Oosterom et al, 2017). Given that the 3D properties in the area in question were registered at different times in the past, when survey plans were submitted on paper, or later in pdf or tiff format, the only option available for this R & D project was manual capture.

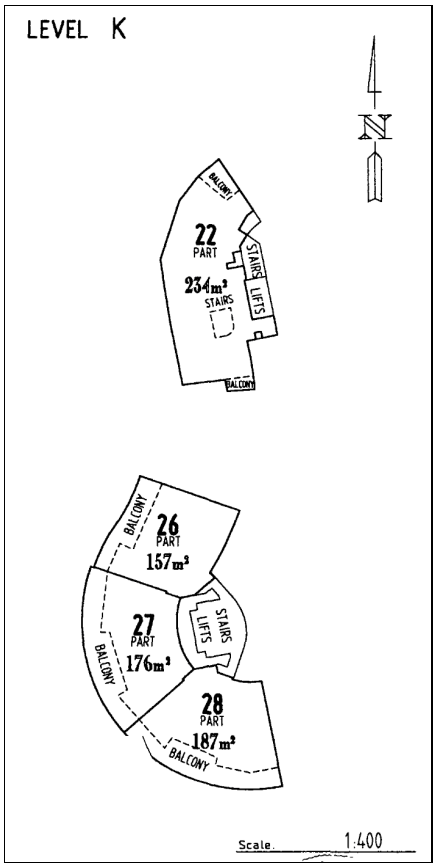


Figure 2. Extract from a building format plan

As can be seen in Figure 2 above, many building format plans show a diagram of the units (to scale), but no dimensions or connection to reference points. This is suitable for registration of the plan and the units in question because the legal definition of the property is given by the physical walls. It does not make the capture easy, and it has been necessary to develop some bespoke software for the purpose. Capture in this form (digitising from images) sets a limit on the accuracy of the data, but this is acceptable from a land administration perspective because it is not the legal boundary that is being captured, merely an indicator of the approximate position of the walls that do define the boundary. Using the bespoke software, it takes ½ to an hour per floor plan to encode a high-rise building of moderate complexity.

3.2 Encoding volumetric spatial units

In contrast to the above, the volumetric plans record the metes and bounds of the spatial units in the same form as the 2D survey plans. That is to say, bearing and distance measurements are supplied, sufficient to determine the X/Y location of all points that define the volumes. The Z values of points are supplied in later tables. Referring to Figure 3 Diagram A below, the position and location of the points (numbered 22 to 29) are defined relative to one another in 2D. 3D points along the "poles" defines in diagram A are defined by assigning them Z values (e.g. 22a is assigned Z = 8.344, 22c is assigned Z = 9.737) Finally, the boundary faces

are defined in an isometric view (Diagram B). The approach taken here is to encode these measurements, and connect at least two of the points to existing DCDB vertices.

