3D Cadastral Visualisation: Understanding Users' Requirements

By

Davood Shojaei

Submitted in total fulfilment of the requirements

of the degree of Doctor of Philosophy

September 2014

Centre for Spatial Data Infrastructures (SDIs) and Land Administration,

Department of Infrastructure Engineering, School of Engineering,

The University of Melbourne

ABSTRACT

Population growth and reduced availability of land are common challenges in urban areas and lead to intensive property development. These developments extend both above and below ground such as high-rise buildings and infrastructure. For these developments, ownership rights are defined using many types of rights, restrictions, and responsibilities (RRRs).

The increasing complexity of multi-level developments and infrastructure exacerbates the challenge inefficiently registering RRRs within land registries, which existing two dimensional (2D) cadastres are only partly able to do. In current cadastral systems, these RRRs are represented using 2D building plans, cross-sections, isometric diagrams and textual descriptions in a paper (or PDF) format.

This paper-based method of representation is inefficient in various ways. For example, this method makes it difficult for non-specialists to understand ownership boundaries. Furthermore, representing ownership rights in high-rises and complex developments needs numerous floor plans and cross-sections which are not easy to interpret. In addition, as these plans are recorded in paper or PDF files, queries and analysis are not possible.

Therefore, there is a need for more effective and efficient representation of RRRs to support registration and understanding of RRRs in complex developments. 3D visualisation can help people better understand 3D ownership information particularly in complex high-rises. To design and develop efficient 3D visualisation applications, there is a need for identifying 3D cadastral visualisation requirements. The research problem underpinning this study is therefore: visualisation requirements to support the development of 3D cadastral applications to represent rights, restrictions and responsibilities have not been clearly identified. An agreed set of requirements will support the development of visualisation applications designed to meet users' needs.

To address the research problem, this research identified detailed 3D visualisation requirements using a requirements engineering approach to support efficient representation of ownership RRRs. These requirements were classified into data requirements, user interface and system requirements, non-functional requirements, visualisation requirements, and analytical requirements.

The validation of requirements included development of two prototypes based on user requirements and gathering experts' feedback using two questionnaires. Implementation of prototypes for representing RRRs, and the feedback on these, established the validity and priority of the requirements.

DECLARATION

This is to certify that:

- the thesis comprises only my original work towards the PhD except where indicated,
- due acknowledgement has been made in the text to all other material used,
- the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices,
- Parts of this work were published in books, journals, refereed conference proceedings, professional magazines, and newsletters as listed in Appendix 1.

____

Davood Shojaei

September 2014

ACKNOWLEDGEMENTS

This thesis appears in its current form due to the assistance and guidance of several people. I would therefore like to offer my sincere thanks to all of them.

First and foremost, I offer my deep and most sincere gratitude to my supervisor and mentor, Professor Abbas Rajabifard, who has supported me continuously throughout my thesis with his patience, motivation, enthusiasm, and immense knowledge. I would have been lost without him. I owe my sincere gratitude to Dr. Mohsen Kalantari for his expert advice, wide knowledge and constructive comments, and for his important support throughout this work. I am also deeply grateful to Professor Ian D. Bishop whose stimulating suggestions and encouragement helped me in all the time of research for and writing of this thesis.

After all these years, I've got quite a list of people who have contributed in some way to this thesis, for which I would like to express thanks. I also wish to thank the staff and postgraduate students from the Department of Infrastructure Engineering for their assistance and support. In particular, to my past and present fellow researchers in the Centre for Spatial Data Infrastructures and Land Administration (CSDILA), thank you for your friendship and support during my candidature. Dr Rohan Bennett, Dr Ida Jazayeri, Dr Serryn Eagleson, Dr Malcolm Park, Ms Jude Wallace, Mr Brian Marwick, Dr Katie Potts, Dr Hamed Olfat, Dr Ali Aien, Mr Sam Amirebrahimi, Dr Muyiwa Agunbiade, Mr Farhad Laylavi, Mr Behnam Atazadeh, Ms Pamela Chew, and Mrs Shima Rahmatizadeh. Particularly, to Ms Serene Ho who shared my daily trials and triumphs, successes and frustrations, thank you for encouragement and wise words when needed.

To the professional staff, Rose Macey and Pauline Woolcock thank you for your assistance and help with the administrative hurdles and organisational challenges.

My special thanks go to Professor Stephan Winter, Geomatics Discipline Leader in the Department of Infrastructure Engineering at the University of Melbourne, for all his valuable feedback and support throughout my PhD.

Thanks are also due to the visiting staff to the Department who provided their invaluable advice and research perspectives, especially Professor Ian Williamson, Professor Stig Enemark (Aalborg University), Dr. Daniel Steudler (Swisstopo), Professor David J. Cowen (University of South Carolina), and Professor Stéphane Roche (Université Laval).

My research would of course not been possible without the support of the Australian Research Council (ARC) Linkage Project on Land and Property Information in 3D and industry partners including the Department of Transport, Planning and Local Infrastructure (DTPLI), the Land and Property Management Authority, the Intergovernmental Committee on Surveying and Mapping, PSMA Australia Limited, Alexander Symonds, Strata Community Australia, AAM Group, and the City of Melbourne.

I would like to especially thank Mr David Hassett (City of Melbourne), Mr Chris Lester, Mr John E. Tulloch, Mr David R. Boyle, Mr Neil Coupar (Land Victoria, DTPLI), Mr Malcolm McCoy, Mr Patrick Meehan (the AAM Group), and Mr Rob Beck (Strata Community Australia, Victoria).

My special thanks go to Ms Jenny Smith, without her, this thesis would be unintelligible.

I was also extraordinarily fortunate to have very good friends during my PhD, in particular Dr Saeed Nadi, Dr Hossein Helali, Ms Parinaz Mohsenpour, Ms Negar Keshavarz, Mr Nima Javid, Mr Alireza Jamshidi and Mr Shahram Darbandi.

My deepest gratitude goes to my family for their unflagging love and support throughout my life; this dissertation is simply impossible without them. I am indebted to my parents, Mr Mansour Shojaei and Mrs Tahereh Shahpouri for their everlasting care, support, advice, and love. My father spared no effort to provide the best possible environment for me to be successful in life. I cannot ask for more from my mother, as she is simply perfect. I have no suitable word that can fully describe her everlasting love to me. I also feel proud of my sister, Bahareh, my brother, Saeed, my brother-in-law, Mr Hamid Shahpouri, and my niece, Hania, for their care, support, and love during these years.

Finally and most importantly, I give GOD the glory for HIS grace and mercy upon my life.

Davood Shojaei

September 2014
Melbourne, Australia

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

2D	Two Dimensional
2.5D	Two And Half Dimensional
3D	Three Dimensional
ABS	Australian Bureau Of Statistics
AHD	Australian Height Datum
API	Application Programming Interface
ARC	Australian Research Council
BIM	Building Information Modelling
B-Rep	Boundary Representation
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CP	Plan of Consolidation
CS	Cluster Subdivision
CSDILA	The Centre for Spatial Data Infrastructures and Land Administration
CSG	Constructive Solid Geometry
DBMS	Database Management System
DCDB	Digital Cadastre DataBase
DEM	Digital Elevation Model
DTM	Digital Terrain Model
DTPLI	Department of Transport, Planning and Local Infrastructure
ESRI	Environmental Systems Research Institute
FIG	International Federation of Surveyors
FOI	Freedom Of Information
GIS	Geographic Information Systems
GML	Geographic Markup Language
GPS	Global Positioning System
GUI	Graphic User Interface
IEEE	Institute of Electrical and Electronics Engineers
IFC	Industry Foundation Classes
ISO	International Standard Organisation
IT	Information Technology
INSPIRE	Infrastructure for Spatial Information in the European Community
KML	Keyhole Markup Language
LADM	Land Administration Domain Model
LASSI	Land And Spatial Survey Information
LASSI-SPEAR	Land And Spatial Survey Information- Streamlined Planning through Electronic Applications and Referrals
LoD	Level of Detail
LP	Lodged Plan
MGA	Map Grid of Australia
MLS	Mobile Laser Scanning
NASA	National Aeronautics and Space Administration
NWW	NASA World Wind
OGC	Open Geospatial Consortium
OP	Original Plans (Crown)
PC	Plan of Consolidation
PDF	Package Definition File
PS	Plan f Subdivision
PSMA	Public Sector Mapping Agencies
RL	Reduced Level
RP	Registered Plan

RRR	Rights, Restriction, Responsibilities
SDI	Spatial Data Infrastructure
SPEAR	Streamlined Planning through Electronic Applications and Referrals
SRS	Software Requirements Specifications
SUS	System Usability Scale
TP	Title Plan
UK	United Kingdom
UML	Unified Modelling Language
UN	United Nations
US	United States
USA	United States of America
VCAT	Victorian Civil and Administrative Tribunal
VFP	Volumetric Format Plans
VIC	Victoria
VOTS	Victorian Online Titles System
VRML	Virtual Reality Modelling Language
WCS	Web Coverage Service
W3DS	Web 3D Service
WebGL	Web Graphic Library
WFS	Web Feature Service
WMS	Web Map Service
WWW	World Wide Web
X3D	Extensible 3D
XML	Extended Mark Up Language

CHAPTER 1

INTRODUCTION

"Losers visualize the penalties of failure. Winners visualize the rewards of success."

–WILLIAM S. GILBERT

1 Introduction

1.1 Research background

Population growth and reduced availability of land are common challenges in urban areas and lead to intensive property development. These developments extend both above and below ground (e.g. high rises, car parks, utility networks, and tunnels). In these developments, property ownership rights are defined with many types of rights, restrictions, and responsibilities (RRRs). According to Enemark (2009) "property rights are normally concerned with ownership and tenure whereas restrictions usually control use and activities on land. Responsibilities relate more to a social, ethical commitment or attitude to environmental sustainability and good husbandry".

Land administration systems provide an infrastructure for implementation of land-management policies and strategies (Williamson *et al*., 2008). Cadastre is an engine of land administration systems which is responsible for registering RRRs (Williamson and Wallace, 2007). Managing these overlapped RRRs in current land administration systems is a challenge, as they are equipped with cadastres that can only maintain 2D spatial information (Aien, 2013).

In addition, the increasing complexity of infrastructures and multi-level developments needs efficient registration of RRRs, which existing 2D cadastres are only partly able to do (van Oosterom, 2013). In current cadastral systems, these RRRs are represented using 2D building plans, cross-sections, isometric diagrams and textual descriptions in a paper (or PDF) format. Floor plans, isometric diagrams and cross-sections (the intersection of a building with a vertical plane) are common methods for representing the third dimension. While this discussion is primarily based on the situation in Australia, many countries have the same paper format representation (Pouliot, 2011)[1].

This paper-based method of representation is inefficient in the following ways:

[1] Based on the questionnaire conducted by FIG joint commission 3 and 7 Working Group on 3D Cadastres.

- Representing ownership rights in high rises and complex developments needs numerous floor plans and cross-sections which are not easy to interpret (Aien *et al*., 2011);
- This method only represents some RRRs and does not visualise real-world components such as walls, doors, slabs, and roofs which can be used as references for understanding the ownership boundaries. This makes it difficult for non-specialists to understand the ownership boundaries;
- It is not possible to rotate the content of paper plans in different axes, or zoom to a specific component;
- Plans are maintained in paper and PDF files, modifications are not easy or efficient; and
- As these plans are recorded in PDF files, queries and analysis are not possible.

In addition to the shortcomings of representing RRRs in a paper-based approach, there are several drivers to utilise 3D visualisation techniques for representing RRRs. These include (Shojaei *et al*., 2013):

- Technology push: there are a rapidly increasing number of 3D visualisation platforms in many disciplines providing realistic representations of the world with real-time navigation;
- Public demand: as people demand more access to information about their environment, they require effective means of communication that do not require specialised training;
- Professional demand: nowadays, 3D visualisations are widely used in various applications such as architecture, urban planning, building development, and disaster management. Therefore, professionals are looking for compatible visualisation systems for also managing RRRs in 3D; and
- Resource efficiency: land and property, as important resources, require modern management approaches for their sustainable use, especially in populated urban areas; and
- System efficiency: 3D visualisations increase the functionality of a cadastre (Stoter and van Oosterom, 2006).

Therefore, there is a need for effective and efficient systems for representing RRRs in 3D. Such systems have several parts: a data model for the information itself, a data format to support the data model, a database to manage data, and visualisation tools for communicating, exploring, querying and analysing the information (Shojaei *et al*., 2013).

This thesis focuses on the visualisation aspects of a 3D cadastral system but recognises that the other parts influence what is possible within the visualisation application. At the same time, the requirements or desired properties of the visualisation applications may influence the choice of the underlying data model and database. The research on 3D cadastral visualisation needs more investigation (Pouliot, 2011, van Oosterom, 2013, van Oosterom, 2012) and is quite different from 3D city model visualisations (Wang *et al*., 2012).

In seeking to define visualisation requirements, certain questions arise.

- Who are the stakeholders?
- What are their needs?

3D cadastral stakeholders range from professionals to citizens. Professionals include notaries, real estate agents, land registries, financial institutions, referral authorities, utility companies, city councils, and land surveyors. Citizens include the public as owners and users (van Oosterom *et al*., 2011).

With regard to their needs, cadastral data define RRRs and cadastral stakeholders need efficient 3D cadastral visualisation applications to communicate to each other in the cadastral domain. These applications should support searching, planning and analysing land related information.

1.2 Research Problem

As outlined above, due to the increasing number of overlapped multi-level developments, particularly in densely populated areas, there is a need for an effective and efficient 3D visualisation of RRRs. However, currently stratified and overlapped RRRs are mainly represented in paper-based plans. This method does not efficiently represent the overlapping ownership boundaries in urban populated areas. To design and develop efficient 3D visualisation applications for representing ownership boundaries, there is a need for developing 3D cadastral visualisation requirements. Therefore, the research problem to be investigated in this thesis is summarised:

Visualisation requirements to support the development of 3D cadastral applications to represent rights, restrictions and responsibilities have not been clearly identified. An agreed set of requirements will support the development of visualisation applications designed to meet users' needs.

1.3 Research Questions

In considering the research problem, a number of key research questions emerged, namely:

1. What are the existing approaches of representing RRRs? And what are their limitations?
2. What are the advantages of utilising 3D visualisation techniques for representing RRRs?
3. What should be visualised in 3D cadastres? What are the 3D visualisation requirements for developing 3D cadastral applications? What type of visualisation features should be included in these applications?
4. How can these 3D cadastral visualisation requirements can be identified, developed and validated to represent RRRs for cadastral purposes?

1.1 Research Aim

This research aims to identify and develop 3D visualisation requirements for representing rights, restrictions, and responsibilities in 3D.

1.4 Research Objectives

In order to achieve the research aim and address the research questions, the following objectives are formulated:

1. To study and understand 3D cadastral concepts;
2. To study and understand 3D visualisation concepts for cadastral purposes;
3. To identify and develop 3D visualisation requirements for cadastres; and
4. To validate and showcase the developed 3D cadastral visualisation requirements.

