Web-based visualisation of 3D cadastre

MSc Geomatics Thesis Proposal

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1 Introduction

Nowadays, more and more countries in the world are developing 3D cadastre, but its visualization is still a big challenge. The aim of cadastre is to make information available to everyone, thus sharing and visualising it on the web would help to fulfill this purpose. An interactive 3D visualization system representing the third geometric dimension in a flexible way would give the user the possibility to explore the complexity of the 3D world and overcome most of the issues of 2D techniques (Pouliot et al., 2017). Nevertheless, properly visualising the 3D volumes representing the ownership of parcels is not so straightforward. There could be issues such as occlusion, distortion, unbounded parcels and difficulties in the perception of position, size and shape of an object (Pouliot et al., 2017). In addition, combining topography (i.e. earth surface and reference objects) and legal boundaries (i.e. cadastral parcels) contributes to create a more familiar view of the world. Although, this makes the visualization more challenging due to the growing number of objects in the viewer.

2 Related work

In this section the relevant literature related and linked to the project is presented. The goal is to have a general overview of the state of the art in 3D cadastre with a focus on visualization. The related work will be briefly described highlighting the gaps that the thesis research is aiming to fill.

2.1 The Russian prototype

The 3D cadastre prototype for the Russian Federation was developed to display both 3D objects and their legal boundaries. The prototype is supported by a web browser based solution running on Internet Explorer and Firefox, after the installation of the BS Contact plug-in from Bitmanagement (Vandysheva et al., 2012), which allows the visualization and interaction with the 3D objects. The 3D geometry is stored in static X3D files, while the corresponding administrative information is stored in additional XML files (Elizarova et al., 2012). The user interface is composed of three main parts: the '3D Viewer', the 'Select' window and the 'Selection Results' window (Figure 1).

The '3D Viewer' is where the interaction takes place, the user can rotate, zoom, pan, switch features on and off and use some special tools for viewing more details. The 'Select' window contains various options for the selection and visualization of 3D parcels. The 'Selection Results' window

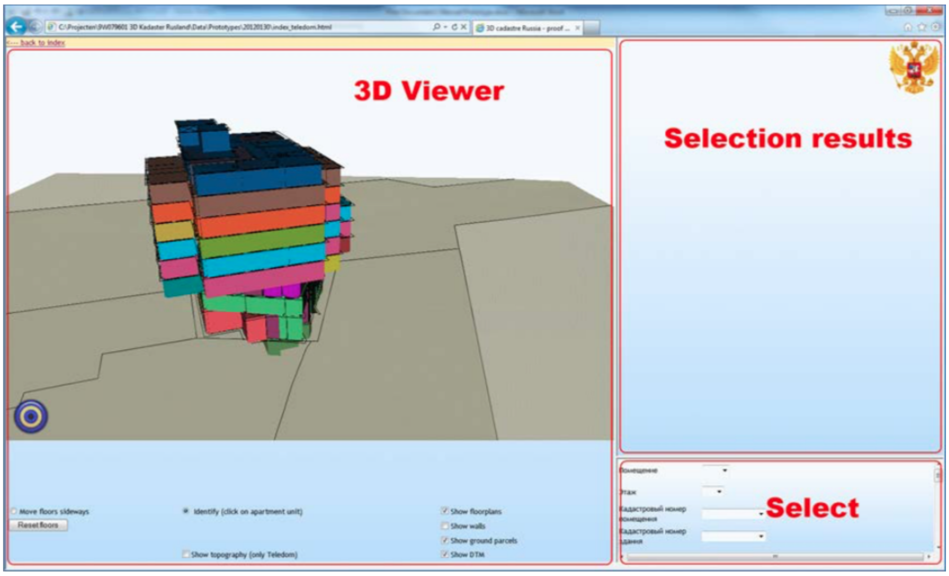

Figure 1: *User interface of the Prototype for the Russian Federation (Elizarova et al., 2012)*

shows information about selected objects (Elizarova et al., 2012).

The prototype supports a wide variety of functions for 3D cadastre visualization, among them we can list:

- Display and interact with 3D objects (rotate, pan, zoom, select, etc.);
- Selection based on multiple attributes such as, owner name, id of cadastral object, address, etc.;
- Possibility to toggle the visibility of layers;
- Possibility to show/hide privacy data based on user's right of access;
- Possibility to toggle the visibility of elements in the 3D model (walls, floors plants, etc.);
- Switch the language of the interface between Russian and English.

One of the main challenges during the development of the prototype were the link between the 3D objects in the Viewer window (X3D files) and the corresponding legal cadastral data in the non-spatial part of the prototype (XML files) (Vandysheva et al., 2012). Another challenge was to match the 3D models with the 2.5D GIS reference data containing ground parcels and a DEM with the terrain elevation (Elizarova et al., 2012).