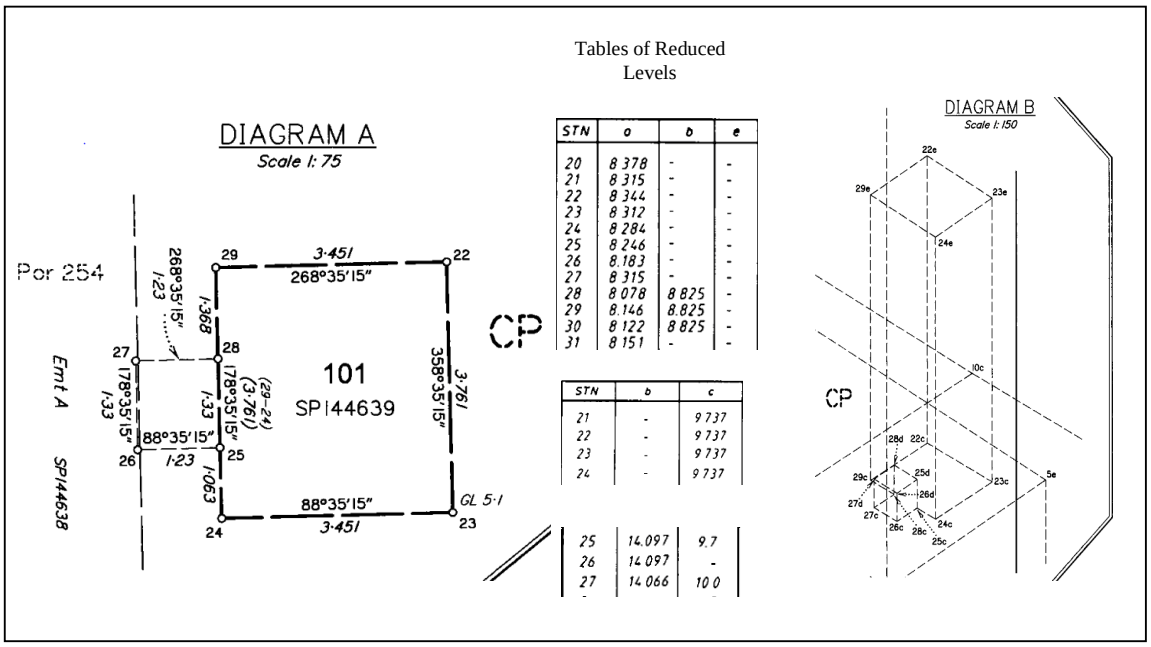
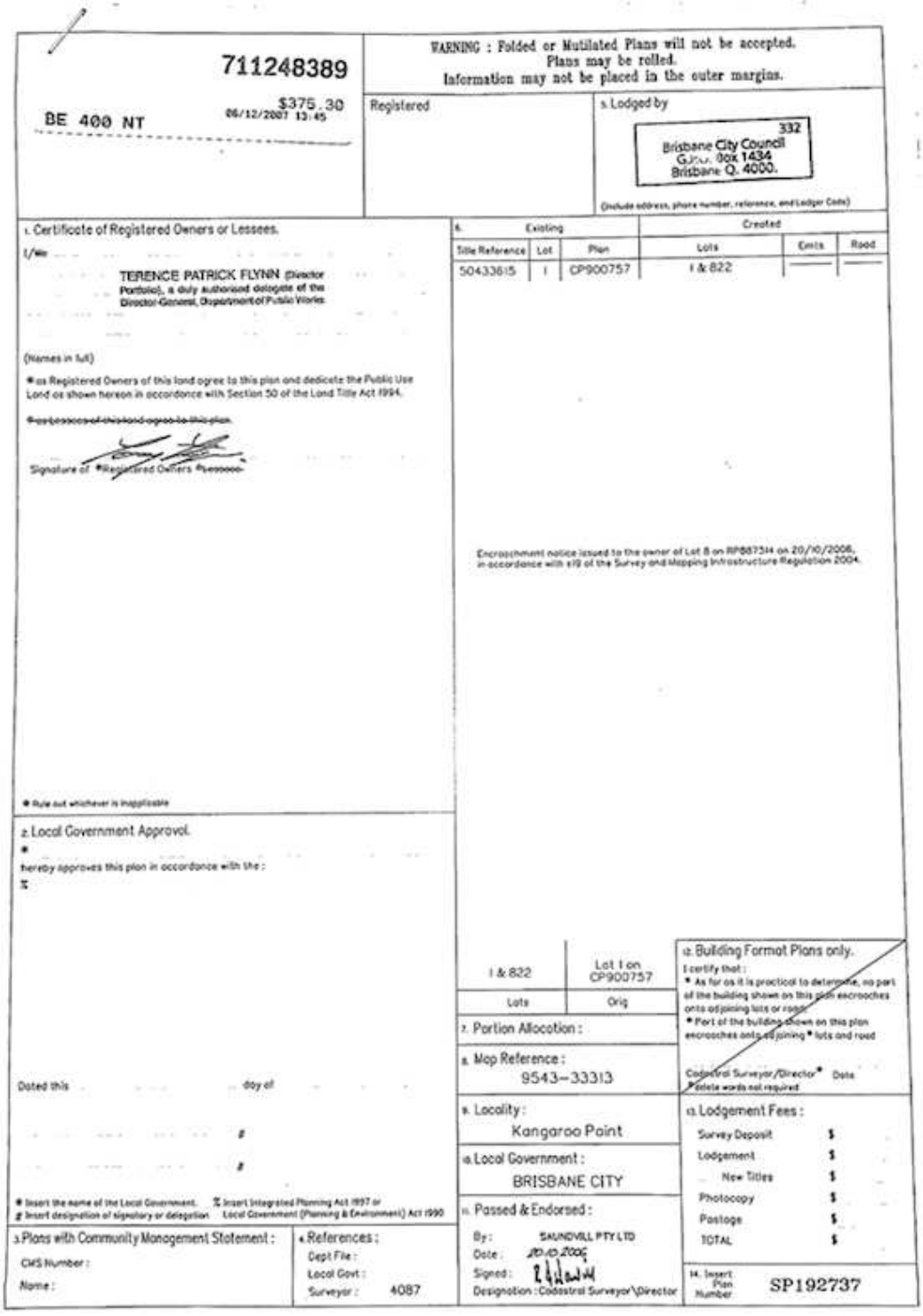


Figure 3. Excerpts from a volumetric plan

Again, bespoke software has been written to accept this encoding, which also takes advantage of the fact that a large majority of 3D spatial units have a simple ”polygonal slice” or ”single-valued stepped slice” form (Thompson, van Oosterom et al, 2015). That is to say, in most cases of volumetric parcels in Queensland, all faces are planar, and either vertical or horizontal. In the case of Figure 3 Diagram B, it is only necessary to encode the 2D footprint, the Z value of the bottom face, and the two top faces. The workload to encode a volumetric spatial unit is highly variable, as the complexity varies.

As previously mentioned, the 3D survey plans of the Brisbane DCDB are stored in plain PDF or TIFF files according to the Queensland regulations (DNRM, 2013) (DNRM, 2016). For this reason, an encoding process is needed to convert the information from paper to digital format. The paper format of the 3D survey plan is shown in Figure 4, Figure 5 and Figure 6 below.

Next, the data needs to be input by hand in a custom-made Excel file extracted from the 2D representation of the parcel in the DCDB, as shown in Figure 7 below. Note that the corner numbers in the Excel sheet need to be encoded to correspond to the corners of the 3D parcel (i.e. 91, 9, 8, 7, 93, 92) as marked on the plan. The letter appended to a corner number indicates whether the corner is on the top (’b’) or bottom (’a’) of the parcel. The upper and lower footprints of the parcels are respectively counter clockwise and clockwise. This parcel has vertical walls, but the top and bottom are not horizontal.



711248389

BE 400 NT

$375.30 06/12/2007 13:45

WARNING : Folded or Mutilated Plans will not be accepted.
Plans may be rolled.
Information may not be placed in the outer margins.

Registered

3. Lodged by

332
Brisbane City Council
GPO Box 1434
Brisbane Q. 4000.

(Include address, phone number, reference, and Lodger Code)

1. Certificate of Registered Owners or Lessees.

I/We

TERENCE PATRICK FLYNN (Director Portfolio), a duly authorised delegate of the Director-General, Department of Public Works

(Names in full)

* as Registered Owners of this land agree to this plan and dedicate the Public Use Land as shown hereon in accordance with Section 50 of the Land Title Act 1994.