1.5 Research Approach

This thesis utilises the requirements engineering method in order to identify, develop and validate the 3D cadastral visualisation requirements. Requirements engineering is "*all of the activities involved in discovering, documenting and maintaining a set of requirements for a computer-based system*" (Kotonya and Sommerville, 1998, Page 8) and requirements definition is a process of carefully developing of the needs of a system. In this method, a mixed research method integrating both qualitative and quantitative approaches was utilised to develop these requirements, which is stronger than relying on a single method. In this research method, Melbourne metropolitan area in Victoria, Australia, was selected as a case study. Case studies help to understand the current practice and existing issues and challenges. Accordingly, the following research approach was designed:

- **Phase 1: Analysis of the background**

In this phase, to establish the theoretical background of the research, an extensive literature review was undertaken on two main areas: 3D cadastre and 3D visualisation. Books, journals, organisation reports, conference proceedings, available visualisation tools, visits and information published over the World Wide Web (WWW) were used to collate a range of information for reviewing in these two areas. This phase was undertaken to address the first two objectives of the research.

- **Phase 2: Identify 3D cadastral visualisation requirements**

To identify 3D cadastral visualisation requirements, various approaches were selected. In addition to the comprehensive literature review, a participant observation approach was used in which two industry placements were undertaken in Victoria, Australia. The placements were held in Melbourne City Council and Land Victoria (Department of Transport, Planning and Local Infrastructure, Victoria). In these placements, the subdivision process was investigated in detail and documented to identify 3D visualisation requirements for representing RRRs. Melbourne metropolitan area was selected as a case study and various aspects were investigated. This phase was undertaken to address research objective 3.

- **Phase 3: Validation of the requirements**

In this stage, to validate the requirements, a validation framework was designed and applied. In this framework, a series of 3D visualisation prototypes, user-based evaluation and questionnaires were used to validate the requirements.

Firstly, a prototype was developed and presented to specialists in a workshop to receive their feedback. Secondly, a questionnaire including requirements was prepared and distributed among 3D cadastral users to receive their feedback. Finally, another prototype was designed and implemented based on some of the identified requirements and evaluated using a questionnaire. This phase was carried out to address research objective 4.

Figure 1.1 demonstrates the research approach including technical steps and relationships between research phases to develop 3D visualisation requirements for representing RRRs.

Figure 1.1: Research approach and connectivity with research objectives.

1.6 Thesis Structure

The structure of this thesis has been formed as illustrated in figure 1.2 to address the research objectives based on the requirements engineering method.

Chapter 2, *Three Dimensional Visualisation in the Cadastral Domain*, defines 3D cadastre and investigates 3D cadastral visualisation activities and problems in terms of visualising RRRs. It then looks at the cadastral users and their needs. Finally, it explores different aspects of visualising RRRs in 3D.

Chapter 3, *Research Design and Methods*, outlines the research design and methods that were utilised to develop a strategy to achieve the objectives and answer the research questions. This chapter first investigates the research conceptual design framework by reviewing the research problem and questions, and then explores the possible research methods available to answer these questions. The chosen research methods are then justified and the final research design is presented.

Chapter 4, *Current Practice of RRRs Representation: Victorian Case Study*, describes the current land administration systems in Victoria, Australia, and current methods of registration and visualisation of RRRs. Two cases in Melbourne, Australia, were selected and the problems regarding the current registration and representation approaches were highlighted. Through these cases, some major visualisation requirements were identified.

Chapter 5, *Requirements for 3D Cadastral Visualisation Applications*, explains the outcomes of the previous chapters and then classifies the identified and developed 3D cadastral visualisation requirements.

Chapter 6, *Development of Prototypes for 3D Cadastral Visualisation*, explores the implementation of two 3D cadastral visualisation prototypes according to the identified requirements. The prototypes are built upon various technologies to showcase the benefits of 3D cadastral visualisation applications and the shortcomings of various technologies to meet users' requirements.

Chapter 7, *Validation of 3D Cadastral Visualisation Requirements*, explores the results of the validation process including the results from the two questionnaires and two prototypes. This chapter also summarises the recommended feedback from end users and experts to improve and prioritise the requirements.

Chapter 8, *Conclusions and Recommendations*, presents the outcomes achieved during this research, reflects on the original research problem and suggests directions for future research efforts.

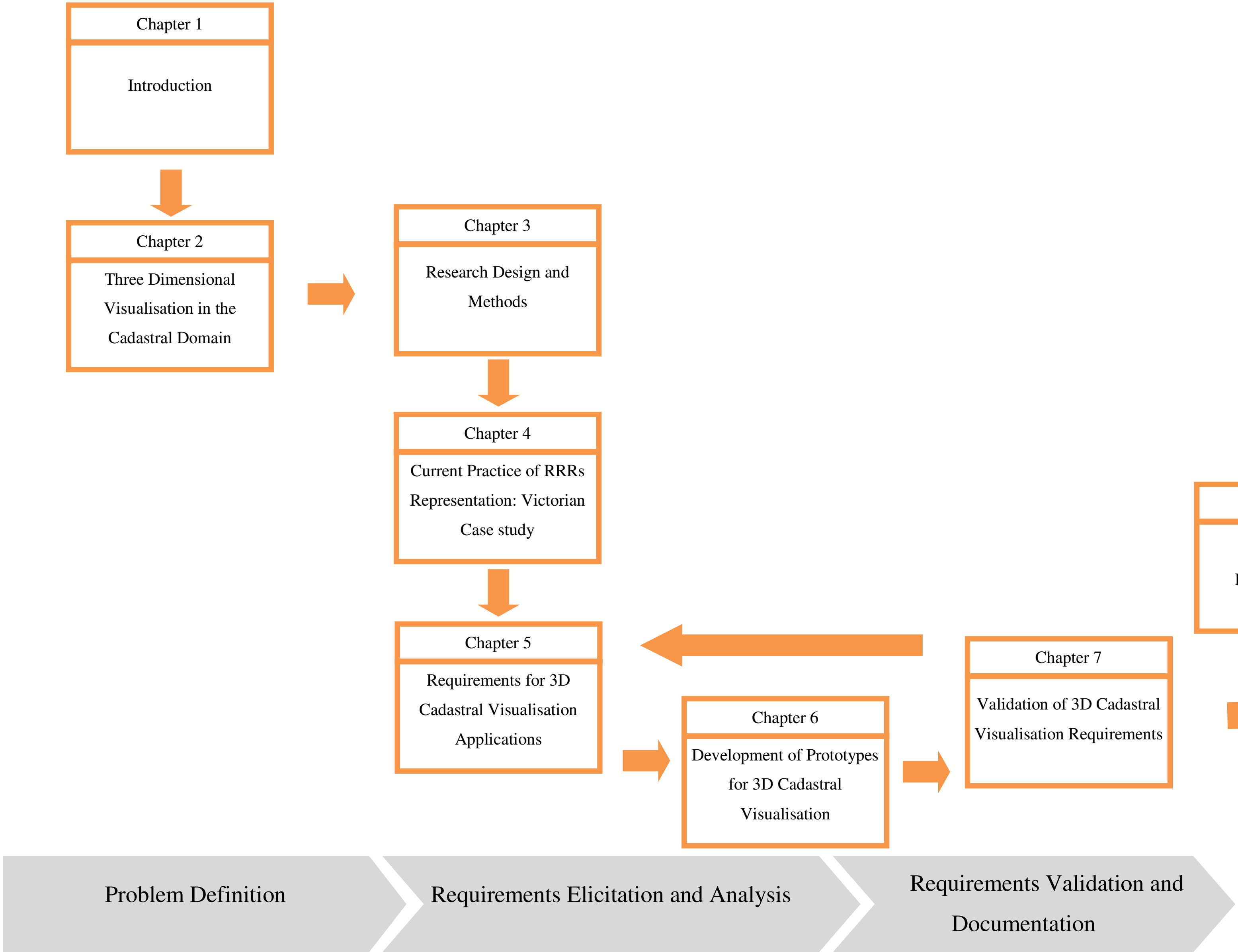


Figure 1.2: Thesis structure based on the requirements engineering method.

1.7 Chapter Summary

This chapter has laid the foundations for the research and introduced the problem, question, aim and objectives of the research. As a problem statement, some of the issues and challenges in representing RRRs were discussed. The chapter also explained several drivers which encourage authorities to move from the current representation approach to a 3D one.

To respond to the problem statement and research questions, four research objectives were considered. Based on these objectives, the next chapter provides a background to 3D visualisation in the cadastral domain.

CHAPTER 2

THREE DIMENSIONAL VISUALISATION IN THE CADASTRAL DOMAIN

"If I can't picture it, I can't understand it."
–ALBERT EINSTEIN

2 Three-Dimensional Visualisation in the Cadastral Domain

2.1 Introduction

This chapter discusses the current needs and challenges to the effective visualisation of cadastres through a review of recent research activities in this field. For the benefit of this research, firstly uniform definitions of cadastre and visualisation are provided, 3D cadastre is then introduced and reasons for moving to a 3D cadastre are explained. After presenting recent activities in 3D cadastre, cadastral users and visualisation requirements are discussed. Finally, various issues in 3D cadastral visualisation are investigated.

Various definitions have been presented for cadastre, but the most common is from the International Federation of Surveyors (FIG) which has an international perspective (FIG, 1995, Page 1):

"*A Cadastre is normally a parcel based, and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities [RRRs]). It usually includes a geometric description of land parcels linked to other records describing the nature of the interests, the ownership or control of those interests, and often the value of the parcel and its improvements [figure 2.1]. It may be established for fiscal purposes (e.g. valuation and equitable taxation), legal purposes (conveyancing), to assist in the management of land and land use (e.g. for planning and other administrative purposes), and enables sustainable development and environmental protection.*"

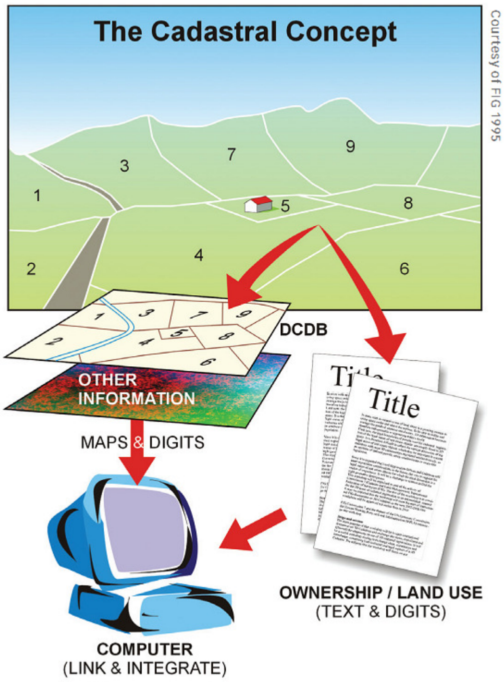


Figure 2.1: The cadastral concept (FIG, 1995).

Several definitions of visualisation have been suggested (MacEachren *et al*., 1992, Card and Mackinlay, 1997, Gershon *et al*., 1998, MacEachren and Kraak, 2001, Friendly, 2009). This thesis adopts the widely accepted definition by Card *et al.* (1999, Page 6):

"*Visualization: The use of computer-supported, interactive, visual representations of data to amplify cognition*".

In the next sections, the challenges of current cadastral representations are discussed further.

2.2 Three-Dimensional Cadastre

Before starting research activities in 3D cadastral visualisation, a clear definition of 3D cadastre is very important. Various definitions for 3D cadastre have been proposed by (Stoter, 2004, Papaefthymiou *et al*., 2004, Jarroush and Even-Tzur, 2004, Dimopoulou *et al*., 2006, van Oosterom, 2013). In this research, the following definition is considered as a reference (Aien, 2013, Page 66):

"3D cadastre is a tool in a land administration system to digitally manage and represent stratified rights, restrictions, and responsibilities (legal objects) and their corresponding physical objects such as buildings, utilities, on, above or under the ground surface in 3D. A

3D cadastre has the capability to capture, store, edit, query, analyse and visualise multi-complex properties."

It is worth noting that the definition of a 3D cadastre is dependent on the legal and organisational context in each jurisdiction (Fendel, 2001, Thompson and van Oosterom, 2011, van Oosterom, 2013).

In addition to the above definition of 3D cadastre, in this research, 3D property (3D property right) is defined as "*real property that is legally delimited both vertically and horizontally"* (Paasch and Paulsson, 2011, Paulsson, 2011). This definition allows for the inclusion of various types of 3D property in different legal systems (Paulsson and Paasch, 2011).

By considering these definitions, moving from a 2D to a 3D cadastre is an important topic that has attracted a lot of attention over the last decade (Grinstein, 2001, Stoter and Salzmann, 2001, Stoter, 2002, Benhamu and Doytsher, 2003, Aydın *et al*., 2004, van Oosterom *et al*., 2005, Dimopoulou *et al*., 2006, Paulsson, 2007, Kalantari *et al*., 2008, Peres and Benhamu, 2009, van Oosterom *et al*., 2011, Aien *et al*., 2012, Jazayeri *et al*., 2014).

Although there have been obvious advances in this domain, jurisdictions considering implementing 3D cadastres are still confronted by multiple challenges and issues. Despite the recent research activities and progress, *"no country in the world has a true 3D cadastre, the functionality is always limited in some manner; e.g. only registering of volumetric parcels in the public registers, but not included in a 3D cadastral map, or limited to a specific type of object with ad hoc semi-3D solutions; e.g. for buildings or infrastructure"* (van Oosterom *et al*., 2011, Page 2).

In developing 3D cadastres, various challenges exist which can be divided into technical, institutional and legal challenges.

On the technical side, still there are some issues regarding 3D data acquisition and sourcing (Jazayeri *et al*., 2014), appropriate 3D geometries (Stoter and van Oosterom, 2005, Karki *et al*., 2013a), 3D data storing and managing in spatial databases (Wammes, 2011), validation rules for examining 3D geometrical objects (Karki *et al*., 2013a), and fully support 3D cadastral visualisation applications (Peres and Benhamu, 2009, Guo *et al*., 2013, Shojaei *et al*., 2013). On the legal side, some countries (e.g. Poland and Nepal) still have limitations for registering 3D property rights (van Oosterom *et al*., 2011). Finally, from the institutional aspect, implementing a 3D cadastre requires a big change in current processes which challenges organisations (Karki *et al.*, 2013a) and sometimes involved parties are reluctant to change (Ho *et al.*, 2013). According to Stoter (2004), the basic needs of a 3D cadastre are:

- Complete registration of 3D rights (explicitly registering the 3D space to which these rights apply); and
- Good accessibility to the legal status of 3D property.

Due to the importance of 3D visualisation in this research, the next section will explore this component of 3D cadastre and related work.

2.3 Why Move to 3D Cadastral Visualisation?

Existing cadastral systems have been developed based on a 2D mapping system, however, in the real world, the actual ownership rights are more than a two-dimensional parcel as they can extend above and below the earth surface. These ownership rights are defined by space columns above or below the surface parcel (Döner *et al.*, 2010). In urban areas, these ownership rights may exist on top of each other, or extend beyond the surface land parcels. In these situations, where there are many overlapping properties, simply considering 2D polygons for defining ownership rights in 3D space is not sufficient.

Overlapped ownership rights are not a new concept and have been accommodated for many years using extended forms of 2D representation. Each jurisdiction has its own method to spatially represent overlapped land and property ownership (Pouliot *et al.*, 2011).

The main existing approaches to representing overlapped ownership rights are mainly classified into the following categories[2] (Karki *et al.*, 2013a, Karki, 2013):

- Building Format Plans (BFPs): ownership rights are defined by the structural elements (walls, floors, etc.) of buildings in survey plans. These plans show diagrams of apartment units (using cross-section diagrams and floor plans). In some jurisdictions, there are no official measurements for building elements (e.g. Victoria, Australia and France). This is the most popular way to represent overlapped ownership rights (see figure 2.2 a); and
- Volumetric Format Plans (VFPs): In this approach, ownership rights are defined geometrically by volumetric objects (isometric). The volumes do not

[2] Pouliot (2011) has addressed some other types of representing 3D property rights.

refer to any physical structure, and indeed there may be no structure present (see figure 2.2 b). This is a less common form of definition of ownership rights in the world.