After the implementation of the prototype, the involved parties decided to make a questionnaire to assess the prototype functionalities and determine future directions. The questionnaire was composed of 44 questions both open and multiple-choice, aimed at the evaluation of the testing made by the participants. The outcome of the questionnaire showed a positive attitude to the future introduction of a 3D cadastre in the Russian Federation (Elizarova et al., 2012).

Two main gaps need to be filled. The 3D cadastre Russian Prototype requires the installation of a plug-in in the web browser to read the X3D files. This makes the dissemination of the application more challenging, since some users could have difficulties with its installation. Another gap that needs to be filled is the fact that the information is not stored in a unique place (i.e. a DBMS) but in separate XML and X3D files. Having the information subdivided into different files makes the update and management of the files more challenging and error prone. Storing the information in a database will prevent this to happen and would ensure the data to be always up to date and available to different users.

2.2 The Queensland cadastre

The 3D registration in Queensland, Australia has partially been solved. Since 1997, it is possible to create parcels with 3D geometries as defined by the juridical framework of Queensland. Nevertheless, the cadastral map only contains the footprints of the 3D parcels. The actual 3D survey plans are stored on paper drawings or on scanned PDF files (Storer, 2004).

Moreover, the cadastral geographic dataset of Queensland has a 'base layer' which consist of a non-overlapping coverage containing parcels, roads, railways, water bodies and intersection parcels (Storer, 2004).

Even though the Queensland legislation is already oriented to the implementation of 3D cadastral parcels, there are still some gaps that need to be filled. First of all, the fact that the 3D parcels are laid down on paper (or on scanned documents) is a mayor shortcoming, since the data cannot be interactively viewed. The 3D drawing only shows the boundaries of the parcel, without any integration with the surrounding parcels. Another gap is the impossibility to check the validity of the 3D object. The parcels are described without the use of 3d primitives, but only by coordinates and edges on the drawings. The last issue is related to the fact that the 3D information is not integrated with the 2D cadastral map, but it is stored in separate static files. Therefore, it would be good to combine this information with the cadastral registration system which is already well implemented (Storer, 2004).

2.3 Other solutions found in the literature

Besides the two examples described above, other open source and proprietary prototypes were built for 3D cadastral systems, both web and desktop based:

- Prototype of 3D ePlan developed by Land Use Victorian Government;
- Two 3D cadastre web map prototypes developed for the jurisdiction of Indonesia, based on KML with Google Earth and X3D with ArcGIS online;
- Desktop based 3D cadastre for the administration of urban land use in Shenzhen, China.

3 Research objectives

3.1 Research questions

The main research question for this thesis is:
What is a good system design to obtain a proper, clear and not misleading visualisation of 3D cadastral parcels through a geo-web viewer?

The subquestions are:

1. *How to tackle issues such as occlusion, distortion and ambiguous perception (in terms of position, size and shape) of objects while interacting with 3D cadastre?*
   The aim here is to investigate issues affecting 3D visualization in general.
2. *What is the best way to combine the visualization of legal boundaries (cadastral parcels) and reference objects (topography)?*
   For orientation purposes, it is important to include reference objects to help us understand the location of the parcels in the real world. Although, adding more objects to the viewer makes the visualization more challenging.
3. *Which interaction techniques should be used in order to enhance user experience in 3D cadastre applications?*
   Here the focus is on the interaction with the platform from a user specific point of view.
4. *What are the options to store and transfer the data? (DBMS or encodings such as XML, JSON, glTF, etc.)*

This aspect is still an issue in many cadastral prototypes and evaluating the possibilities will help to choose the more effective option.

5. *What is the best system architecture for 3D cadastre visualization?*
   The system architecture includes: communication protocols, encodings, shipping, caching and data storage.

3.2 Research scope

The scope of the MSc thesis is to implement a prototype for the visualization and dissemination of 3D cadastre through a web based viewer. The focus will be mainly on visualization, in particular, on how to solve the visualization issues of 3D parcels. Other concerns related to 3D cadastre such as, how to solve topology issues (i.e. overlap, intersection, etc.), efficient storage of the data, speed and performance of the web viewer are out of scope.
The research will be carried out as follows. First the requirements for 3D web visualization will be analyzed and then a web based platform supporting 3D visualization will be chosen to develop the viewer. Finally, if time allows, a usability test will be carried out to check the performance and give feedbacks about the web viewer functionalities implemented.

4 Methodology

The research scope has been defined above, therefore the next step is to outline a clear methodology for the thesis research. The methodology will address all the research questions and it will give an overview of the phases of the project. The approach followed is the so-called 'Design Science Research Approach' (Hevner and Samir). Figure 2 displays a flowchart of the overall process of visualization and dissemination of 3D cadastre. The main phases are:'Research start-up', 'Literature Research', 'Technology Research', 'Prototype Development' (and 'Usability Test'), which are described more in detail in the following subsections.

4.1 Research Start-up

The research start-up phase includes the definition of the graduation topic together with the supervisors, the definition of the research questions and subquestions, and a preliminary draft of the research to be carried out. This phase ends with the P1 presentation. Once the main goal has been defined, the research narrows down to more specific issues.