* as Lessees of this land agree to this plan.

Signature of *Registered Owners *Lessees

* Rule out whichever is inapplicable

2. Local Government Approval.

* hereby approves this plan in accordance with the :

%

Dated this day of

# #

* Insert the name of the Local Government. % Insert Integrated Planning Act 1997 or
# Insert designation of signatory or delegation Local Government (Planning & Environment) Act 1990

3. Plans with Community Management Statement :

CMS Number :

Name :

4. References :

Dept File :

Local Govt :

Surveyor : 4087

6. Existing

Title Reference	Lot	Plan
50433615	1	CP900757

Created

Lots	Emts	Road
1 & 822		

Encroachment notice issued to the owner of Lot 8 on RP887344 on 20/10/2006, in accordance with s19 of the Survey and Mapping Infrastructure Regulation 2004.

1 & 822	Lot 1 on CP900757
Lots	Orig

7. Portion Allocation :

8. Map Reference :
9543-33313

9. Locality :
Kangaroo Point

10. Local Government :
BRISBANE CITY

11. Passed & Endorsed :

By : SAUNDVILL PTY LTD

Date : 20.10.2006

Signed :

Designation : Cadastral Surveyor\Director

12. Building Format Plans only.

I certify that :

* As far as it is practical to determine, no part of the building shown on this plan encroaches onto adjoining lots or roads

* Part of the building shown on this plan encroaches onto adjoining * lots and road

Cadastral Surveyor/Director* Date

* delete words not required

13. Lodgement Fees :

Survey Deposit	$
Lodgement	$
New Titles	$
Photocopy	$
Postage	$
TOTAL	$

14. Insert Plan Number SP192737

Figure 4. Example of 3D survey plan - Lot 822 (page 1 of 3)

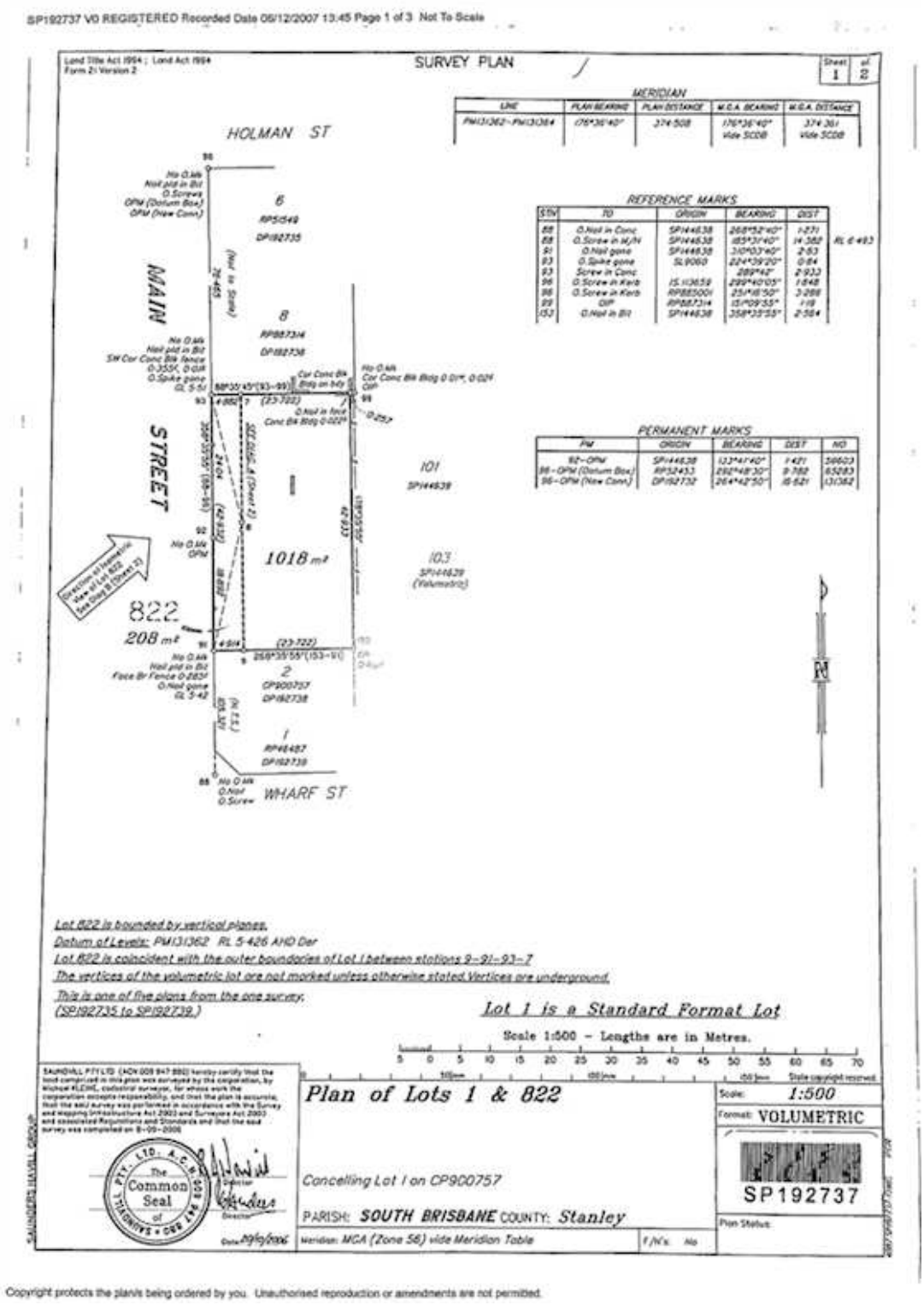


Figure 5. Example of 3D survey plan - Lot 822 (page 2 of 3)