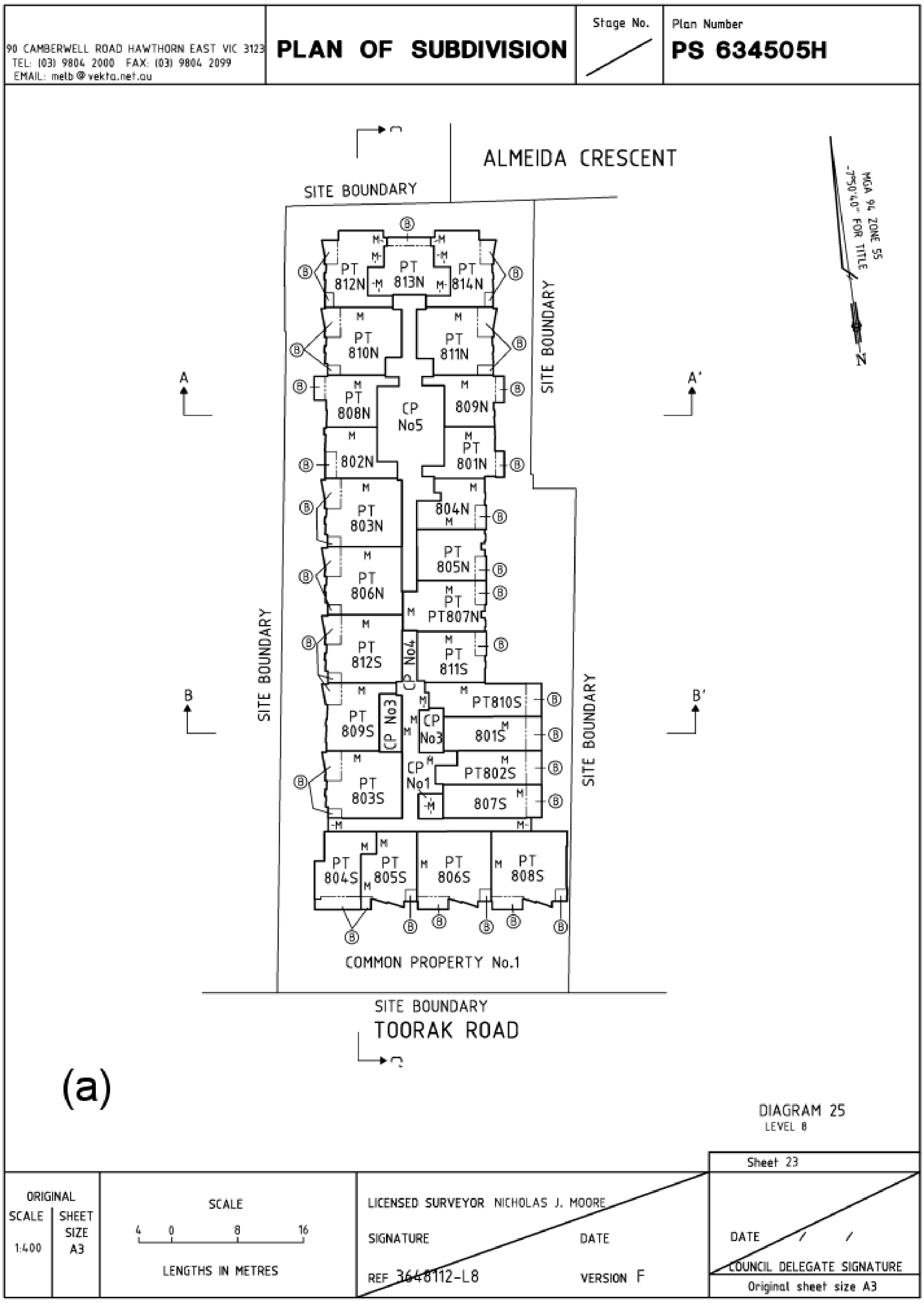


Figure 2.2: (a) Building Format Plan, Victoria, Australia (Land-Victoria, 2011)[3].

[3] ©State of Victoria, 2009. Materials supplied by the State of Victoria under the Creative Commons Attribution – Noncommercial 2.5 Australia Licence. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc/2.5/au/.

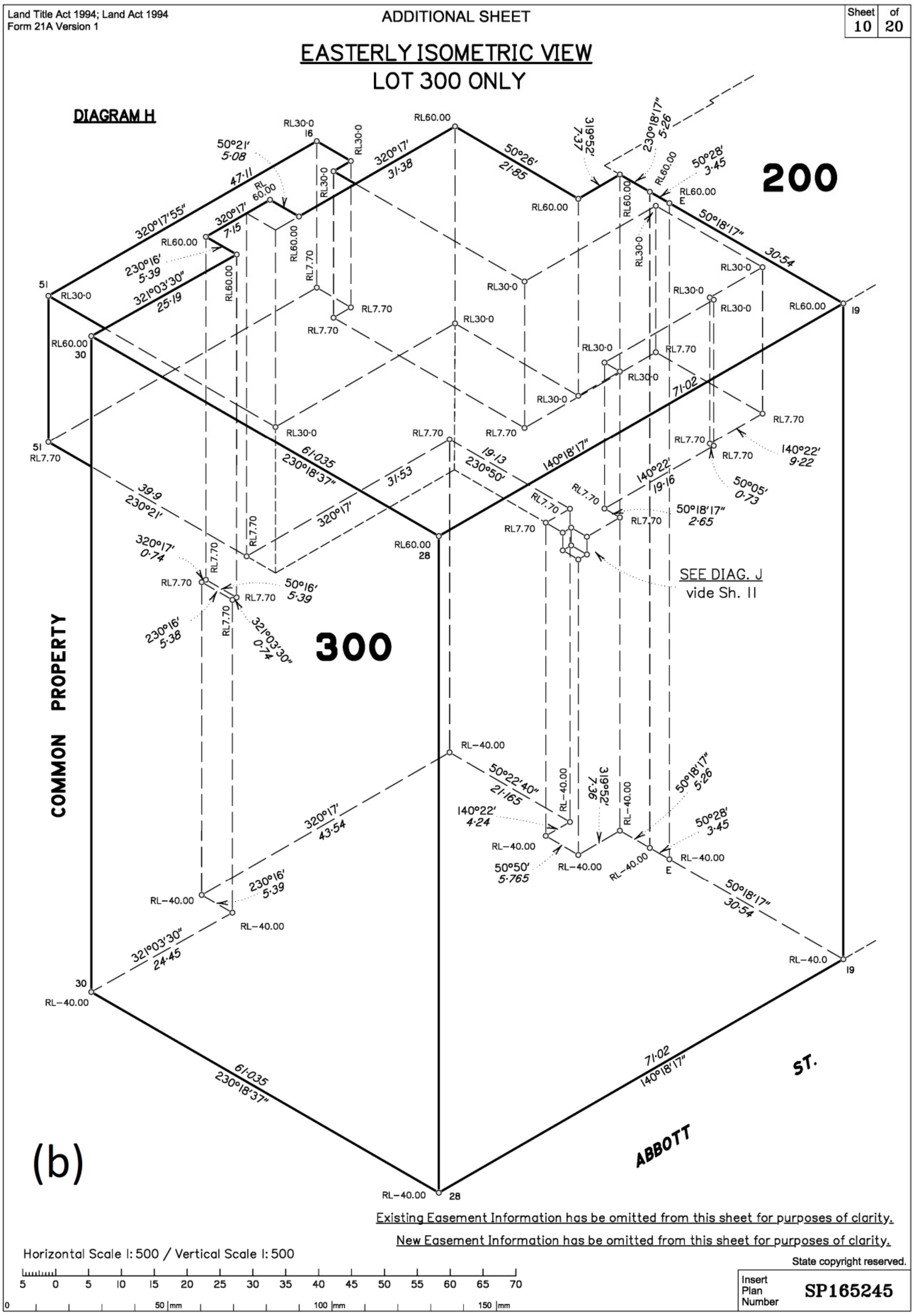


Figure 2.2: (b) Volumetric Format Plan (Isometric diagram), Queensland, Australia[4].

Using these methods (BFP and VFP), ownership rights are registered by land registry organisations.

[4] http://www.digitalamigo.com.au/WEB%20SITE/PDFs/Volumetric%20Example%20Sh10.pdf

Researchers in the field have identified a wide range of overlapping issues associated with cadastral representation, especially in complex subdivisions. These include:

- Current methods of representation may be cognitively taxing to understand the cadastral situation (Stoter *et al*., 2012b);
- Understanding the plans requires a high level of expertise and usually only expert users can understand them;
- Due to the complexity of multi-level developments, numerous plans and sections are required for interpretation (Jarroush and Even-Tzur, 2004, Aien *et al*., 2011, Khoo, 2011);
- Interpreting complex subdivision plans is time-consuming because of the number of pages;
- This method of representation lacks interactivity (Stoter *et al*., 2004, Döner *et al*., 2010). It is not possible to rotate paper plans in different axes, or zoom to a specific component. As ownership boundaries are drawn on paper (PDF), the ownership boundaries cannot be interactively viewed. This is very important as it facilitates the interpretation of complex parcels correctly (e.g. figure 2.2 b) (Stoter and van Oosterom, 2005);
- In case of building subdivisions, each floor is presented individually and there is not an integrated representation to visualise the interactions of all ownership rights;
- In subdivision plans, only one building is described and there is no integration with neighbouring parcels (Stoter *et al*., 2004). Therefore, it is not possible to check them for spatial validity and logical consistency (e.g. overlap, intersect) (Stoter and van Oosterom, 2005);
- Individual apartments (as main objects in cadastres) are not represented in the Digital Cadastre Database (DCDB); only the whole parcel of apartments (Döner *et al*., 2010);
- Vertical information is not represented in all subdivision plans in some jurisdictions (e.g. Nepal) (Acharya, 2011);
- Most plans represent only the legal objects (e.g. lots, easements, and common property areas) and do not visualise building structures (e.g. doors, walls, windows, and slabs) (Fendel, 2001, Acharya, 2011). As there is no visual link

to the real world, this makes it difficult for the public to understand the ownership boundaries (Shojaei *et al.*, 2013);

  - Various types of RRRs are not geometrically represented in subdivision plans. For example, height and depth limitations are not represented spatially in subdivision plans in Victoria and in these cases notations are written on the plans;
  - Queries, analyses, searching and measurements (Acharya, 2011) are not (efficiently) possible. As subdivision plans are not recorded digitally, queries and analyses (e.g. validating of 3D volumes to check if they are closed and there are no gaps, crossing edges and faces) are not possible (Stoter and van Oosterom, 2005, van Oosterom *et al.*, 2005);
  - Subdivision plans are presented and maintained in papers and PDF files, therefore, modifications and storage are not efficient (Shojaei *et al.*, 2013).

- The current plan preparation and plan examination process is inefficient and labour-intensive (DSE, 2010a);
  - Subdivision plans are prone to various types of errors including geometric, content and associated human error (DSE, 2010a). Maintenance is error prone too. The maintenance of RRRs at the time of new subdivisions, particularly in case of existing underground infrastructures, is not simple; and
  - There is a lack of prospective skilled human resources for examination of registering ownership rights (DSE, 2010a).

Due to these limitations, efficient management of ownership rights, restrictions and responsibilities is difficult with 2D cadastres in current land administration systems which are equipped with only 2D approaches (paper-based or PDF) for representing cadastral data (Aien *et al.*, 2011).

In addition to these shortcomings, many other researchers have identified interlinked drivers and advantages in moving from the current 2D presentation approach to efficient 3D digital cadastral visualisation applications. These include:

  - The technologies and approaches to acquire, process and visualise 3D data are mature enough for cadastral applications (Ross, 2010, Khoo, 2012);

  - Increasing value of property increases the importance of managing land and property more efficiently (Stoter and van Oosterom, 2005, Döner *et al.*, 2010, Elizarova *et al.*, 2012);
  - Due to increasing the complexity of urban areas, efficient visualisation applications are essential (Döner *et al.*, 2010, Khoo, 2012);
  - As a result of population growth in urban areas, the numbers of overlapped properties are increased (Döner *et al.*, 2010);
  - More above and underground infrastructures such as tunnels, cables and pipelines (water, electricity, sewage, telephone, gas, glass-fibre data cables, TV cables), underground parking places, shopping malls, buildings above roads/railways and other cases of multilevel buildings have been developed in the last 40 years (Stoter and van Oosterom, 2005, Döner *et al.*, 2010);
- There is a need for registering ownership rights efficiently to facilitate management of ownership rights, particularly in complex buildings (Vandysheva *et al.*, 2012);
  - As the public demand more access to information about their environment, they require effective means of communication that do not require specialised training (Pietsch, 2000, Shojaei *et al.*, 2013);
  - 3D visualisations are widely used in various applications such as architecture, urban planning, building development, and disaster management (Czerwinski *et al.*, 2006, Stoter *et al.*, 2008, Schulte and Coors, 2008, Métral *et al.*, 2008, Walenciak *et al.*, 2009, Pontiggia *et al.*, 2010). Professionals are looking for compatible visualisation applications for managing ownership rights in 3D (Shojaei *et al.*, 2013);
  - The availability of 3D data is increasing (Ross, 2010, Streilein, 2011);
  - The importance of natural resources is increasing. Land and property, as important resources, requires modern management approaches for their sustainable use, especially in populated urban areas (Shojaei *et al.*, 2013);
  - In the long term, 3D cadastres could provide the main data required for 3D city models (Stoter and Salzmann, 2003) and data can be utilised in various applications (Fendel, 2001) such as urban planning (Fendel, 2001), and disaster management (Kolbe *et al.*, 2005);
  - 3D visualisation creates a strong visual impression to draw and keep the attention of an audience (Pouliot, 2011);

- 3D visualisation improves communication and facilitates dialogue (Ross, 2010, Pouliot, 2011, Dimopoulou and Elia, 2012, Abdul Rahman *et al*., 2012);
- A 3D cadastral visualisation would improve the management process by supporting the management of ownership rights (Griffith-Charles and Sutherland, 2013);
- 3D representation of cadastre would enhance the understanding of the situation (Pouliot *et al*., 2010, Abdul Rahman *et al*., 2011);
- 3D visualisations increase the functionality of a cadastre and improve efficiency in managing land related matters (Stoter and van Oosterom, 2006, Abdul Rahman *et al*., 2012, Dimopoulou and Elia, 2012);
- Growing 3D visualisation technologies (Fendel, 2001, Aditya *et al*., 2011) in many disciplines providing realistic representations of the world with real-time navigation (Abdul Rahman *et al*., 2012, Shojaei *et al*., 2012);
- 3D representation for cadastres would improve management of RRRs by facilitating understanding the space arrangement of rights (Papaefthymiou *et al*., 2004, Benhamu, 2006, Pouliot *et al*., 2010);
- 3D visualisation better simulates the reality than does 2D presentation (Van Driel, 1989);
- 3D visualisation provides better systems for analysing and examining of data which has been presented using only 2D methods (Smith and Paradis, 1989);
- 3D representations facilitate registration of underground rights, restrictions and responsibilities (Vandysheva *et al*., 2012, Abdul Rahman *et al*., 2012);
- 3D cadastre using efficient 3D visualisation contributes to sustainable, uniform and efficient land administration systems (Pouliot, 2011, Dimovski *et al*., 2011);
- The quality of social, political and economic life is enhanced by improving the quality of decision-making using 3D visualisation in cadastre (Fendel, 2001);
- Instead of storing hard copy (or PDF files) in title, 3D representation of each property is provided using a cadastral application (Chai, 2006);
- *"The ability to display 3D characteristics of properties will facilitate a better definition of the judicial situation of the properties within the spatial reality"* (Benhamu and Doytsher, 2003, Page 364); and

- *"The three dimensional presentation will provide better means for inspection and analysis of data, than the existing 2D one"* (Shoshani *et al.*, 2004, Page 8).