4.2 Literature and Technology Research

The literature study focuses on existing 3D cadastre applications which have a similar purpose than this MSc thesis research. Many countries all over the world are moving towards the implementation of a three dimensional cadastre. The aim of this research is to investigate what has been done and what are the gaps that need to be filled in the future. This will give insights about which directions the research should follow. Moreover, a set of requirements for 3D visualization are defined. Among them:

- 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

For a more detailed description of the requirements see (Cemellini, 2017). Among others the literature study includes examples such as the 3D cadastre Prototype for the Russian Federation and the Brisbane cadastre described above.

The technology research focuses on existing WebGL platforms that can be used as a framework for the 3D cadastre prototype. A good knowledge of existing platforms and their capabilities can help building a successful cadastral prototype (Shojaei, 2014). Also in this case, a list of requirements is needed to test the platforms:

- 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)

For a more detailed description of the requirements see (Cemellini, 2017). The purpose of the study is to find the platform with the highest number of requirements already implemented and/or the possibility to modify its source code in order to implement additional functionalities. The web viewers analyzed will be based on the cutting-edge WebGL technology, mainly because of its plug-in free interface.

4.3 Prototype Development

The core of the MSc research is the development of the 3D cadastre visualization prototype .
The choice of the data is crucial to build a reality-like prototype. In this case the dataset chosen is part of the Brisbane DCDB (the data format and the issues related to the data will be explained in the next sections). Generally, the availability of the data is one of the main issues. Luckily, we managed to obtain the data since the implementation of the prototype will also benefit the Brisbane cadastre.

Another issue is the choice of the most suitable data format. The 3D parcels of the Brisbane DCDB are only available in PDF format, therefore the data needs to be encoded in a digital format to be stored in a spatial database (see Section 6 for a more detailed description). It is implicit that, although out of scope of the MSc research, the data preparation/encoding phase is necessary for the realization of the prototype.

After the data has been prepared, the web viewer needs to be set up and the data stored at the back-end so that it can be retrieved by the client during interaction. The functionalities will then be implemented following the requirements for 3D cadastre visualization listed above. Most likely, only a part of the requirements will be implemented due to time constraints. As mentioned before, the web viewer will be WebGL based, a cross-platform open source web standard for a low-level 3D graphics API based on OpenGL ES. A big advantage of WebGL is that it brings 3D into the web without the installation of plug-ins and it is implemented directly into the web browser (KronosGroup, 2017). Moreover, several open source JavaScript libraries can be used to simplify the programming process (Shojaei, 2014). The functionalities will then be tested making sure they solve common 3D visualization problems, such as occlusion, distortion and difficulties in the perception of position, size and shape of objects.

The last step is the definition of the client-server interaction to ensure the user-friendliness of the cadastre application. In particular, this phase will investigate on which is the best system architecture (i.e. communication protocols, encodings, shipping caching and data storage) for this purpose.

4.4 Usability test

If time allows, a usability test will be performed on potential users of the application. The users should be chosen from different sectors to reflect a wide variety of user groups. The users will have to answer a set of questions regarding specific tasks that they have to perform on the web viewer. The goal is to make sure that they can perform such tasks in an intuitive way. If they cannot find a way to perform the exercises, the probably the user friendliness of the viewer needs to be improved. Finally, the results of the questionnaire will be processed to obtain feedbacks for the further development of the 3D cadastre prototype.