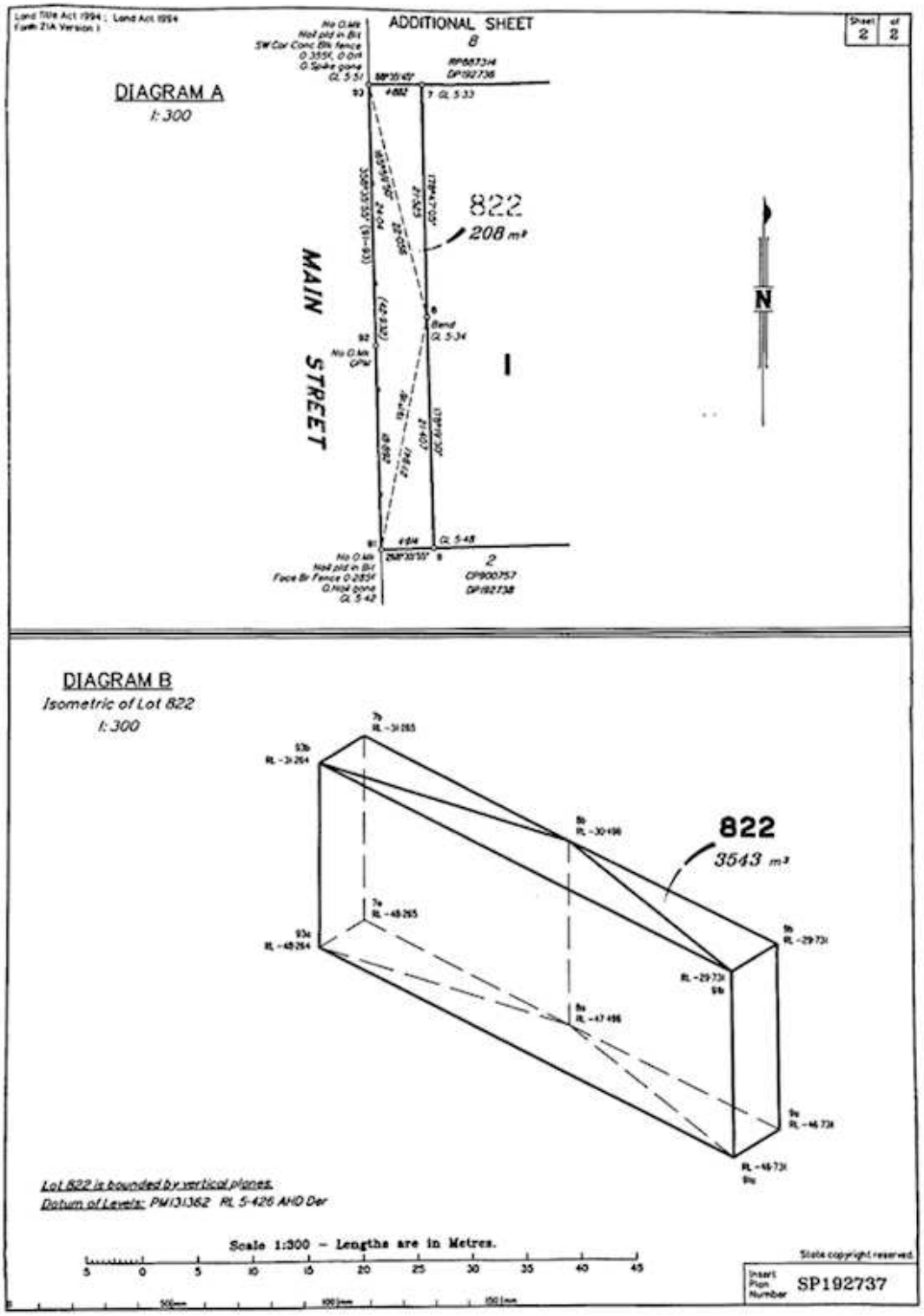


Figure 6. Example of 3D survey plan - Lot 822 (page 3 of 3)

DCDB Parcel 822/SP192737 25159/233	Lon	Lat	Pid	Cnr Nr	X	Y	B and D	Elevations
S SW	153.0354519	-27.466975	-1	91	103	0		
SE E	153.0355025	-27.466974	-1	9	601	12		
	153.0354952	-27.466781	-1	8	530	2156		
N NE	153.0354911	-27.466598	-1	7	489	4181		
NW W	153.0354415	-27.466599	-1	93	0	4170		
	153.0354445	-27.466708	-1	92	30	2961		
****	additional edges if needed							
****	additional elevations if needed							
93 a -48.264 b -31.264								
91 a -46.731 b -29.731								
9 a -46.731 b -29.731								
8 a -47.496 b -30.496								
7 a -48.265 b -31.265								
****	parcels							
Parcels Lot 822 25159/233								
Footprint								
A 93a 7a 8a 9a 91a								
B 93b 91b 9b 8b 7b								
****	Textural data							
Date	06/12/2007							

Figure 7. Example of Excel file - Lot 822 (manual data entry highlighted)

Finally, a Java program reads the Excel file and loads the 3D parcel into the database. It is important to keep in mind that, even though the encoding of the parcels is performed automatically by a computer program, the passage from the PDF/TIFF survey plan to the Excel format has to be done manually. Therefore, it is a non-trivial and time-consuming operation.