According to these drivers, the advantages of utilising 3D visualisation technologies in future cadastre are very significant. The characteristics of future cadastres have been addressed by many researchers (Kaufmann and Steudler, 1998, Stoter, 2000, Ting and Williamson, 2000, Benhamu and Doytsher, 2003). Future cadastres must be able to manage growing complexities of RRRs because of environmental, social and economic imperatives (Ting and Williamson, 2000). The future cadastres will be analytical, and three-dimensional (Bennett *et al.*, 2010), and like 2D cadastre will be concerned with people, land and law (Benhamu, 2006). The full 3D cadastre offers various improvements over traditional cadastre (Stoter and van Oosterom, 2005). This requires the development of appropriate applications for managing land and property information efficiently (Griffith-Charles and Sutherland, 2013, Guo *et al.*, 2013) to achieve sustainable development objectives.

To understand the current status of progression of 3D visualisation in cadastres, the next sections will explore related work in 3D cadastral visualisation.

2.4 Three-Dimensional Cadastral Visualisation Literature

The first workshop in 3D cadastre was organised by FIG in 2001 at Delft University of Technology, the Netherlands (sponsored by FIG joint commission 3 and 7 Working Group). In this workshop, visualisation issues were identified as an important outcome (Fendel, 2001) and further investigation in this domain was considered essential. According to the literature, 3D cadastral representation research can be classified into two main groups.

The first group investigates 3D geometric representation (Benhamu and Doytsher, 2003, Guo *et al.*, 2013) and various methods were proposed such as simple extrusion (Pouliot *et al.*, 2010), constructive solid geometry (CSG) (Jarroush and Even-Tzur, 2004), boundary representation (B-Rep) (Karki *et al.*, 2010), polyhedrons (Arens *et al.*, 2005, Stoter, 2004), and regular polytopes (Thompson, 2007). These methods focus on 3D geometry construction, 3D topology and spatial representation of 3D property, which are beyond the scope of this thesis. The second group investigates how to represent 3D property using visualisation applications. Several prototypes were developed. Table 2.1 summarises the main research activities in 3D cadastral visualisation prototype development since 2001[5]. These range from simple models extruded from parcels of an area, actually 2.5D, to accurately defined true 3D models closely reflecting the as-built reality (Jarroush and Even-Tzur, 2004, Griffith-Charles and Sutherland, 2013).

In table 2.1, various aspects including data type, platform, visualisation application, and functionality of the prototype were considered in order to categorise them. In this table, data type refers to the genesis or format of data visualised in the prototype. Data may come from CAD (e.g. dwg or dgn files), GIS[6] (e.g. Shapefiles, Geodatabases), web-based formats such as VRML, X3D, KML, or other types.

The third column on table 2.1 compares prototypes based on the type of platform (desktop, web and mobile-based). The fourth column lists the names of visualisation applications utilised in the prototypes. Column five looks at the environment of the developed prototype, whether virtual reality or augmented reality. Column six reports the maximum level of detail (LoD) represented in the prototype following the options identified in CityGML (Kolbe *et al.*, 2005). The next column looks at what types of functionality the prototype supports. Column eight looks at whether the developed prototype is based on a requirement identification process or not, and the final column reports whether the prototype was evaluated by users.

[5] Although this is an attempt at an exhaustive list, it is possible that some relevant papers were not included. Also, some of the papers repeated their work and published again.

[6] Geographic Information Systems

Table 2.1: 3D cadastral visualisation research activities.

Researchers	Data Type	Platform (Desktop, Web, Mobile)	Visualisation Application	Environment	LoD	Functionality	Requirements Identification	Assessment & Evaluation by Users
(Jamil *et al.*, 2013)	GIS	Desktop (web access)	ArcGIS Explorer/ ArcGlobe	VR	LoD 2/3/4	Visualisation	No	No
(Ammar and Neeraj, 2013)	GIS	Desktop	ArcScene	VR	LoD 3	Visualisation	Yes	No
(Zulkifli *et al.*, 2013)	CAD	Desktop	Bentley MicroStation	VR	LoD 2	Editing	No	No
(Budisusanto *et al.*, 2013)	GIS	Desktop	GLScene	VR	LoD 3	Visualisation	Yes (not specified)	Yes
(Guo *et al.*, 2013)	GIS	Web	SkylineGlobe	VR	LoD 2	Visualisation	No	No
(Shojaei *et al.*, 2013)	GIS	Desktop	ArcGlobe	VR	LoD 2	Visualisation	Yes	Yes
(Vandysheva *et al.*, 2012)	X3D	Web	BS Contact	VR	LoD 3	Visualisation	No	No
(Elizarova *et al.*, 2012)	X3D	Web	BS Contact	VR	Lod 3	Visualisation	Yes	Yes
(Chiang, 2012)	CityGML	Web	Java 3D, SkylineGlobe	VR	LoD 3	Visualisation	No	No
(Ying *et al.*, 2012)	GIS	Web	SkylineGlobe	VR	LoD 2	Visualisation	No	No
(Shojaei *et al.*, 2012)	LandXML	Web	Google Earth API	VR	LoD 3	Visualisation	No	No
(Tsiliakou and Dimopoulou, 2011)	GIS	Desktop	ArcScene	VR	LoD 3	Visualisation	No	No
(Hassan and Abdul Rahman, 2011)	GIS	Desktop	ArcScene	VR	LoD 3	Visualisation	No	No
(Stoter *et al.*, 2011)	3D PDF	Desktop	Acrobat Reader	VR	LoD 2	Visualisation	No	No
(Ying *et al.*, 2011)	Not specified	Desktop	SketchUp	VR	LoD 3	Visualisation and generating topology	No	No
(Aditya *et al.*, 2011)	CAD & KML	Web	Google Earth plug-in	VR	LoD 3	Visualisation	No	No
(Olivares García *et al.*, 2011)	KML	Desktop	Google Earth	VR	LoD 3	Visualisation	No	No
(Guo *et al.*, 2011)	GIS	Desktop	SkylineGlobe	VR	LoD 2	Visualisation	No	No
(Spirou-Sioula *et al.*, 2011)	CAD	Desktop	AutoCAD Map 3D	VR	LoD 2	Visualisation	No	No
(Spirou-Sioula *et al.*, 2011)	GIS	Desktop	ArcScene	VR	LoD 3	Visualisation	No	No
(Vandysheva *et al.*, 2011)	X3D	Web	XNavigator	VR	LoD 2	Visualisation	Yes	No
(Dimovski *et al.*, 2011)	GIS	Web	NASA World Wind	VR	LoD 2	Visualisation	No	No
(Abdul Rahman *et al.*, 2011)	CAD	Web	Autodesk Map 3D	VR	LoD 3	Visualisation	No	No
(Lemmen *et al.*, 2010)	VRML	Web	Cortona	VR	LoD 2	Visualisation	No	No
(Aditya *et al.*, 2009)	X3D	Web	Octaga	VR	loD 2	Visualisation	No	No
(Aditya *et al.*, 2009)	KML	Desktop	Google Earth	VR	LoD 2	Visualisation	No	No
(Dimopoulou *et al.*, 2006)	GIS	Desktop	Geomedia	VR	LoD 2	Visualisation	No	No
(van Oosterom *et al.*, 2005)	GIS	Desktop	ArcScene	VR	LoD 3	Visualisation	No	No
(Jarroush and Even-Tzur, 2004)	CAD	Desktop	AutoCAD	VR	LoD 2	Visualisation	No	No
(Stoter *et al.*, 2004)	CAD	Desktop	Bentley MicroStation	VR	LoD 2	Visualisation	No	No
(Stoter and Salzmann, 2003)	CAD	Desktop	Bentley MicroStation	VR	LoD 1	Editing	No	No
(Stoter and Salzmann, 2003)	VRML	Web	VRML plug-in	VR	LoD 1	Visualisation	No	No
(Stoter, 2002)	CAD	Desktop	Bentley MicroStation	VR	LoD 2	Visualisation	No	No
(Grinstein, 2001)	Not specified	Desktop	3D Studio	VR	LoD 2	Visualisation	No	No

Table 2.1 shows that most activities in 3D cadastral development are still at the prototype level and that there are many validation steps before they can become real 3D cadastral visualisation applications (Pouliot, 2011).

Several prototypes were developed to represent 3D ownership rights. Although some of them could help representing ownership rights in 3D, there are still some issues in most of these prototypes. Firstly, users of the prototypes were not clearly identified and their requirements were not comprehensively elicited. Secondly, there are no 3D visualisation applications developed mainly for cadastral purposes, and finally, the developed prototypes were not completely evaluated.

Thus, research on 3D cadastral visualisation needs more investigation (Pouliot, 2011, van Oosterom, 2012, van Oosterom, 2013) and it is quite different from 3D city model visualisations (Wang *et al*., 2012).

The number of reported 3D cadastral prototypes increased significantly in 2011 and thereafter (see Column 1, table 2.1 and also figure 2.3).

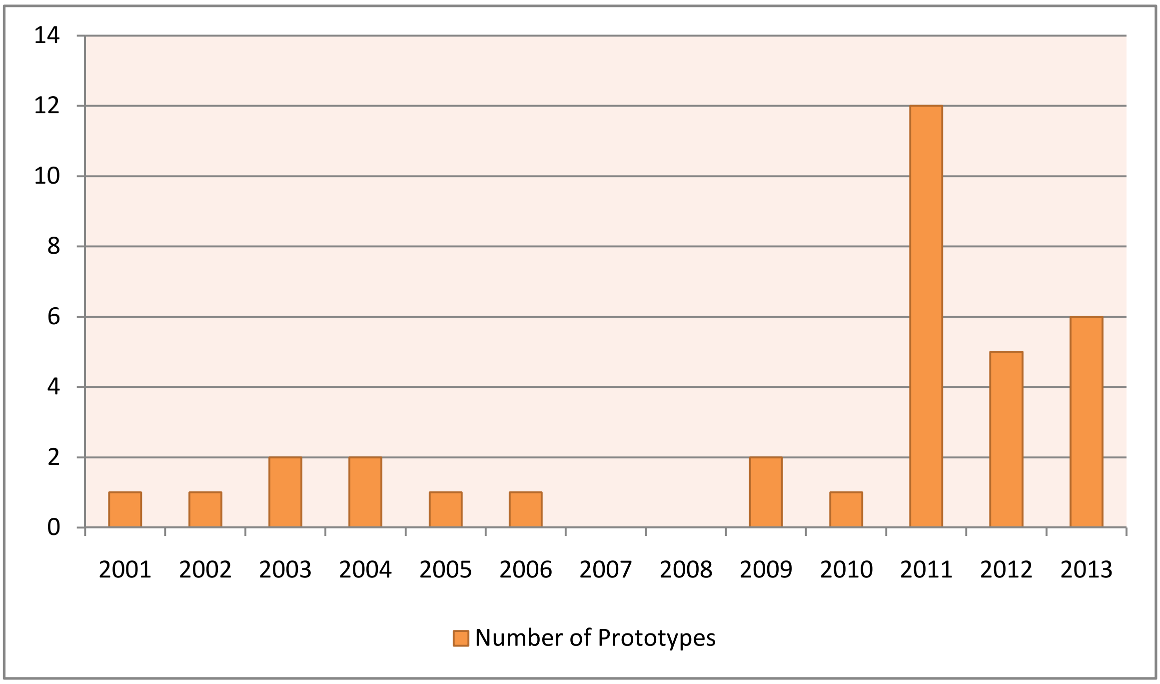


Figure 2.3: The trend of the number of prototypes developed since 2001 in published papers.

Table 2.1 illustrates the types of data that shifted, over the period of interest, from mainly CAD formats to mainly GIS formats. GIS products now support 3D visualisation and so are more adaptable to applications like 3D cadastre. Also, there is a growing interest after 2009 in developing web-based applications. However, still there are no applications developed for mobile platforms and also no prototypes in augmented reality. The main reason may be that mobile platforms still need more computing power to represent massive cadastral data in 3D.

As shown in table 2.1, of 34 developed prototypes, five were developed based on surveys of user requirements and only three were explicitly evaluated by users. Due to the importance of requirement identification and evaluation, these prototypes are described further.

Ammar and Neeraj (2013) listed the system requirements for developing a 3D cadastral prototype. The system requirements were divided into main requirements, constraints and minor requirements. The only visualisation requirement was listed as representing unit apartments in high rises across the country. Other requirements, such as the ability to search and identify cadastral objects and to attach ownership information to them, were also mentioned. However, the identified requirements were quite limited and nor was the prototype evaluated by users. Figure 2.4 shows a snapshot of the developed prototype.

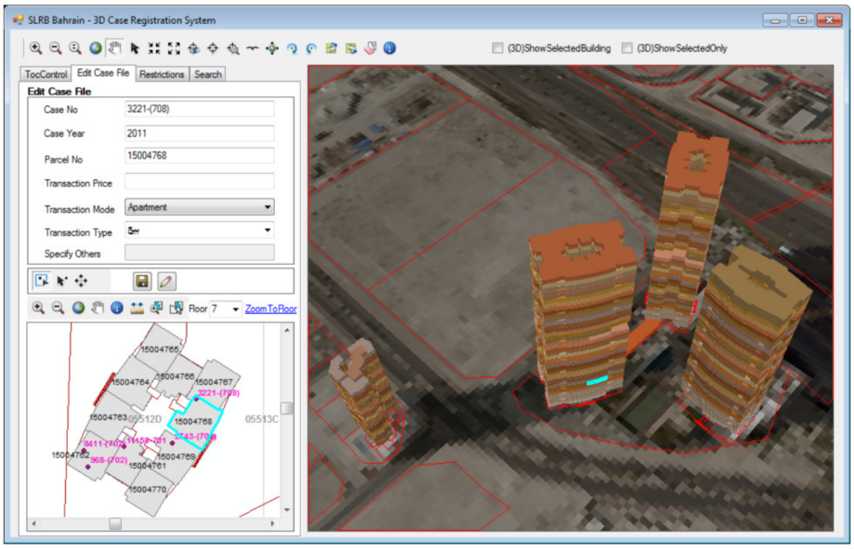


Figure 2.4: SLRB Bahrain - 3D property registration prototype (Ammar and Neeraj, 2013).

Budisusanto *et al.* (2013) developed a prototype for 3D cadastres designed for the following purposes:

- deed/certificate checking (exploring survey and attributes data);
- ownership right processing (registration and transfer); and
- ownership right transfer.

This interface of the prototype provides different functions for users based on their assigned tasks and guest users can use the application with limited capabilities. However, there is no clear information regarding the visualisation requirements and why they chose GLScene as a visualisation library. The authors evaluated the usability of the prototype using four participants from a land registry, a building management company and a university; and through a structured interview after using the prototype. However, there is no justification regarding the number of participants, the background of users and their experience. Figure 2.5 displays the interface of the prototype.