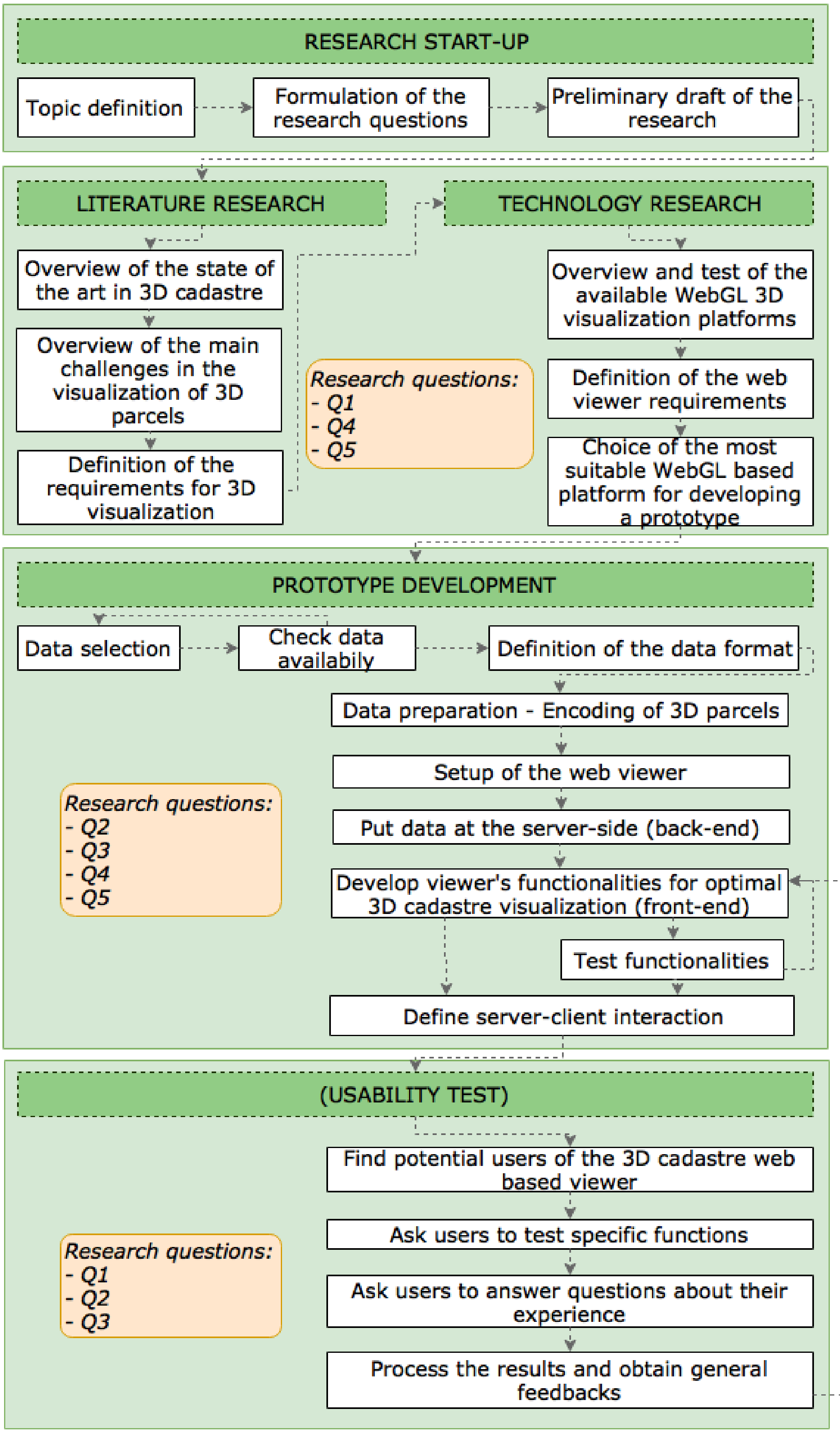

Figure 2: *Design Science Research approach applied to 3D cadastre visualization*

5 Time planning

5.1 Timetable of the activities

The timetable is defined by five important deadlines in which the student has to present his or her work (the so-called P1, P2, P3, P4 and P5). The table below shows the dates of the presentations, some of them still need to be decided.

Event	Date
P1 - Progress review Graduation Plan	13th November 2017
P2 - Formal assessment Graduation Plan	17th January 2018
P3 - Colloquium midterm	19th - 23rd March 2018
P4 - Formal process assessment	22nd - 31st May 2018
P5 - Public presentation and final assessment	25th June - 13th July 2018

Moreover, a more detailed schedule of the single activities is presented. Each activity is defined by a start and an end date.

Start	End	Activity
4th Sept	12th Nov	Research start-up
		P1 - Progress review Graduation Plan
9th Oct	7th Jan	Literature research
16th Oct	31st Dec	Technology research
27th Nov	16th Jan	Check data availability and data preparation
		P2 - Formal assessment Graduation Plan
18th Jan	31st Jan	Web Viewer setup
1st Feb	19th Mar	Implement prototype's functionalities
		P3 - Colloquium midterm
19th Mar	30th Apr	Finalize web viewer's functionalities
19th Mar	30th Apr	Usability test (if time allows)
19th Mar	21st May	Thesis writing
		P4 - Formal process assessment
21st May	13th Jun	Finalize thesis
14th Jun	24th Jun	Prepare final presentation
		P5 - Public presentation and final assessment

5.2 Meetings

The meetings are scheduled every two weeks with both supervisors: Prof. dr. ir. Peter van Oosterom and Drs. Marianne de Vries. Additional guidance and feedbacks about 3D parcels in Brisbane, Australia will be provided by Dr. R.J. Thompson. The co-reader still need to be decided.

5.3 Progress monitor

Before every meeting the 'Progress Monitor', a concise document summarizing the progress of the previous weeks, is handed in to the supervisors. This provides to the mentors a quick update about the progress made, the causes of possible delays and the future directions. Figure 3 shows an example of Progress Monitor. The Progress Monitor is an adaptation from (Gosling and Noordam, 2006).

Progress monitor

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18/12/2017

1.Main results past couple of weeks:
Encoding of simple parcels of the DCBD (mainly along the underground tunnel). I started from the 'easy' ones to understand the mechanism.
2.Difficulties/delays:
Set up of the working environment on my own computer (still not successful). I worked on the encoding itself (excel files), but Rod had to check whether the encodings were correct or not from his computer.
3.Plans for next weeks:
Work on the encoding of the remaining parcels and on the paper for the MSc graduation proposal (P2) + slides.