3.3 History of spatial units

In the process of encoding 3D parcels of both kinds, it became clear that the DCDB has not been static since these parcels were first recorded. It proved necessary to allow to back-capture the history, and for historic details to be accommodated in the prototype database. Back capture of history has not been attempted yet, apart from a single case, but provision has been made in the schema and capture software.

4. STORAGE SCHEMA

The data for research described here does not at present cover the entire requirements of a cadastral database, notably excluding the party and RRR (Rights, Restrictions and Responsibilities) data, however the schema is designed flexibly, to accommodate:

- Parcel data in 2D (from the Queensland Government);
- Elevation data (courtesy of Fugro);
- Information form plans of survey (from the Queensland Government);
- Building/topographic (references objects) 2D/3D;
- Rights (or RRRs more general);
- Parties.

An early decision was made to keep the database in a form equivalent to that used in the current Queensland DCDB, but to expose views of that data in a form which is compatible with the LADM. This achieves four purposes: 1. It allows simpler loading of future data from the Queensland DCDB. 2. It allows modification of the prototype database structure without

invalidating work being done on the visualization. 3. It provides the possiblitiy of defining a LADM derived protocol for delivery of mixed 2D/3D+t Cadastral data. 4. It indicates that a database which is not defined with LADM in mind can still support such a protocol.

The database used in this research is also planned to be used for research on appropriate storage for mixed 2D+t and 3D+t Cadastre, and as such will be quite volatile in structure. To avoid the different strands of research interfering, it was decided that the data would always be made available for viewing/manipulation in a standard, but quite basic form. Thus 3D spatial units will be made visible (in the format of LA_SpatialUnit objects), with the extents defined by plane faces (LA_BoundaryFace).

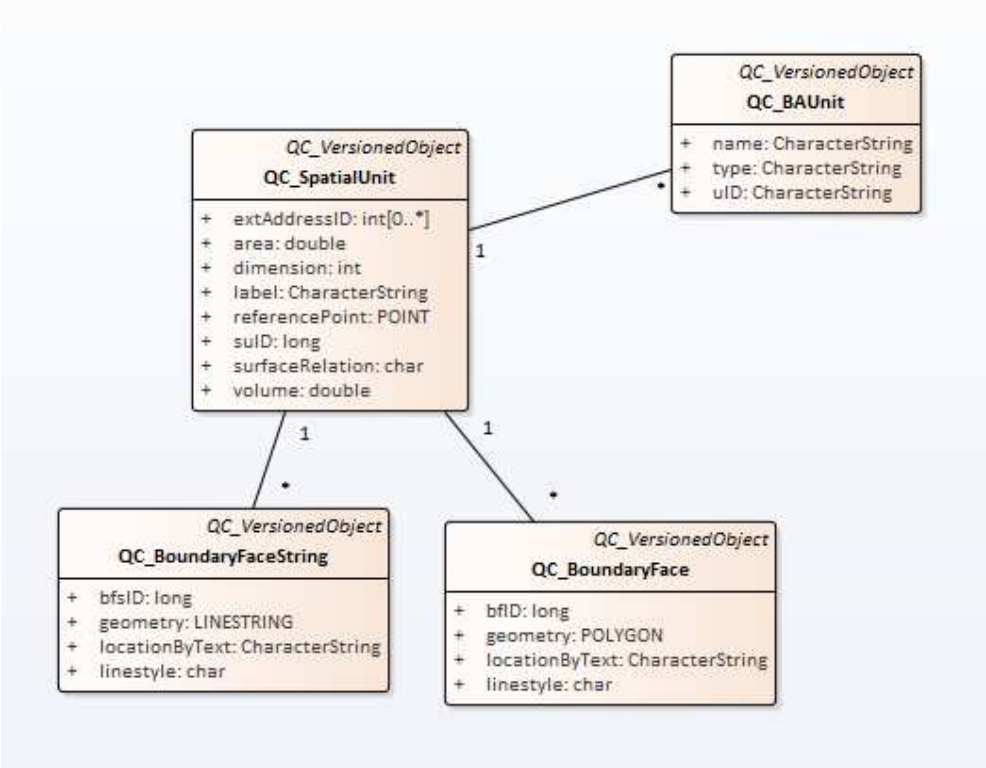


Figure 8. Spatial unit structure based on LADM

There is no attempt made to share faces between adjoining spatial units, and all faces observe anti-clockwise sense (viewed from the outside) (That is the convention of the normal vector pointing outwards is used). 2D spatial units will be made visible as LA_SpatialUnit objects, with the choice of a single LA_BoundaryFaceString making a closed polygon (anti-clockwise when viewed from above), or a number of face strings (each attributed with a "line style") which may be joined in order to make a closed polygon. The polygon may be complex (with holes), but not multiple. The lot details will be made visible in the format of LA_BAUnit objects. The term "made visible" in the preceding is intended to indicate that there may be views of database tables created that have the appropriate appearance and behavior, or redundant tables (materialized views) may be created if the views cannot be implemented

efficiently. As research on the database structure, the decision view/redundant table may change without having a major effect on front-end development.

The objects described in Figure 8 above represent the data as seen by a front-end process. Note the close relationship between these objects and the LADM defined objects, the prefix QC (for Queensland Cadastre) has been used to distinguish them from the LADM equivalents. The actual database structure is (at least initially) as shown in Figure 9 below. The mapping between the object attributes are as follows (Table 1, Table 3, Table 5 and Table 6). An indication of the SQL necessary to define these views can be found in Table 2 and Table 4. These will probably not be the final versions of the views, but the data content will remain constant (or equivalent) during the research.