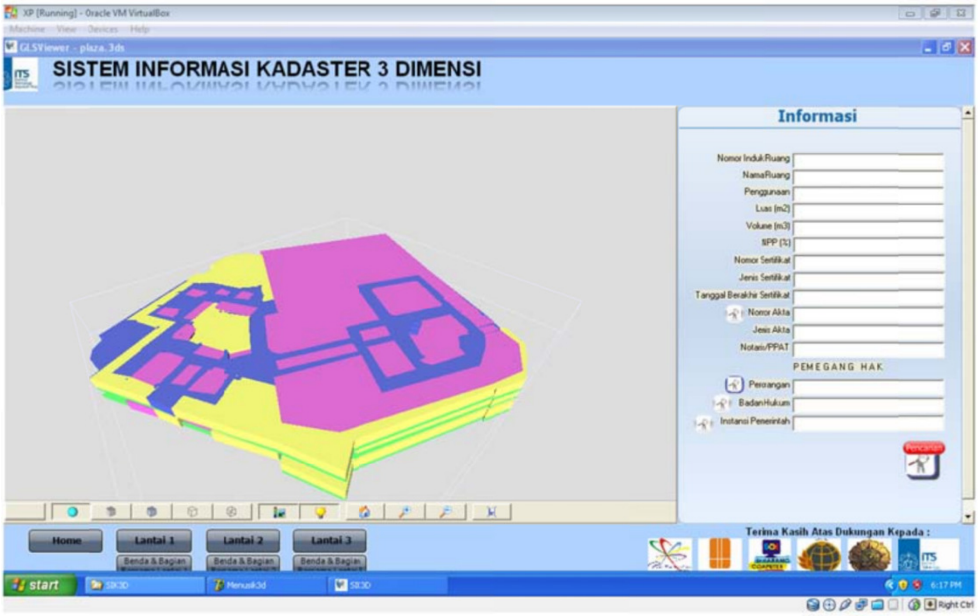


Figure 2.5: The interface of the developed prototype. (Budisusanto et al., 2013).

As part of the research reported in this thesis, Shojaei *et al.* (2013) undertook a comprehensive study of the visualisation requirements for developing a 3D cadastral visualisation prototype. They explained the diverse types of users, identified their different visualisation requirements and classified them into three main categories, namely cadastral features, visualisation features and non-functional features. Finally, a prototype was developed based on these requirements. The prototype is able to represent above- and below-ground RRRs with required navigation controls. It also includes various tools to identify, measure, and search RRRs. Then, it was evaluated through a case study. In order to evaluate the prototype, 20 participants were chosen, the prototype was demonstrated and their feedback was documented. Figure 2.6 presents a snapshot of various parts of the prototype. This prototype was superseded by another, as reported later in this thesis.

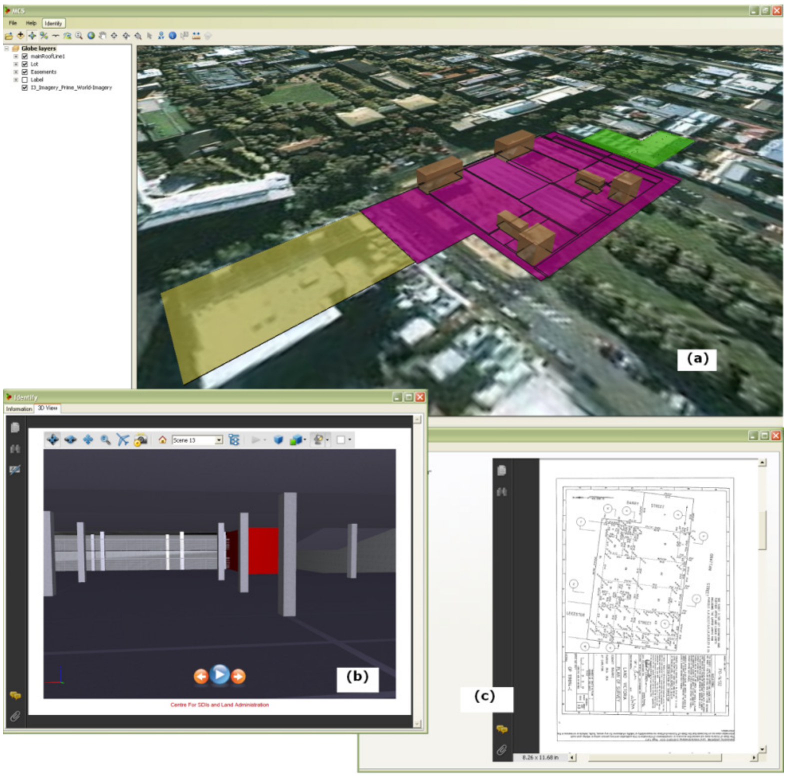


Figure 2.6: (a) A snapshot of the prototype; (b) 3D PDF of the car park; and (c) the survey plan of the car park (Shojaei *et al*., 2013).

Elizarova *et al*. (2012) developed a prototype for representing 3D property of multilevel complex buildings and subsurface networks using the BS Contact plug-in[7]. They report that the prototype was developed to gather the functionality requirements for 3D cadastre. Some of the visualisation features, such as rotation, zooming, switching objects on and off, and identifying objects were addressed in the paper. Finally, the prototype was evaluated by cadastral experts using a structured questionnaire. According to the results and received feedback, having better contact with users/clients may result in more tests in an operational situation, leading to an optimal application. Figure 2.7 illustrates a snapshot of the prototype.

[7] http://www.bitmanagement.com/products/interactive-3d-clients/bs-contact

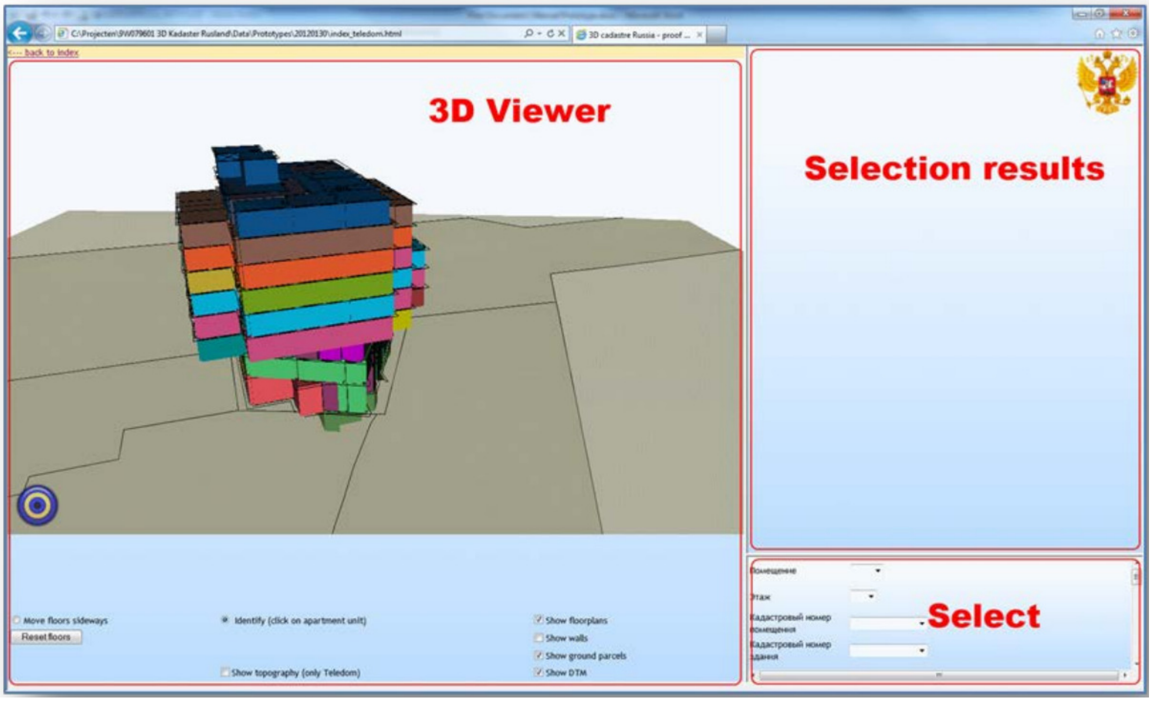


Figure 2.7: The user-interface of the prototype using BS Contact plug-in (Elizarova et al., 2012).

By analysing these activities in 3D cadastral visualisation, some issues and problems become apparent which are summarised below:

- Most of the developed prototypes have not been based on user requirements;
- 3D cadastral visualisation requirements have not been completely identified (in Shojaei *et al*. (2013) authors identified the main requirements);
- Cadastral users were not clearly identified;
- Use cases of 3D cadastral prototypes have not been fully explained;
- Although there are many 3D visualisation applications, there are no 3D visualisation applications which fully supports 3D cadastral user requirements; and
- Despite several prototypes being developed, only some of them were evaluated by users. Also, the evaluation was not comprehensive or clearly explained.

These identified issues in 3D cadastral visualisation are significant gaps in the literature and further research in this domain is necessary.

In addition, cadastral data includes both legal and physical data (Aien *et al*., 2012, Ying *et al*., 2012) and visualisation of these different types of entity introduces special needs. There are significant differences between representing physical and legal objects:

- Physical objects (entities) include walls, roofs, ceilings, doors, windows, etc. and are visible;
- Legal objects are conceptual and cannot be seen;
- In some cases, a physical object can be a representative for a legal object. For example, a wall is a physical object but may also represent the edge of a property. In this case, the physical and legal entities are coincident and the same data may represent both. However, in some cases, legal objects associated with physical objects may not have the same geometry (Doner *et al*., 2008). For example, an underground pipeline may have a 5-metre buffer as a right to prevent serious damages. In these cases, the legal space is registered and not the pipeline;
- There are various types of legal objects which are not simple to represent, such as unbounded 3D property rights (Thompson and van Oosterom, 2011); and
- Legal objects may have a fuzzy boundary (e.g. 3D property rights with a shared edge with ocean or rivers).

In order to tackle these problems, some related topics are introduced in the following sections. Firstly, cadastral users need to be identified.

2.5 Cadastral Users

The first step towards developing 3D cadastral visualisation requirements is to identify cadastral users and understand their usage.

Cadastral users may be professionals or other citizens. Professionals include land registry organisations, real estate agents, financial institutions, referral authorities, utility companies, councils, and land surveyors. Citizens include the public as owners and users (van Oosterom *et al*., 2011).

Khoo (2012) identified various users and stakeholders of cadastral data in Singapore (figure 2.8). Similar users exist in other countries.

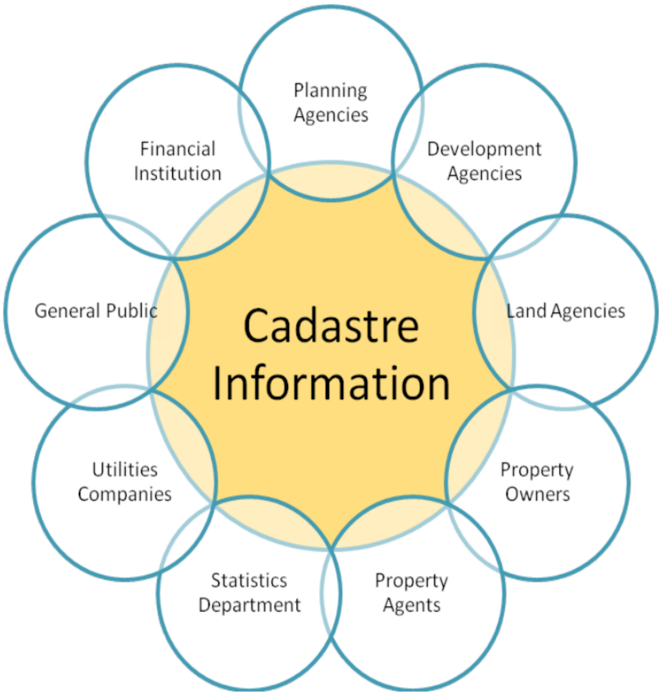


Figure 2.8: Various users and stakeholders of cadastral data in Singapore (Khoo, 2012).

Cadastral users can be categorised into direct and indirect users (table 2.2). Direct users contribute directly to the land administration processes, while indirect users benefit from cadastral data. Differentiating between direct and indirect users depends on the land administration processes of each jurisdiction.

Table 2.2: Typical cadastral users.

Cadastral Users	
Direct Users	**Indirect Users**
Notaries	Financial institutions
Land Registry	Utility Companies
Real Estate Agents	Lawyers
Referral Authorities	
Planning Agencies (Councils, Planners)	
Land Surveyors	
Architects	
Development Companies	
The Public (owners and users)	
Owners' Corporations	

3D cadastral data would help various types of users with their businesses. 3D cadastre can provide users with accurate data along with the required attributes to facilitate processes. For instance, 3D cadastre can provide tax-related data (e.g. area, land use, occupation, value, rent) to help the taxation process. Also, lawyers claimed that 3D cadastre would minimise disputes and risk of misinterpretations (Griffith-Charles and Sutherland, 2013). 3D cadastre would assist planning agencies by providing required up-to-date information to represent the current status of the area as part of the planning process for further developments.

Ross (2010) identified four main functions of virtual cities in urban planning and management:

- Presentation and exploration;
- Analysis and simulation;
- e-collaboration; and
- Infrastructure and facility management.

From this study, the literature and the current status of cadastres, these functions are also expected to be applicable to a 3D cadastre. A 3D cadastre functions as a tool for presenting 3D property rights for registration purposes, for analyses and simulation for property management. It could also be used as a supporting communication tool for land administration. In addition, by integrating data of referral authorities, 3D cadastre can support infrastructure management (e.g. pipes, cables, and tunnels). Table 2.3 further explores these primary functions and their associated purposes, with examples, data requirements and user groups.

Table 2.3: Main functions and associated proposes, examples, data requirements and user groups in 3D cadastral visualisation.

	Presentation & Exploration	**Analysis & Simulation**	**e-Collaboration**	**Infrastructure & Facility Management**
Purposes	Providing visual access to 3D property rights to raise awareness and support decision making.	Processing 3D cadastral data	Supporting collaboration among stakeholders via ICT	Supporting maintenance and renewal of infrastructures
Examples	-Visualising RRRs such as lots, easements and common property areas associated with an apartment -Presentation of analysis results	-3D clash detection for registration of 3D property rights -3D noise emission -Flood modeling and simulation -Indoor navigation and evacuation -Visibility analysis	-Organising e-participation and e-consultation -Emergency response -e-submission of 3D cadastral data	-Creation of maintenance reports -Risk mitigation -Planning for new infrastructures
Main data requirements	-3D legal data -3D physical data -Administrative information (official measurements (bearing & distances)	-Very diverse data from purely legal and physical data to noise pollution (depends to analyses and applications)	-3D legal data -3D physical data -Administrative information (official measurements (bearing & distances)	-3D legal data -3D physical data -Administrative information (official measurements (bearing & distances) -Specific information related to maintenance of infrastructures
Main system requirements	-3D visualisation functions -Editing functions -Navigation functions -Searching and querying functions	-3D visualisation functions -Editing functions -Navigation functions -Searching and querying functions -Analysis functions	-3D visualisation functions -Editing functions -Navigation functions -Searching and querying functions -Publishing functions	-3D visualisation functions -Editing functions -Navigation functions -Searching and querying functions -Analysis functions
Main users	-Land registry -Land surveyors -Councils -The public -Developers -Architects	-Land registry -Land surveyors -Councils -Developers -Architects	-Land registry -Land surveyors -Councils -The public -Developers	-Referral authorities -Land registry -Councils -Developers -Architects

In addition to these primary users and functions, it is expected that after implementing a 3D cadastre, new types of users and usages would emerge due to the high flexibility of 3D cadastral data for various applications. User requirements in the context of 3D cadastre are discussed in the next section.