Figure 3: *Progress Monitor example*

6 Tools and datasets used

6.1 Tools

The main tool needed to develop the 3D cadastre prototype is a WebGL based platform on which the web viewer will be based. The choice of the most appropriate platform is crucial, therefore a review of the available platforms has been made in an earlier study to compare their characteristics (Cemellini, 2017). The requirements check in the different platforms is summarized in figure 4. The green checkmark means that the requirement has been verified to exist, the orange question mark means that no evidence has been found or no one still implemented it, and the red cross mark means that it is certainly not possible to implement that requirement.

The result of the testing pointed out the strengths and weaknesses of each web viewer, addressing the final choice on iTowns, Cesium JS and

	Platforms					
Requirements	**iTowns**	**Cesium JS**	**OSM buildings**	**WebGL Earth**	**Geobrowser 3D**	**ESRI Cityengine Web Viewer**
Navigation tools and view controls	✔	✔	✔	✔	✔	✔ but not tooltips
Integrating topography and reference objects	✔	✔	✔	✔	✔	✔
Transparency	✔	✔	✔	✔	✔	✔
Object selection	?	✔	✔	✔	✔	✔
Object search	?	✔	✔	✔	✔	✔
Wireframe display	✔	✔	?	?	?	✔
Explode view	?	?	?	?	?	?
Sliding	?	?	?	?	?	?
Cross-section view	?	?	?	?	?	✔
Visualization cues	?	?	?	?	?	?
3D measurement tools	✔	✔	?	?	✔	✔ only through programming
3D buffer	?	✔	?	?	?	?
Display partly unbounded objects and 'complex' geometries	?	?	?	?	?	?
Platform and browser independence	✔	✔	✔	✔	✔	✔
Handling massive data and caching/tiling between server and client	✔	✔	✔	✔	✔	? but foresees the possibility of handling massive cadastral data
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	✔	✔	✔	✔	✔	✔ Python scripting interface
2D overview map (orientation)	✔	✔	?	?	?	?

Figure 4: *Requirements check in the different WebGL platforms (Cemellini, 2017)*

ESRI CityEngine, primarily because of the number of requirements already implemented, their extensibility and the support provided to the developers. Further analysis will determine which one is the most appropriate to develop a user-friendly 3D cadastre application. The choice will be made also according to the data and the data format used for implementing the final prototype.

The encoding of the data will be carried out through a Java code courtesy of Dr. R.J. Thompson. While the code for the prototype implementation will be written in JavaScript programming language and some of its libraries will be used to simplify the rather complicated WebGL programming process.

Another tool that will be used is the DBMS PostgreSQL for the storage and retrieval of the data. In particular, its PostGIS extension will be used to add support for geographical objects.

6.2 Data

A variety of data will be used in the project:

- 2D cadastral parcels (from Queensland Cadastre)
- 3D survey plans (from Queensland Cadastre), either in 'building format' and in 'volumetric format' More precisely, the volumes will represent three main categories in the real world: buildings, tunnels and air space.
- Registration of rights, restrictions and responsibilities (if available)
- Elevation data (DTM or contour lines)
- Reference data (topographic objects in 2D or 3D - buildings, roads, etc.)

The cadastral data used for the project is taken from the Queensland Digital Cadastral Database (DCDB), a collection of all the property boundaries and related property description of land parcels in Queensland (Australia) (QueenslandGovernment, 2018). The reason of this choice stems from the fact that the Queensland cadastre has the longest tradition and the biggest amount of data available so far.
The area of interest is situated in the centre of Brisbane, approximately in the area of the Story Bridge and the Kangaroo Point. The bounding box of the area is shown in figure 5.

In order to make the visualization more complete and meaningful, the plan is to add a Digital Terrain Model (DTM) containing ground data. The addition of reference objects and terrain elevation data contributes to create a reality-like environment, helping the user to recognize and reference the legal objects that would otherwise float on the canvas. At the moment of writing, the availability of the DTM is still unsure.