Table 1. Mapping between QC_SpatialUnit (based on LA_SpatialUnit) and Parcel

QC_SpatialUnit	Parcel
suID	Segment_Nr × 1000 + Parcel_Nr
area	Calc_Area
volume	Calc_Volume
dimension	3 if any Polyhedron_Face objects present, otherwise 2.
label	<empty string>
referencePoint	Point (Centroid_Lon, Centroid_Lat, Centroid_Z)
extAddressId	Primary_Name_Id
surfaceRelation	Coverage_Id

Table 2. SQL to create QC_SpatialUnit view

```
create or replace view QC_SpatialUnit as
select
  segment_Nr * 1000 + parcel_nr as suID,
  case when plan_nr = '' then ''
      when unit_nr <> '' then plan_nr||'/'||lot_nr||'/'||unit_nr
      else plan_nr||'/'||lot_Nr end as uID,
  calc_area as area, calc_Volume as volume,
  case when centroid_z = 'NaN' then 2 else 3 end as dimension,
  '' as label,
  case when centroid_z = 'NaN'
      then st_setSRID(st_makepoint(centroid_lon, centroid_lat),4283)
      else st_setSRID(st_makepoint(centroid_lon, centroid_lat,
          centroid_Z),4283) end as referencePoint,
  primary_name_id as extAddress,
  coverage_id as surfaceRelation,
  creating_lock_nr, destroying_lock_nr
from parcel;
```

Table 3. Mapping between QC_BAUnit (based on LA_BAUnit) and Lot or Unit

QC_BAUnit	Lot or Unit
uID	Plan_nr / Lot_nr or Plan_nr / Lot_nr / Unit_nr
name	<empty string>
type	Tenure_Status_Id (e.g. freehold, leasehold …)

Table 4. SQL to create QC_BAUnit view

```
create or replace view QC_BAUnit as
select
   case when plan_nr = '' then ''
      when unit_nr <> '' then plan_nr || '/' || lot_nr || '/' || unit_nr
      else plan_nr || '/' || lot_Nr end as uID,
   '' as name,
   tenure_status_id as type,
   creating_lock_nr, destroying_lock_nr
from lot;
```

Table 5. Mapping between QC_BoundaryFace (based on LA_BoundaryFace) and Polyhedron_Face

QC_BoundaryFace	Polyhedron_Face
bfID	(Segment_Nr × 1000 + Parcel_Nr) * 10000 + Face_Nr
geometry	P_Shape
locationByText	"B" for building format units, null otherwise
linestyle	Linestyle (indicates road boundaries etc)

Table 6. Mapping between QC_BoundaryFaceString (based on LA_BoundaryFaceString) and Parcel

QC_BoundaryFaceString	Parcel
bfID	(Segment_Nr × 1000 + Parcel_Nr) * 10000 + corner number
geometry	P_Shape split into individual linestrings
locationByText	"N" for natural boundaries, null otherwise
linestyle	Linestyle (indicates road boundaries etc)

In the case of a LA_BoundaryFaceString ⇔ Parcel, the Parcel.Linestyles text is unpacked, and the values are associated to the line segments of the P_Shape polygon – that is, the polygon is divided into individual linestrings at each change of linestyle. The view described in Table 6 requires this unpacking of the polygon object and text string. To date, it has been implemented in procedural language, but may not be possible in a simple SQL view. A simplified version of the view, which omits the linestyle is sufficient for the present. When selecting data via the views, the users will see LADM terminology only (for tables, attributes, relations, code lists, etc.).

Using a web based solution makes a lot of sense for dissemination, as web browsers offer a relatively hardware/ software independent platform, reaching many possible users without great efforts at the user side. Therefore, at the server side, a web data service is established on top of the LADM views in the database, exposing the 2D and 3D cadastral information to the outside world. At the client side a 3D geo-information aware WebGL based solution is applied to visualize the 3D parcels (and reference objects) and interact with the information. Important is that the client uses a limited amount of information as all information in the DCBD would be far too much; only looking at the 2D parcels this is already too much (more than 3 million parcels, with many attributes). Server-client caching techniques are used to manage the communication between server and client.