2.6 3D Cadastral Visualisation Requirements

Identification of user requirements is very important to develop successful computer applications. In the cadastral context, eliciting 3D visualisation requirements helps software developers to implement efficient 3D cadastral visualisation applications to represent RRRs effectively.

In the first 3D Cadastres workshop in 2001, visualisation issues were identified as an important outcome (Fendel, 2001), however at that time, no recommendations were developed for 3D cadastral visualisation (Pouliot, 2011). Now, after more than a decade, there is still no complete set of cadastral visualisation requirements. The importance of developing 3D cadastral visualisation requirements has been highlighted by many researchers (Sørensen, 2011, Stoter *et al.*, 2011, Pouliot, 2011). 3D cadastral visualisation requirements need to be considered across several domains that converge to convey a comprehensive and coherent message to users (Pouliot, 2011).

Requirements can be viewed from different perspectives and each perspective has a different definition. In this thesis two main perspectives are used:

- 3D cadastral user requirements (usages); and
- 3D cadastral visualisation requirements.

The first looks at the expectations and needs for running cadastral businesses. For example, land registries need to view 3D property rights. The second perspective addresses 3D cadastral visualisation application requirements. For instance, a cross-section tool in a cadastral visualisation application would assist understanding of ownership information complexities (Shojaei *et al.*, 2013). In this thesis, the focus is mainly on 3D cadastral visualisation requirements. Some 3D cadastral user requirements were discussed in (Wang *et al.*, 2012, Shojaei *et al.*, 2013) in order to assess 3D cadastral visualisation requirements.

Wang *et al*. (2012) assessed the suitability of some visualisation variables (orientation, size, shape, colour, and texture) to meet 3D cadastral user requirements. These visualisation variables were assessed against the following user requirements:

- Visualising bounded and partially bounded 3D property rights;
- Representing relationships between land parcels and 3D property rights;
- Visualising relationships between physical objects (e.g. walls, doors, windows, and slabs) and associated 3D property rights;
- Representing relationships between 3D property rights; and
- Visualising official measurements.

Shojaei *et al*. (2013) addressed the user requirements of land registries, land surveyors, owners' corporations, city councils, lawyers and conveyancers. The 3D cadastral visualisation requirements were separated into cadastral features, visualisation features and non-functional features. A distinction between different types of features was also made by Vandysheva *et al*. (2011), who divided visualisation requirements into functional and technical requirements.

Within the 3D cadastre requirements of all users there may be some conflicts, as each user group has their own needs based on different expectations, skills, knowledge and backgrounds (Ross, 2010). Therefore, requirements need to be associated with particular users and a comprehensive set of requirements covering all potential users is not feasible.

In other disciplines, researchers have addressed requirements for 3D visualisation in other contexts. Hildebrandt and Döllner (2010) addressed generic requirements for service-oriented 3D visualisation applications such as support for interactivity, multiple views, styling visual representations, and integration. Ross (2010) identified some requirements of 3D city models for urban land management. Lloyd and Dykes (2011) have investigated human-centred approaches following ISO13407 to elicit requirements for geo-visualisation application design in crime management.

Notwithstanding this research, there is no comprehensive list of cadastral visualisation requirements and further elaborations are required for future cadastral visualisation application developments. The next section explores cadastral data and various data formats.

2.7 Data and Data Formats

As previously mentioned, the focus of this research is on geospatial data visualisation and particularly representation of 3D property rights. For a successful visualisation application, a clear understanding of available data types and identification of suitable formats to store the data is very important.

The need for 3D data is growing rapidly in many disciplines such as urban planning, soil engineering, mapping, aviation, transportation, land use planning, and earth science. However, cadastres are not the main driver for 3D data acquisition and management (Streilein, 2011).

Representing both physical and legal objects in a 3D visualisation application would assist users to understand the ownership boundaries in complex situations. In cadastre, the data may be ambiguous, as ownership boundaries could be located at the exterior or interior face, or even in the middle of the wall. Often such ambiguities are resolved by textual description (e.g. "*the interior of the wall*") on the plan of subdivision. By representing physical objects for reference, the location of legal objects would be clearer (van Oosterom *et al*., 2011). Therefore, cadastral applications need to be able to represent both physical and legal data independently to leave no room for ambiguity (Hao *et al*., 2011).

Ambiguity in ownership rights is also clarified by the concept of 3D partition of space, where the space is partitioned into 3D legal objects. For example, the space between two telephone antennas is specified with a 3D partition (right of sight) which should not be intersected with other 3D partitions (buildings) (Lemmen *et al*., 2011).

Data in 3D cadastral visualisation can be divided into two main categories:

- Unofficial data: data which has not yet been registered. In some literature, it is called unauthoritative data. The life cycle of data ends before registration; and
- Official data: data which has been registered (authoritative data). Subdivision plans are examples of authoritative data.

Unofficial data may need to be edited as well as viewed. However, official data is viewed by many users and no change is possible. Therefore, different visualisation applications that can edit and view data are required in these two main categories. Unofficial data can be supported mainly by CAD and BIM[8] software products as these offer powerful tools for creating and editing 3D volume objects. Editing is done only by those involved in design and registration of the property relationships. However, official data has a wider user group. Therefore, simple visualisation applications and particularly the web-based applications are preferred (Aditya *et al*., 2011).

Currently, according to the FIG Working Group survey, no jurisdiction stores 3D volumetric objects for cadastral purposes (Pouliot, 2011) digitally. Therefore, one of the main challenges in implementing a 3D cadastre would be sourcing 3D data. Virtual 3D city models are a fundamental source of 3D information which can be utilised to assist in 3D cadastre processes (Ross, 2010). However, most virtual 3D city models look the outside of buildings and structures, which are not detailed enough for 3D cadastral purposes.

To store, deliver and exchange 3D data, many data formats exist which have different specifications. Table 2.4 represents some of the popular data formats for storing 3D data.

Table 2.4: Popular data formats for storing 3D data.

File Format	Description
CityGML	OGC City Geography Markup Language Encoding Standard (OGC CityGML, 2012)
KML(KMZ)	Keyhole Markup Language, a popular format from Google for 2D/3D purposes (OGC KML, 2008)
X3D (VRML)	Successor of VRML (ISO/IEC19777:2006, 2006)
GeoVRML	This format aims to provide facility to enable spatial data to be visualised over the web with a standard VRML plug-in[9].
GML	OGC Geography Markup Language (OGC GML, 2012)
DXF, DWG, DGN	Drawing CAD Formats supported by variety for CAD software products
3DS	A 3D format for Autodesk 3ds Max
Shapefile	The ESRI data format for spatial data[10]
Collada	Industrial automation systems and integration - COLLADA digital asset schema specification for 3D visualisation of industrial data (ISO/PAS 17506:2012, 2012)
3D PDF	Document management - Portable document format (ISO 32000:2008, 2008)
IFC	Industry Foundation Classes for data sharing in the construction and facility management industries (ISO 16739:2013, 2013)
LandXML	A non-proprietary standard for data exchange in land administration processes[11]

[8] Building Information Modelling
[9] http://www.ai.sri.com/geovrml/
[10] http://www.esri.com/library/whitepapers/pdfs/shapefile.pdf
[11] http://www.landxml.org/

These formats, which have been used for storing and representing 3D property rights, have different specifications that differentiate them from each other. The following are more widely used and discussed further:

- Industry Foundation Classes (IFC)

IFC is a commonly used format in Building Information Modelling (BIM) and the significant advantages of BIM have encouraged many governments to consider it in the planning stages (e.g. UK and Singapore). BIM provides detailed 3D data information for developments (Frédéricque *et al.*, 2011) and has a good potential to be used in 3D cadastre as it accurately describes the as-designed physical objects in buildings and structures. BIM can be utilised for various structural analysis and cost calculations during the design process. It uses international standards (e.g. IFC) for exchanging data among stakeholders and software products. Using BIM provides various graphical representations such as floor plans, cross-sections, and 3D models in various LoDs (Ross, 2010).

However, there are some issues associated with implementing this format for 3D cadastre. Firstly, the consistency of the design models with as-built models: after construction a checking process is required by land surveyors to validate the design models with the as-built models (Stoter *et al.*, 2011). Secondly, although this approach seems very efficient, many built buildings do not have BIM files and a process to generate their BIM files is required. Thirdly, BIM files are very detailed (Ross, 2010, Prooijen *et al.*, 2011) as they include various information such as wall materials, and internal utility networks which are not important for some cadastral users. Therefore, an automatic generalisation process for BIM data is essential (Frédéricque *et al.*, 2011). Fourthly, there is a semantic mismatch between BIM schema and other geospatial schemas such as CityGML (Isikdag and Zlatanova, 2009), therefore exporting IFC to other 3D formats may cause some problems. Lastly, and most importantly, IFC and BIM do not currently support 3D legal objects and it is not possible to store 3D property rights in current IFC files.

- CityGML

City Geography Mark-up Language (OGC CityGML, 2012) is a standard of the Open Geospatial Consortium (OGC) for representing cities via a semantic data model (Ross, 2010). CityGML is able to store building information in several levels of geometric and semantic detail. Due to the advantages of CityGML, it has a growing following. Firstly, it is an OGC standard based on Geography Mark-up Language (GML) which enables users to benefit from Web Feature Services (WFS) and also integrate CityGML files with other data sources from OGC (Döllner and Hagedorn, 2007). Secondly, CityGML is an expandable format which can be used for various applications (Czerwinski *et al.*, 2006). Thirdly, several compatible tools (e.g. import/export tools, viewers, and a database schema) are freely available. Integrating BIM and CityGML is an active research topic and several solutions for integrating these formats have been proposed (Döllner and Hagedorn, 2007, El-Mekawy, 2010). However, due to semantic mismatch between IFC and CityGML schema, there is no simple integration approach (Prooijen *et al.*, 2011).

CityGML is considered an important data format and has potential for storing 3D cadastral data (Vandysheva *et al.*, 2011, Chiang, 2012, Çağdaş, 2013). There are a number of applications for visualising CityGML such as Autodesk LandXplorer CityGML Viewer, and FZKViewer.

- Keyhole Markup Language (KML)

One of the popular data formats in 3D industry is KML. KML is an OGC Standard and various applications, such as Google Earth and SketchUp support this format. As shown in table 2.1, various researchers in 3D cadastre have utilised this format for storing 3D property rights (Shojaei *et al.*, 2012).

- X3D (VRML)

Extensible 3D (X3D) is a royalty-free open standard file format to represent and visualise 3D objects using XML. It is also ratified as an ISO standard (ISO/IEC 19775-1:2013). It was developed from the Virtual Reality Modelling Language (VRML) and evolved into the X3D standard. X3D files can be visualised using standalone applications such as BS Contact or using in-browser capability. X3DOM is JavaScript/HTML driven and allows inclusion of X3D elements as part of HTML5 DOM elements. Vandysheva *et al.* (2012) used this format for representing 3D property rights in Russia.

- LandXML

LandXML is a XML-based data format which is widely used to exchange civil engineering and survey measurement data. LandXML schema has the following main components:

  - Initialisation

- Metadata
- Geometry
- Survey data

Initialisation specifies units, coordinate systems and a description of the application that created the LandXML file. Metadata includes some description of the data such as name, version, date, and comments. Geometry is the main part of the schema and contains geometrical information such as coordinates, parcels, and surfaces. Survey data includes information about the surveying process, such as survey observations and metadata about the surveying configuration (Shojaei *et al.*, 2012). Various research in 3D cadastre has used LandXML as a format for transferring cadastral data (Karki *et al.*, 2011, Shojaei *et al.*, 2012, Soon, 2012).

- 3D PDF

3D data can be represented by 3D PDF files. PDF is a common format and has a free viewer (Adobe Acrobat Reader) which can be used in various devices (Prooijen *et al.*, 2011). Also, several software products (e.g. SketchUp, and SolidWorks) are able to create 3D PDF files (see figure 2.9). One of the advantages of this format is the ability to store legal documents and associated geometry as an integrated file (Vandysheva *et al.*, 2011). In addition, the possibility to easily interact with and query 3D models is very useful for understanding the situation (Stoter *et al.*, 2011). Shojaei *et al.* (2013) used this format to represent a 3D model of a car park at the University of Melbourne.

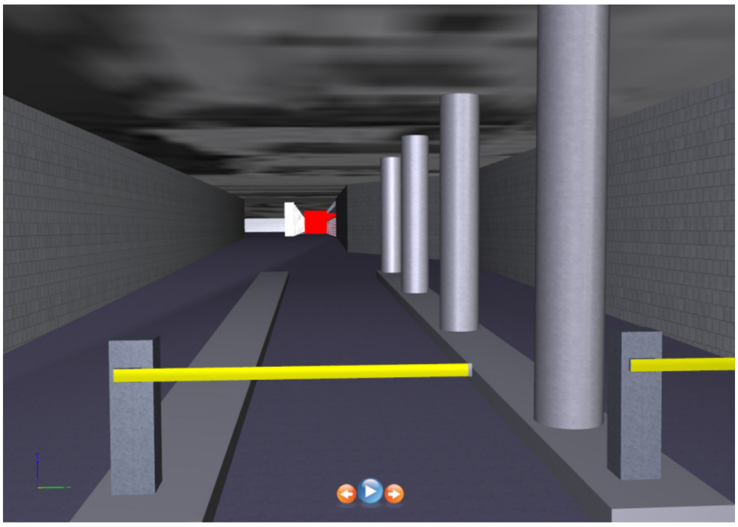


Figure 2.9: 3D PDF of a Car Park at the University of Melbourne.

The above-mentioned formats have different capabilities which can be used for various applications.

There are other aspects in cadastral data which need to be considered. For example, in some jurisdictions (e.g. Victoria, Australia), ownership boundaries in strata buildings are referenced to physical objects (e.g. walls, ceilings and roofs) and no coordinates are stored nor any measurements suitable for converting these plans to 3D models. In these cases, providing an accurate 3D model is necessary for visualisation.

Another issue is what type of cadastral objects must be registered in 3D cadastre and at what level of detail? The answers depend on the functions of 3D cadastral data in each jurisdiction. Therefore, the required granularity of data depends on the local rules and regulations and approved data model. The next section discusses related standards for visualisation.

2.8 Related Standards

There are various standards for visualisation of 3D data developed by the International Organisation for Standardisation (ISO), Open Geospatial Consortium Inc. (OGC) and Infrastructure for Spatial Information in the European Community (INSPIRE).

At ISO, the TC184 technical committee is working on visualisation standardisation for CAD models and certified royalty-free open standard X3D, for interactive visualisation and communication of 3D content.

In 2012, the Land Administration Domain Model (LADM) (ISO19152/TC211, 2012), was approved officially by the ISO for 3D cadastre as a standard data model. LADM focuses mainly on defining a data model for implementation of a 3D cadastre. In LADM, the classical concept of cadastre was extended to support spatial representation of overlapped 3D property rights (Dimopoulou and Elia, 2012). In this standard, the Surveying and Spatial Representation Package describes how to geometrically represent spatial units (property rights) using 2D parcels (Boundary Face String class) or 3D volumes (Boundary Face class) (Pouliot *et al*., 2013). For instance, spatial units are represented using Boundary Face Strings for 2D boundary representations and Boundary Face for 3D boundary representations.