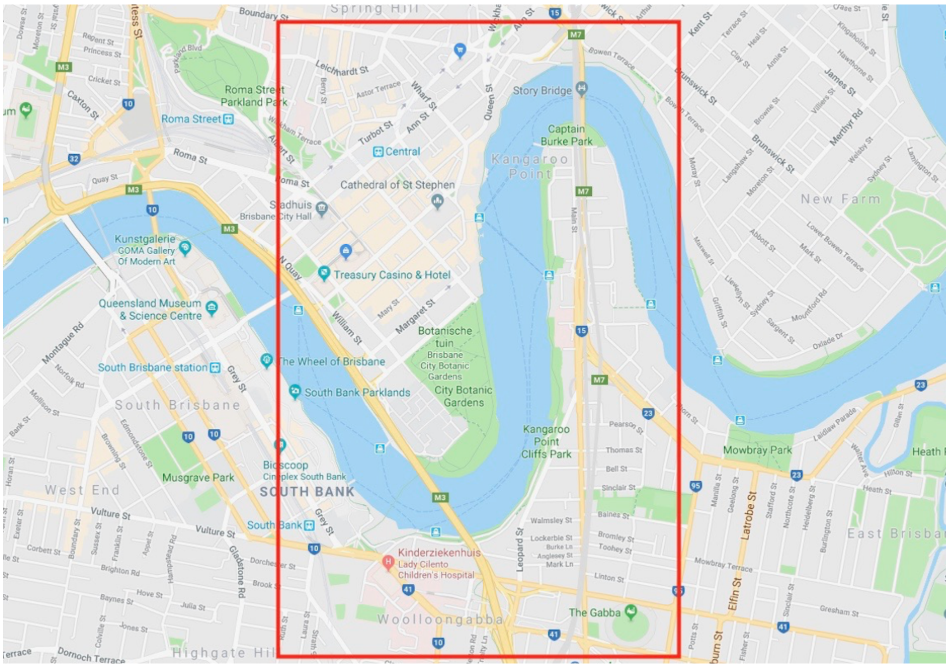
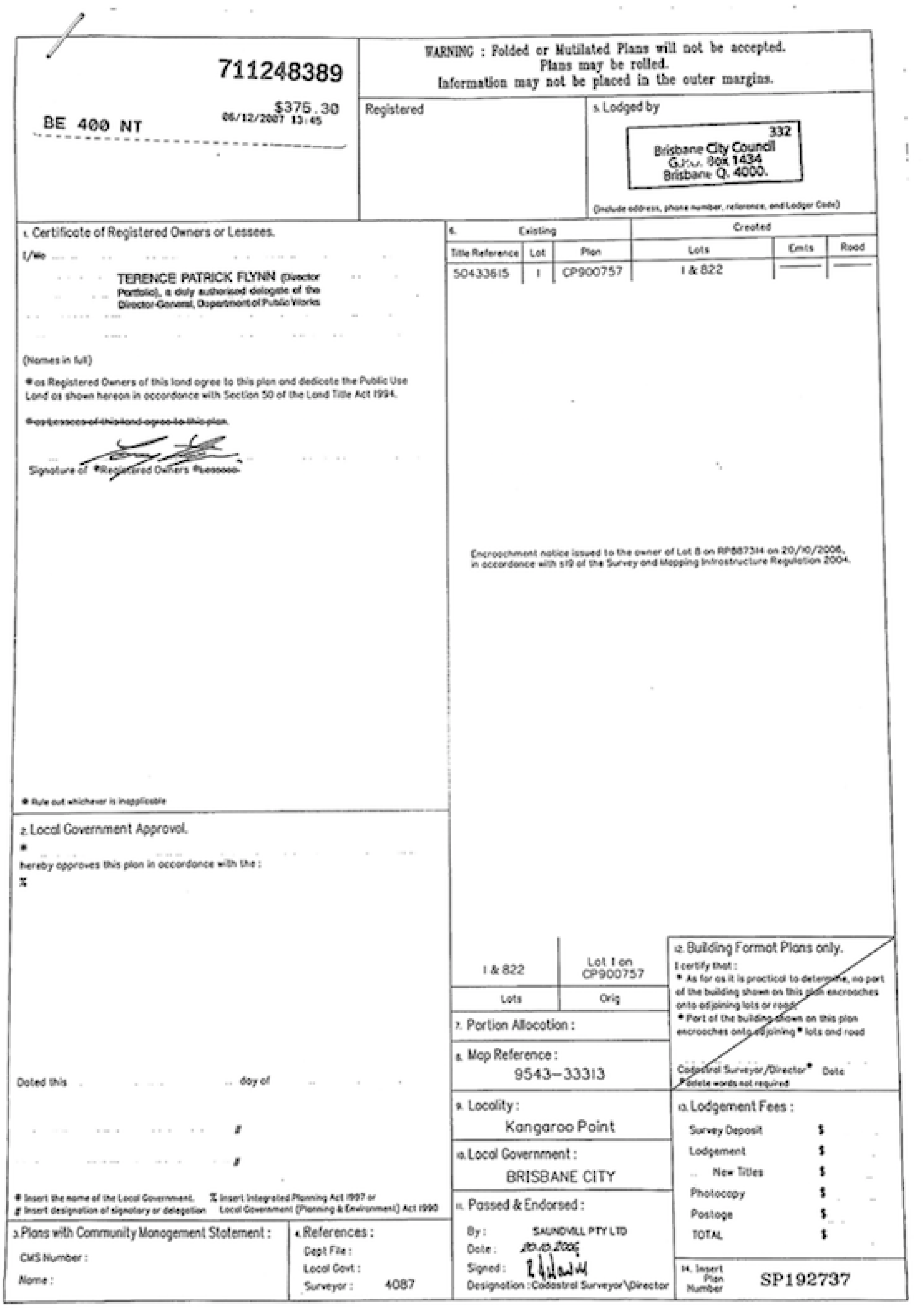