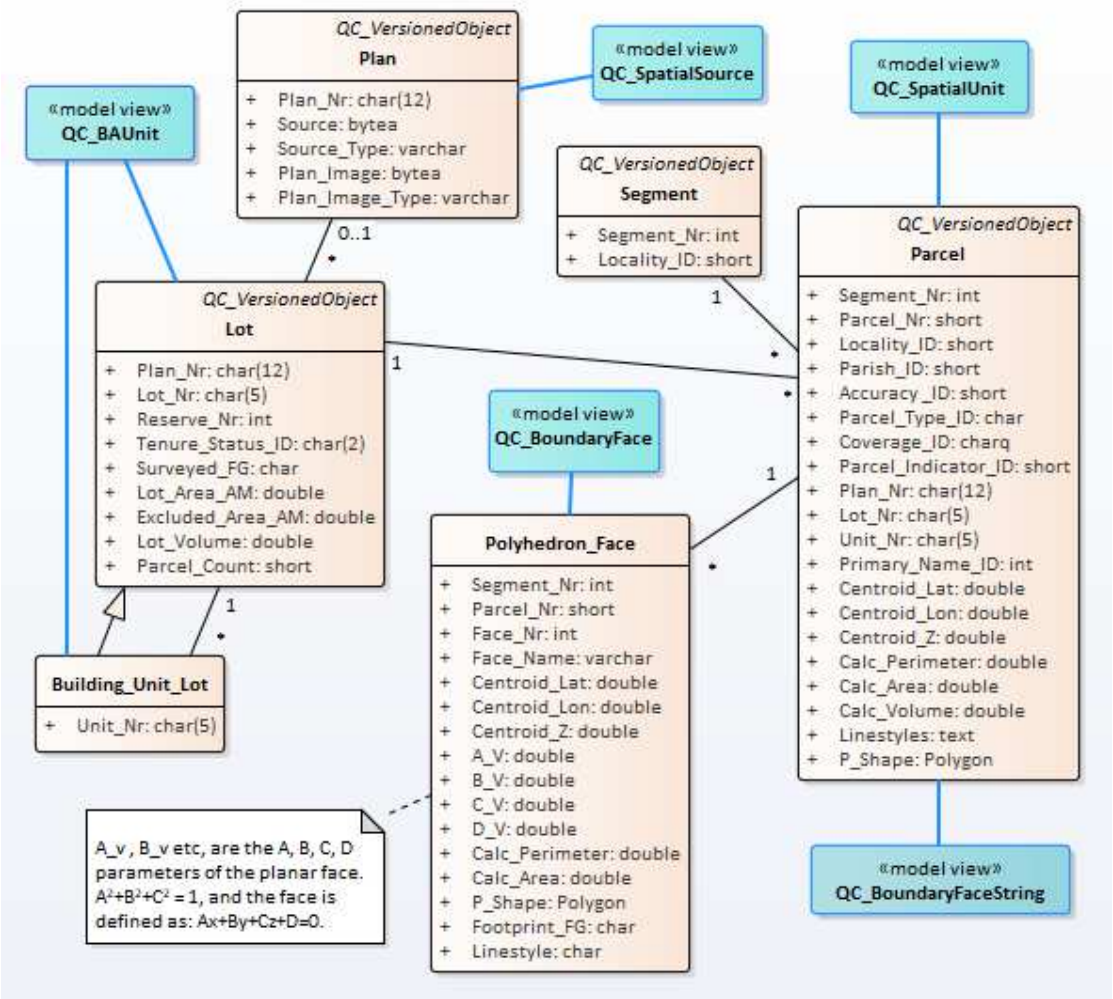


Figure 9.The database schema, with links to the LADM objects shown in blue

5. PROGRESS

As mentioned earlier, a large selection of 2D parcels have been loaded from the Queensland DCDB. This will ensure that there are enough data to make the system loads realistic. Capturing the 3D parcels has been more difficult, but progress is being made. A prototype for the visualization and dissemination of 3D cadastre is currently under development. In particular, it combines different types of data to give context to the 3D cadastral parcels (2018). Among the data to be included in the prototype we can find:

– 3D survey plans (from Queensland Cadastre), either in 'building format units' and in 'volumetric parcels', which will be described in the next subsections
– 2D cadastral parcels (from Queensland Cadastre);
– Registration of rights, restrictions and responsibilities (if available);

– Elevation data (DTM or DEM, depending on the availability) in order to make the visualization more complete and meaningful;
– Reference data such as topographic objects, either in 2D or 3D.

5.1 Building format units

To date, three non-trivial plans have been converted and entered, consisting of five buildings (two of the plans are for complexes of two buildings each), and 349 individual units (but note that in some cases, balconies and car parks are counted as separate units, so the true number of units would be closer to 200). These can be seen in Figure 10, which also shows the 2D parcels from the DCDB. The building in the foreground of Figure 10 has been modified in terms of the subdivision into units, and if viewed as at an earlier date looks a bit different. This is an issue to be investigated in the near future, to allow visualization of variations in the Cadastre – perhaps with a "time slider".

Figure 10. Three plans of building format units

5.2 Volumetric parcels

A section of the "Clem 7" road tunnel has been captured and is visible in Figure 10 above and Figure 11 below. It should be noted that the tunnel volume is fragmented at the boundaries of the surface parcels, so that the section is composed of many individual parcels. The large grey "monolith" is a parcel which runs from the tunnel to a height of 200m. There is clearly no construction within the space, which has probably been reserved to prevent building above a

tunnel access point. In Figure 11, although it is being viewed over Google Earth, all parcels (2D and 3D) have been pushed up by 50m. This allows below ground parcels to be seen by making the 2D parcel representations partially transparent.