The OGC has also published its Styled Layer Descriptor and Symbology Encoding Implementation Specification for symbolisation and colouring of spatial data for 2D Web Map Services (OGC, 2007).

INSPIRE has developed some standard styles for data specification in various domains, such as cadastre, hydrography, transportation, and addresses. For cadastral domains, the document 'Data Specification on Cadastral Parcels Guidelines' specifies 21 requirements and 29 recommendations for cadastral data (2D parcels) (INSPIRE, 2010). It addresses issues such as data content and structures, reference systems, data quality, dataset-level metadata, delivery medium, and data capture.

Despite the above related standards and activities, currently there is no specific recommendations to define the requirements for 3D cadastral visualisation applications (Pouliot, 2011). Therefore, standards are required to clearly define how to generate 3D cadastral data, represent 3D property rights and associated physical objects, and how to publish and submit them to authorities (van Oosterom, 2013). The next section investigates 3D visualisation applications and techniques.

2.9 Three-Dimensional Visualisation Applications and Techniques

3D visualisation of real environments using computer-based techniques has been an area of active research for more than 20 years (Pittman, 1992, Bishop, 1992, Sinning-Meister *et al.*, 1996, Batty, 1997, Batty *et al.*, 1998, Ross, 2010) and visualisation is a huge sphere of research and includes various aspects which integrates computer graphics, image processing, user interface, and human perception (Pouliot, 2011).

Geospatial technologies have evolved very quickly in recent years and new applications and techniques have emerged (Frédéricque *et al.*, 2011). Now 3D technology is more widespread and offers new approaches for various domains. However, representing property ownership information is still limited in 3D and needs more attention.

Data, users, usages and standards are important factors to consider in choosing visualisation applications and techniques for a domain (Andrienko *et al.*, 2005). There are many visualisation techniques, and researchers have suggested various classifications for them. Qin *et al.* (2003), for example, saw data type, display mode, interaction style, analytic task and data model as important factors for classification of visualisation techniques.

In the cadastral domain, various visualisation and rendering techniques and visualisation applications have been used to facilitate cadastral processes. Moreover, other visualisation techniques and technologies like Augmented Reality (Stoter and van Oosterom, 2006), Collaborative Visualisation Environments (Ho and Rajabifard, 2012a), and Game Engines (Pouliot, 2011) were suggested to improve communication in the cadastral domain. Although these technologies are promising, they are not yet sufficiently widespread or robust for operational cadastral systems with large data volumes and intensive usage.

As discussed in section 2.7, a visualisation application for cadastral applications needs to be able to represent both physical and legal data. Representing both physical and legal objects for all buildings in a city often involves massive volumes of data (Corrêa, 2004). Therefore, an efficient rendering engine with appropriate acceleration techniques is required.

Posada-Velásquez (2006) classified acceleration techniques as including:

- Culling (occlusion/visibility): All rendering applications use techniques for excluding occluded geometry. These are most efficient when done in hardware (as through a graphical processing unit);
- Geometric simplification: Geometric simplification techniques such as levels of details (LoD) are widely used to simplify geometries in visualisation applications. CityGML uses this technique for representing geometries in various abstractions (Gröger *et al*., 2008); and
- Image-based representation: In this technique, texture mapping is used to represent the complexity of geometries (Heckbert, 1986).

While it may be important to render all the visible physical objects at one time in order to understand the structure of a city, it is more common to look at property information more locally in order to understand very specific details of RRRs. In these cases, each building may be represented individually and there is less need to have a system with high performance and advanced rendering techniques. Currently, there is little research to support choices on appropriate visualisation techniques for cadastral applications.

In terms of 3D visualisation applications, various prototypes have been developed utilising 3D visualisation applications for communicating 3D spatial data and exploring cities and landscapes. In the past, many solutions were limited with respect to the quality of presentation, interactivity, intensity of data, or required resources (CPU processing and high cost of products) (Ross, 2010). However, emerging powerful computer systems have provided efficient 3D visualisation applications that create impressive models and animations. For instance, large and detailed 3D city models, with complex functions, can now be represented on the Internet.

According to the usage requirements, many systems, including Geographic Information Systems, Computer Aided Design and Modelling systems (CAD/CAM), image processing software, animation creation software, and web-based applications have been developed and utilised for representing 3D objects.

3D software products have different capabilities which make them suitable for different purposes. Some products may be good for 3D model generation or editing, but may not able to represent 3D models realistically. Some may be very efficient in 3D data processing, but fail to efficiently manage 3D objects (Guo *et al*., 2013). According to Guo *et al*. (2011), a 3D product may not be able to meet all requirements of a 3D cadastral system, necessitating the integration of different products.

Some visualisation products which can be utilised for 3D cadastral representation are described in the following section.

- Adobe Acrobat Reader

3D PDF files are utilised for representing 3D information, and various applications can export this format (See section 2.7). Adobe Acrobat Reader can represent 3D objects, explore the scene, and interact with objects (Prooijen *et al*., 2011). In Acrobat Reader users are able to rotate, scale, slice, and select 3D objects (Vandysheva *et al*., 2011). Figure 2.10 represents a sample of a 3D PDF file in Acrobat Reader.

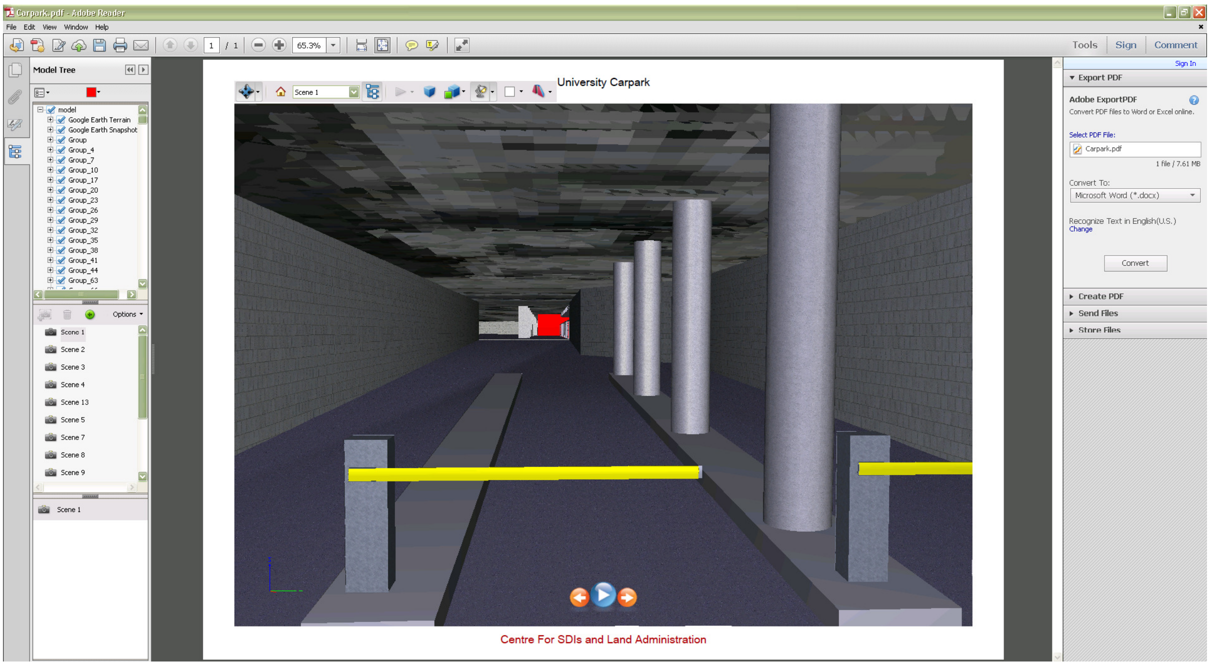


Figure 2.10: Adobe Acrobat Reader.

Shojaei *et al*. (2013) utilised Adobe Acrobat Reader for representing 3D property rights. Although representing 3D cadastral objects is simple with Adobe Acrobat Reader, there are limitations in terms of interaction with objects. This application is only able to represent a few buildings at a time.

- ESRI Products

Geographic Information Systems can help land administration processes by providing several 3D tools. Existing 3D GIS techniques are utilised in many applications such as urban planning and architecture design. In addition, 3D GIS has a great potential for implementation of 3D cadastre due to its available 3D functions. ESRI as a well-known solution developer in the GIS domain has developed some products for representing 3D spatial data namely ArcGlobe, ArcScene, CityEngine, and ArcGIS Explorer. During the last decade in 3D cadastral research, several prototypes were developed using ESRI products (Tsiliakou and Dimopoulou, 2011, Shojaei *et al*., 2013, Ammar and Neeraj, 2013).

- NASA World Wind[12]

NASA World Wind is a geographic information application and fully 3D interactive globe developed by the NASA Ames Research Center. It provides satellite imagery and a terrain

[12] http://worldwind.arc.nasa.gov/java/

model for the Earth. Java developers are able to integrate this into their web pages or use it as a stand-alone application for various applications. This visualisation application is standard-based, open-source technology and works on cross platforms. The simplicity of the application has motivated developers to use this for various usages. For instance, Dimovski *et al*. (2011) have utilised NASA World Wind to implement an operational web-based 3D cadastral visualisation application based on the needs of the Agency for Real Estate Cadastre of the Republic of Macedonia. Figure 2.11 represents a snapshot of this developed 3D cadastral visualisation application.

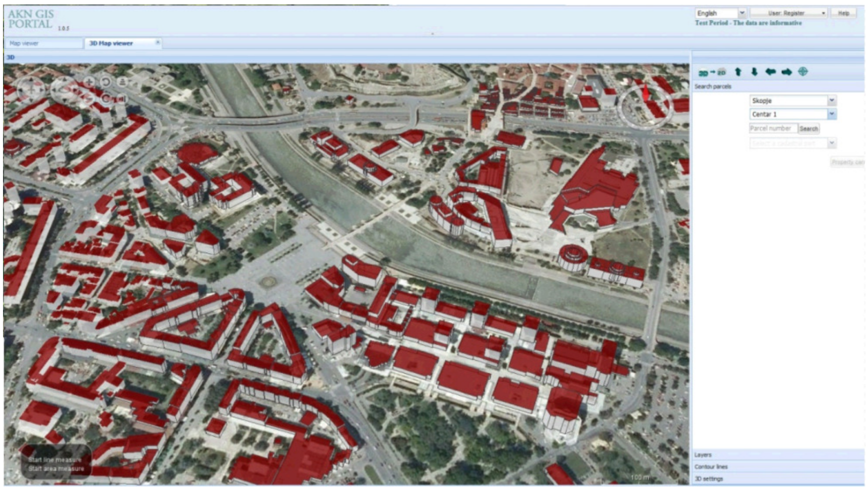


Figure 2.11: NASA World Wind as an application for representing 3D models (Dimovski et al., 2011).

- BS Contact (X3D)[13]

BS Contact is a 3D web-based visualisation application suitable for representing X3D data formats. Vandysheva *et al.* (2012) have developed a web-based 3D visualisation prototype in the Russian Federation utilising the BS Contact plug-in to represent 3D volume objects and associated administrative data.

- TerraExplorer[14]

TerraExplorer is a visualisation application for exploring, editing, analysing and publishing photo-realistic 3D environments. One TerraExplorer product is Skyline Globe Viewer, which

[13] http://www.web3d.org/x3d/
[14] http://www.skylinesoft.com/skylineglobe/corporate/products/terraexplorer.aspx

provides advanced API capabilities for web-based 3D visualisation applications. Installing the plug-in is required to use this viewer. In addition to the viewer, TerraExplorer Plus and Pro provide users with capabilities to edit features, add layers, and publish data to be visualised in the Skyline Globe Viewer. This application has been utilised in some activities in 3D cadastre research and several prototypes were developed (Guo *et al.*, 2011, Chiang, 2012, Ying *et al.*, 2012, Guo *et al.*, 2013). Figure 2.12, illustrates a snapshot of TerraExplorer integrated in a prototype.

Figure 2.12: A prototype developed using TerraExplorer (Guo *et al.*, 2011).

- XNavigator[15]

XNavigator is an open source interactive 3D viewer, developed at the University of Bonn, for exploring 3D city models and landscapes and an online viewer for OpenStreetMap Globe[16]. The software is built on Java technology and runs on a wide range of platforms. The 3D graphics use OpenGL hardware acceleration and the Java technology allows integration into web pages. XNavigator relies on client-server architecture and supports Open Geospatial Consortium (OGC) standards. Various OGC services such as Web 3D Service (W3DS), Web Map Service (WMS) and Web Feature Service (WFS) are supported. Vandysheva *et al.* (2011) developed a prototype for representing 3D property rights using XNavigator as a 3D web browser. This prototype is simple to operate and provides navigation tools, streams 3D data from the server, selects and identifies objects, supports lighting, and supports various representations (e.g. wire frame, flat, and phong shading).

[15] http://xnavigator.sourceforge.net/doku.php
[16] http://osm-3d.org

- Autodesk

The Autodesk family supports various applications with professional products for creating, editing, and managing 2D and 3D data. AutoCAD is a very popular application in this family for creating 2D and 3D models, and cadastral users widely use this software (Aditya *et al.*, 2011). Among this family, Revit is widely used by architects for creating 3D designs and BIMs, and it supports IFC as a file format for exchanging data.

- Bentley MicroStation

Bentley MicroStation is a useful application for editing 2D and 3D objects and has been used for many years in cadastral applications. It can connect to spatial databases (e.g. Oracle) and can manage data, visualise, and import and export 3D data. This product was utilised by some researchers (Stoter and van Oosterom, 2002, Stoter and Salzmann, 2003, Zulkifli *et al.*, 2013) for representing 3D property objects, as it supports some required functionalities for 3D modelling and can easily to do batch processing and control data quality (Pouliot *et al.*, 2010). In addition, Bentley developed the i-model as a 3D standard for exchanging 3D models and their associated properties (Prooijen *et al.*, 2011). There are free viewers for this format and various Bentley products can generate i-models. i-models can be utilised for various functions such as clash detection, review, schedule simulation and budget estimation. Also, i-models can be accessed using mobile devices for fieldwork. By using this standard, project team members are able to interact with shared 3D models.

- Google Earth

Google Earth is one of the most popular 3D visualisation applications, used widely for various applications. It provides a virtual globe that allows users to see geographic locations at various levels of detail (Erba and Piumetto, 2012). The Google Earth Plug-in and its JavaScript API enables embedding Google Earth in web pages. Also, the API is able to load 3D models in KML/KMZ formats, which allows sophisticated 3D applications. A large number of applications have been developed using Google Earth in various domains. In 3D cadastre, Aditya *et al.* (2009), Aditya *et al.* (2011), Olivares García *et al.* (2011), Trias, *et al.* (2011), and Shojaei *et al.* (2012), developed prototypes for representing 3D property rights.

- WebGL

WebGL is a cross-platform, royalty-free web standard based on OpenGL that provides users with 3D models in HTML 5. WebGL brings plug-in-free 3D to the web through all major browsers. WebGL is a low level API for programmers and drawing even a simple 3D model, such as a cube, needs a lot of work. Accordingly, several open-source JavaScript libraries have been developed to simplify the programming of 3D scenes using WebGL technology. They provide higher level access to the API to make it simple for programming. For instance, Three.js[17], SpiderGL[18], Kuda[19], Cesium[20], and SceneJS[21] are widely used for 3D web-based applications. Three.js is the most popular and has a good number of users who can help fellow developers in difficulties.