Figure 5: *Bounding box of the Brisbane area*

6.2.1 Data encoding

As previously mentioned, the 3D survey plans of the Brisbane DCDB are stored in plain PDF 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 figures 6, 7 and 8. Next, the data needs to be input by hand in a custom made Excel file as shown in figure 9. Note that the corner numbers in the Excel sheet correspond to the corners of the 3D parcel (i.e. 91,9,8,7,93,92). The letter placed next 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 counterclockwise and clockwise.
Finally, a Java program reads the Excel file and encodes the 3D parcel. It is important to keep in mind that, even thought the encoding of the parcels is performed automatically by a computer program, the passage from the PDF survey plan to the Excel format has to be done manually. Therefore, it is a non-trivial and time consuming operation.



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

5. Lodged by

332
Brisbane City Council
G.P.O. 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

6. Existing			Created		
Title Reference	Lot	Plan	Lots	Emts	Road
50433615	1	CP900757	1 & 822	—	—

Encroachment notice issued to the owner of Lot 8 on RP887314 on 20/10/2006, in accordance with s19 of the Survey and Mapping Infrastructure Regulation 2004.

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

Lots	Orig
1 & 822	Lot 1 on CP900757

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 road;
* 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 $

3. Plans with Community Management Statement :
CMS Number :
Name :

4. References :
Dept File :
Local Govt :
Surveyor : 4087

14. Insert Plan Number SP192737

Figure 6: *Example of 3D survey plan - Lot 822 (page 1 of 3)*

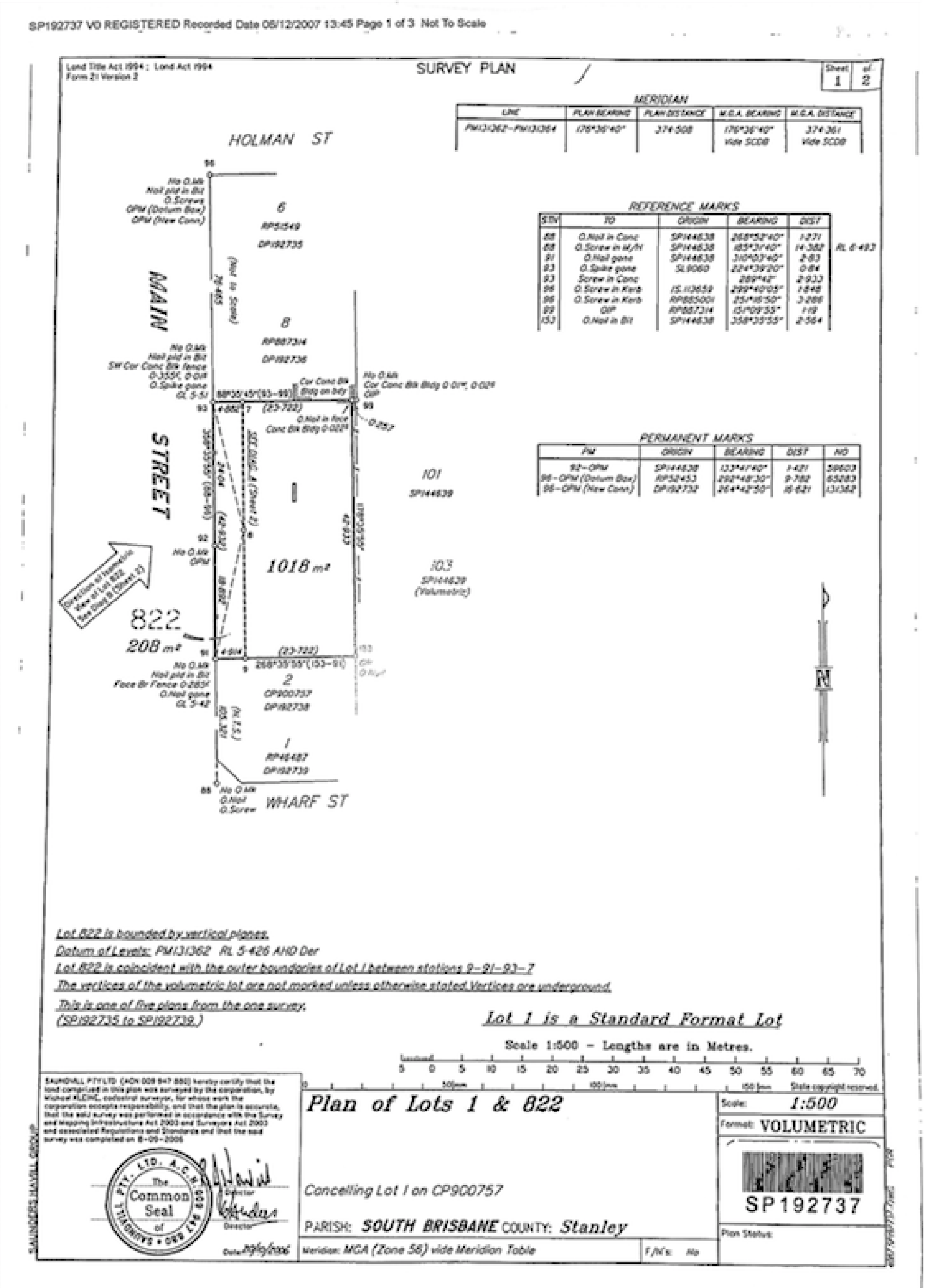


Figure 7: *Example of 3D survey plan - Lot 822 (page 2 of 3)*

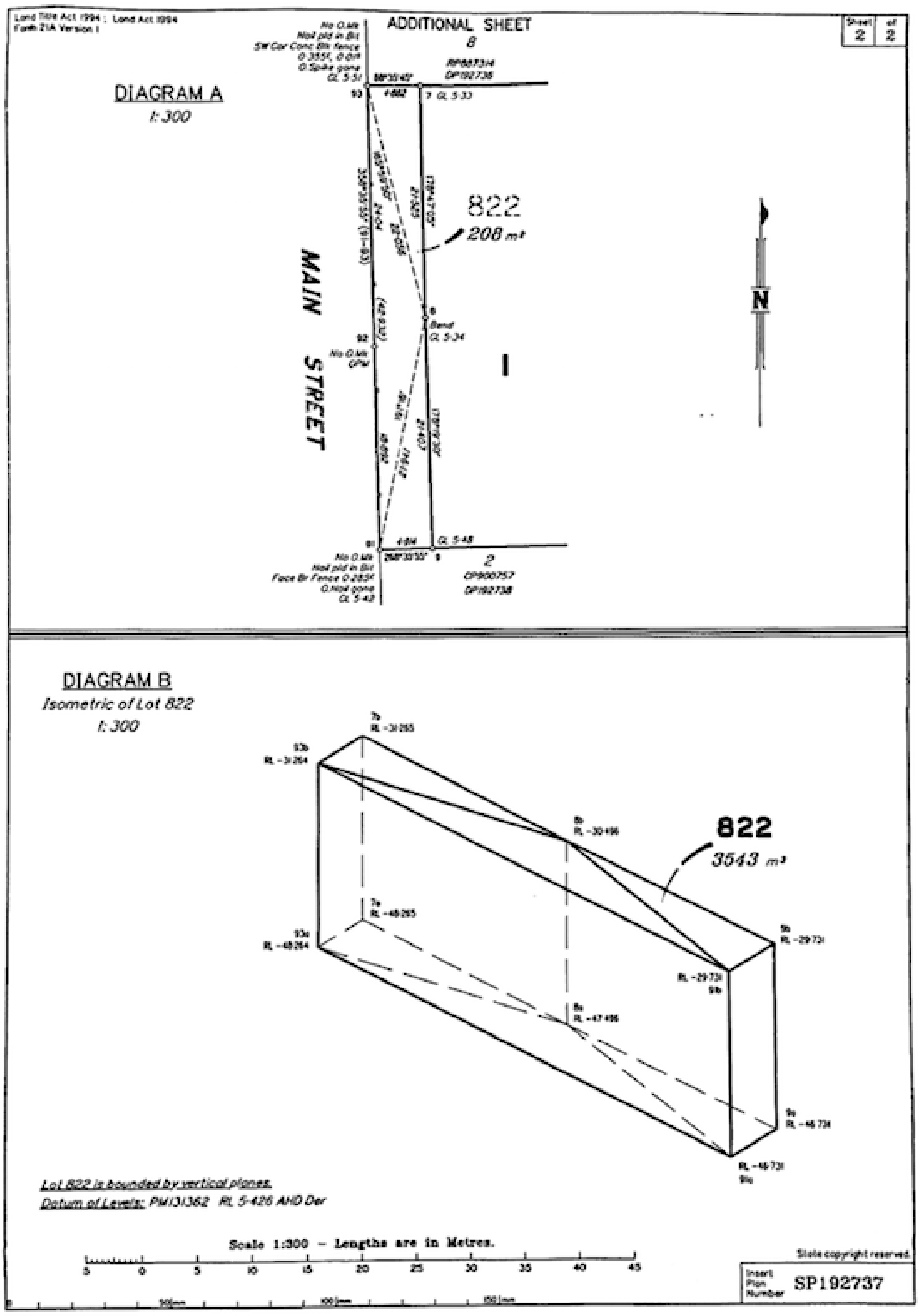


Figure 8: *Example of 3D survey plan - Lot 822 (page 3 of 3)*

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 9: *Example of Excel file - Lot 822*

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