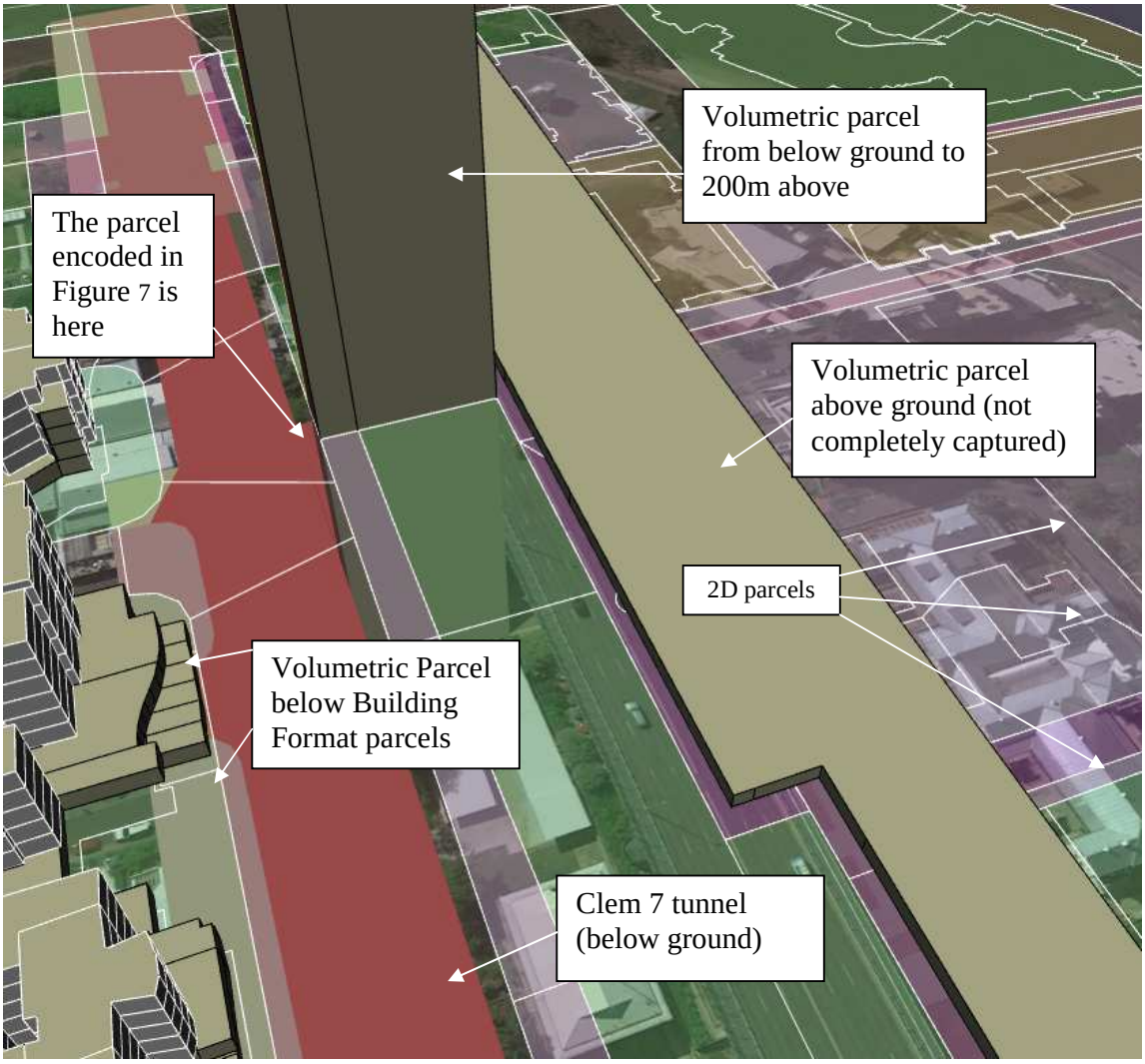


Figure 11. A mixture of 2D parcels, building format and volumetric parcels

6. CONCLUSIONS AND FUTURE RESEARCH

A schema has been developed to accommodate a mixed 2D and 3D Cadastre, with a time component. This schema provides sufficient functionality to provide LADM-compatible views of the data for the purpose of developing visualization tools, and for the further development of the schema itself. A significant volume of 2D+t Cadastral data has been loaded, which also contained 2D+t representations of 3D parcels. A moderate number of 3D building units, and a smaller number of volumetric parcels have been hand-encoded using

bespoke software, and added to this database. The mixture has been displayed in KML through Google Earth.

This research is very much a "work in progress", and the following are planned for the near future:

- *Temporal Dimension:* The Cadastral data from the Queensland Cadastre is already in the form of 2D+t parcels. In addition, the 2D representation of the many thousands of 3D parcels in the state have a time component. The software is capable of capturing historic 3D parcels, and in the case of one building format plan, this has been done. The aim is that the visualization software should be capable of making the historic changes clear to the user (perhaps using a "time slider" approach);
- *Client-Server Protocol:* Whatever form the final interaction between the client process and the database server takes, the protocol will be documented and made public. This will make it possible to mix-and-match different client tools with different DBMS's and database schemas;
- *Tuning and Performance issues:* This part of the research is in relatively early stages. Initial indications are positive, but there have been no tuning/compromise decisions made yet;
- *Topological Database Schema:* All 3D parcels that are added to the database are being validated using the axioms described by Thompson and van Oosterom (2012), but this is on an individual parcel basis only at present. It is intended to apply multi-parcel validation (to ensure adjacent parcels are non-overlapping in 3D and time) as a later phase of the research. An earlier paper argued that the protocol for the transport of cadastral information in the form of plans of survey should use a topological protocol (Thompson, van Oosterom et al, 2017). It is natural to extend this topology to the database schema itself. The current Queensland Cadastre in 2D+t does not use topological form, but has the necessary linkages to make this change relatively easy. 3D+t topology is still in the process of investigation.

7. ACKNOWLEDGMENTS

The authors wish to thank Sudarshan Karki (Queensland Government, Department of Natural Resources, Mines and Water) for assistance and advice he has provided; Martin Kodde (Fugro) and Glen Ross-Sampson (Roames) for the provision of a surface model (DEM) of the region in question.

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BIOGRAPHICAL NOTES

Rodney James Thompson has been working in the spatial information field since 1985. He designed and led the implementation of the Queensland Digital Cadastral Data Base, and is now advising on spatial database technology with an emphasis on 3D and temporal issues. He obtained a PhD at the Delft University of Technology in December 2007.

Peter van Oosterom 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. From 1985 until 1995 he worked at the TNO-FEL laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral (Geographic) database. Since 2000, he is professor at the Delft University of Technology, and head of the 'GIS Technology' Section, Department OTB, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on '3D Cadastres'.

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Marian de Vries holds an MSc in Economic and Social History from the Free University Amsterdam, The Netherlands (VU). She worked some years at the Free University and the University of Nijmegen, then switched to become a software developer. Since 2001 she works as researcher at the Section GIS Technology, OTB, Delft University of Technology. Focus of her research is on distributed geo-information systems. She participated in a number of projects for large data providers in the Netherlands such as Rijkswaterstaat and the Dutch Cadastre.

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