There are many other 3D visualisation applications which are currently used for various purposes. Table 2.5 has listed some other visualisation applications. This is an active topic in industry and in research, and new applications emerge on a regular basis.

Table 2.5: Some 3D visualisation applications[22].

Autodesk LandXplorer	Geoweb3d Desktop	Carmenta	Power GEOPAK	GeoVisionary
Autodesk Infraworks	LandSim3D	Scenario 3D	GizmoSDK	IMAGIS
Autodesk Revit	CityScape	Creator	Global Mapper	LSS Vista / 3D Vantage
Quest3D	Citysurf	Cruiser	Imagine VirtualGIS	Makai Voyager
Key 2 Virtual Insight (K2Vi)	Cloddy	DbMAP 3D	Leveller	re-lion Builder
SketchUp	Insight3D	EarthVision	Blaze Terra	RhinoTerrain
GeoScope	3DCarto	fourDscape	CommunityViz Scenario3D	Geo Surface3D
Cortona3D	Blueberry3D	GeoFusion	Equater	Simurban
SpacEyes3D	GEOMEDIA 3D (Intergraph)	Norkart Virtual Globe	3D GIS Sivan Design	Landscape Explorer 3D
TSGFly	3DEM	ossimPlanet	Visual Nature Studio	Grass GIS
TerraTours	Biosphere3D	SketchUp	VWorldTerrain	Earth3D
TerrainView	Deegree3D	Blom3D	Tekla	VEO
Unity	Torque3D	Blender	Torque3D	Presagis

[17] http://threejs.org/
[18] http://spidergl.org/
[19] https://code.google.com/p/kuda/
[20] http://cesiumjs.org/
[21] http://scenejs.org/
[22] Some of these applications are found in http://vterrain.org/

Choosing an appropriate 3D visualisation application is a big challenge for developers due to the variety available and the continually emerging new technologies. Therefore, a good knowledge of existing software and its capabilities can help in developing successful cadastral systems. An evaluation of these products before starting an application development can significantly save time and cost. Various criteria should be considered when evaluating these products. Pouliot (2011) has addressed some criteria such as mono, stereo, immersive, collaborative, platform, interactive, static, import and export capabilities for visualisation system evaluation. The quality of representation in successful and popular tools should also be considered for representing 3D legal objects (van Oosterom *et al.*, 2011).

As shown in table 2.1, these applications were utilised in several prototypes to represent 3D ownership rights. Although some of them could help representing ownership rights in 3D, there are still some issues with most of these prototypes. Firstly, users of the prototypes were not clearly identified and their requirements not comprehensively elicited. Secondly, there is no 3D visualisation application mainly for cadastral purposes and finally, the developed prototypes were not completely evaluated.

In addition to the above-mentioned applications, 3D printers are getting popular among industry. 3D printing technology has proven its value in reproducing complex 3D models from digital design and visualisation software. Scaled-down models of buildings can assist users to see physical objects and their relations with legal objects. Further investigation is required in this domain.

The next section discusses the remaining issues in 3D cadastral visualisation from various aspects.

2.10 Remaining Issues

Since the discussions about the implementation of 3D cadastre in 2001, various issues have emerged and several solutions have been proposed. Although several activities in 3D cadastral visualisation were conducted during these years, there are several issues which need more investigation. In this section, some of these issues are addressed:

- How to represent 3D property objects with curved surfaces in 3D cadastral visualisation applications (Stoter *et al.*, 2012a);
- How to represent unbounded 3D volume objects (Stoter *et al.*, 2012a, van Oosterom, 2013);

- How to visualise dense 3D volumetric partitions such as in a complex building (van Oosterom, 2013);
- How to represent earth's surface and other reference objects (van Oosterom, 2013);
- How to represent subsurface 3D property rights (e.g. utilities and associated rights);
- What levels of detail are required for representation of 3D property rights (Fendel, 2001);
- Is it sufficient to represent an indication of the position of a building and not the exact boundaries (Fendel, 2001);
- Representing volumes without physical objects should be possible (e.g. rights of two antennas to see each other for communication (Fendel, 2001);
- How represent big 3D property rights (e.g. tunnels) underneath or above two or more land parcels (Fendel, 2001);
- How to represent fuzzy boundaries (e.g. 3D property objects next to rivers) (Fendel, 2001);
- How to protect privacy of data in 3D visualisation applications (Pouliot, 2011);
- How to consider human perception in 3D visualisation (Pouliot, 2011);
- Which visualisation technique is suitable for users (e.g. mono, stereo, web, mobile or desktop applications);
- How to use visualisation variables (e.g. colour, texture, and transparency) to maximise visibility (Pouliot, 2011);
- Which data format is suitable for delivering and exchanging 3D cadastral data (Pouliot, 2011); and
- What are types of 3D cadastral objects need to be visualised.

In this thesis, some of the above-listed issues are further investigated in the following chapters.

2.11 Chapter Summary

The main purpose of using 3D visualisation in cadastres is in describing ownership boundaries horizontally and vertically in a 3D space. Representing ownership information in

3D can facilitate understanding of ownership boundaries, particularly in complex developments.

In this chapter, 3D cadastre and visualisation were defined. Various aspects for 3D visualisation of ownership rights were explored. Some 3D visualisation applications were then introduced and their limitations were discussed. Finally, some remaining issues in 3D cadastral visualisation were presented according to the literature.

The wide variety of users in land administration provide information and communication challenges. The diverse authorities, institutions and individuals, and their different requirements, skills, knowledge, and backgrounds cause some issues and challenges in proper communications. Various types of representation, whether a floor plan, a PDF file of a plan, or a textured 3D model are used selectively by architects, developers, land registries and local governments, to communicate within land administration processes. In addition, paper-based (PDF) subdivision plans are utilised to represent land ownership rights.

While 3D visualisation helps communication, decision making processes, understanding of data, and problem awareness, its transition into land administration processes has been slow due to several factors. These factors are lack of required data, costs, technology, usability and acceptance (Ross, 2010).

Considerable research on implementation of 3D cadastral prototypes and 3D visualisation applications is reported in the literature. However, still there is no fully implemented application for 3D cadastre. Most of the developed prototypes have remained at a prototype level and further validation is required to consider them as end products. One of the main issues identified in this chapter is the lack of fully documented 3D cadastral visualisation requirements for cadastral users.

The lack of fully developed 3D cadastral visualisation requirements causes inefficiency in developing applications for cadastral users. Based on the focus of this research, 3D cadastral visualisation requirements are elicited and documented. The next chapter presents research methods for developing 3D cadastral visualisation requirements.

CHAPTER 3

RESEARCH DESIGN AND METHODS

"To accomplish great things we must first dream, then visualize, then plan… believe… act!"

–ALFRED A. MONTAPERT

3 Research Design and Methods

3.1 Introduction

The previous chapter reviewed the research literature in 3D cadastral visualisation and related aspects. This chapter explains the design and methods that were developed and used to achieve the research objectives defined in chapter 1.

This chapter firstly develops a conceptual design framework by reviewing the research problem and questions. Then, possible research approaches are described that can answer research questions. The selected research approaches are then discussed and justified and the research phases presented. Finally, requirements engineering, part of the main activity in this research, is explained in detail.

3.2 Conceptual Design Framework

The concept of 3D cadastre and related research in 3D cadastral visualisation were addressed in chapter 2. As a result, several challenges were identified: difficulty in understanding current cadastral representation for non-expert users; the time-consuming nature of understanding plans; lack of interactivity in representing ownership rights; and limitations in representing various types of RRRs.

Given the above-mentioned problems, the research problem underpinning this research was articulated as:

Visualisation requirements to support the development of 3D cadastral applications to represent rights, restrictions and responsibilities have not been clearly identified. An agreed set of requirements will support the development of visualisation applications designed to meet users' needs.

This problem prevents the development of efficient 3D visualisation applications specifically for cadastral purposes.

The following research questions associated with this research problem were also addressed in chapter 1:

1. What are the existing approaches of representing RRRs, and what are their limitations?

2. What are the advantages of utilising 3D visualisation techniques for representing RRRs?
3. What should be visualised in 3D cadastres? What are the 3D visualisation requirements for developing 3D cadastral applications? What type of visualisation features should be included in these applications?
4. How can these 3D cadastral visualisation requirements be identified, developed and validated to represent RRRs for cadastral purposes?

In accordance with the aim and objectives of this research, the main outcome of this study is developing 3D cadastral visualisation requirements. Requirements engineering refers to the process of eliciting, analysing, validating and documenting software requirements (Kotonya and Sommerville, 1998), and is applied in this study to develop 3D cadastral visualisation requirements. The requirements engineering process is described in more detail in section 3.5.

The conceptual framework illustrated in figure 3.1 was designed to achieve the aim and objectives of this research based on requirements engineering. Two key concepts, the 3D cadastre and its visualisation, are considered together in this research to address the key factors around the research problem.

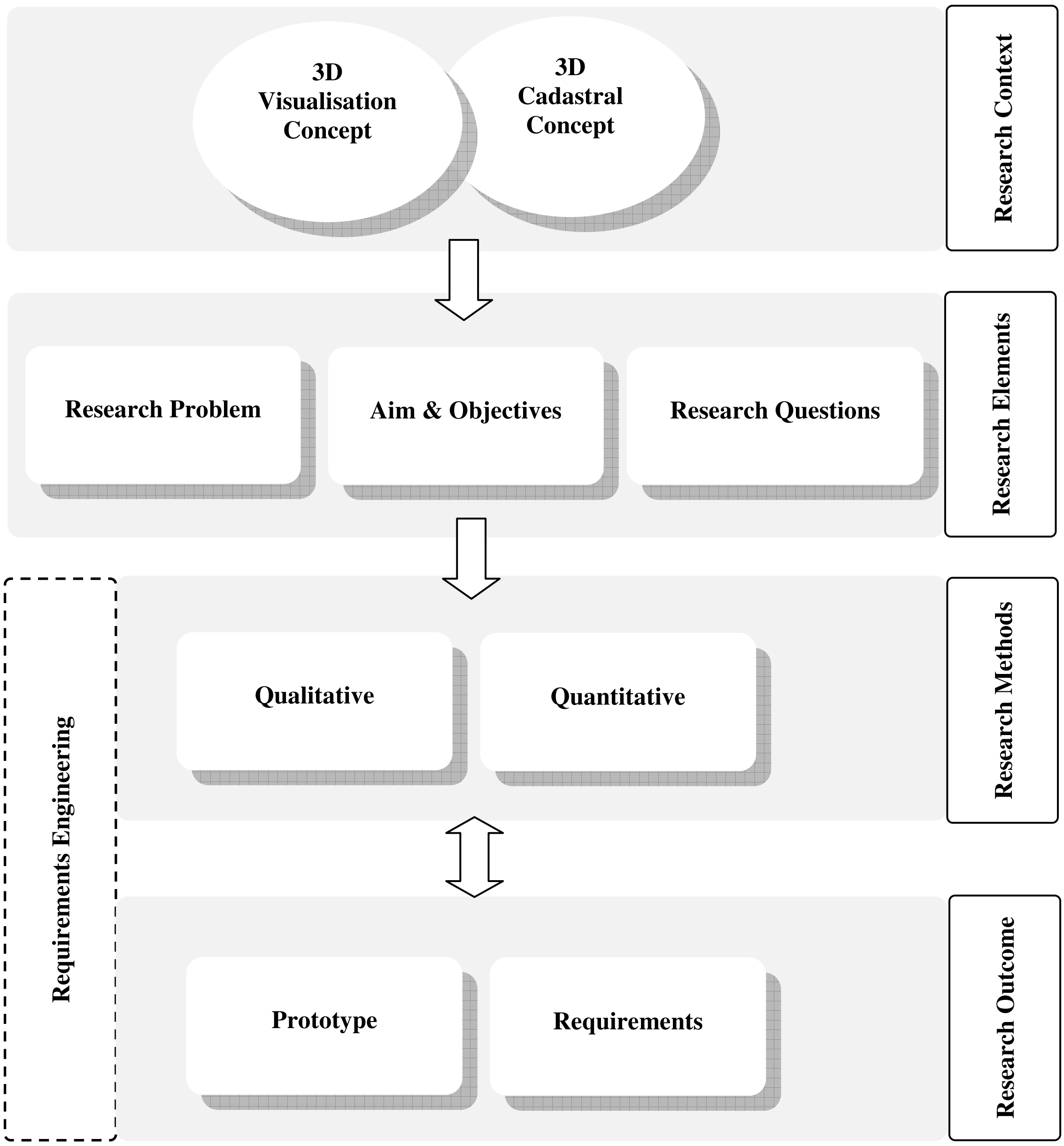


Figure 3.1: Conceptual design framework.

In this research, both qualitative and quantitative approaches were required, as neither approach could suffice to develop and validate requirements and prototypes for 3D cadastral visualisation. The next section addresses the selection of the research approach.

3.3 Selection of Research Approach

This section describes both qualitative and quantitative approaches and examines them within the context of this research. Various data collection methods are discussed and justified.

3.3.1 Qualitative Methods of Research

Qualitative methods were developed in order to study social and cultural phenomena. Some examples are action research, case study research and ethnography (Myers, 1997). These methods' emphasis is on analysing textual data collected using the above-mentioned methods (Borrego *et al.*, 2009).

Qualitative approaches enable researchers to understand people and how they act and what they say using social and cultural context. Talking to people or reading what they have written help us understand their thoughts to justify their actions (Myers, 2009). Qualitative research uses or interviews to ask open-ended questions such as "what", "why", "how" and "when". Researchers usually take notes during these processes, or conversations are recorded and transcribed which then becomes the main source used to answer the research questions. A positive aspect of qualitative research is that the descriptive data allows a great depth of understanding (Merriam, 2009). In qualitative methods, usually a limited number of responses are involved (Potts, 2013) and a random sampling is not appropriate. In this approach, talking to relevant people is the main focus and snowball sampling is recommended, in which, people recommend others for the interview or related surveys (Devlin, 2006). This process stops when new participants tell the same story as prior participants (Auerbach and Silverstein, 2003).

In this research, a qualitative approach seems very appropriate for understanding the current shortcomings in representing ownership information, the existing processes, and users' requirements. This provides an opportunity to use a variety of data collection methods including case studies, interviews, questionnaires, and participant observation to improve understanding of the context.

3.3.2 Quantitative Methods of Research

Quantitative methods can be used to validate a hypothesis using numbers and statistical methods. In this approach, figures are compared in order to draw conclusions regarding phenomena.

Unlike qualitative methods, quantitative methods' questions are fixed. These methods are suitable for studies which require meaningful comparison of answers. Quantitative methods often require a large number of participants in order to validate the results.

Quantitative methods were utilised in this research to evaluate the usability of a prototype system as well as to validate the identified requirements. Due to the importance of usability in this research, it is discussed here further.

- **Usability Scale and Justification**

Usability is a type of quality control for developing successful interactive software systems, defined as the *"Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"* (ISO 9241-11, 1998, Page 2).

Garmer *et al*. (2004) used group interviews and usability tests in order to elicit and specify user requirements for medical equipment. Both methods tend to involve users to elicit and specify user requirements, although each has slightly different foci. The usability test concentrates on discovering problems related to the user interface through making scenarios for users to carry out particular tasks and interact with the interface. During the test, users are able to provide feedback or identify problems for improvements. However, *"Usability is not a quality that can be spread out to cover a poor design like a thick layer of peanut butter"* (Nielsen, 1993, Page 16). Nielsen illustrated a simple model of system acceptability and the position of usability (figure 3.2). It is clear that system acceptability has many factors and usability is not the only criterion.

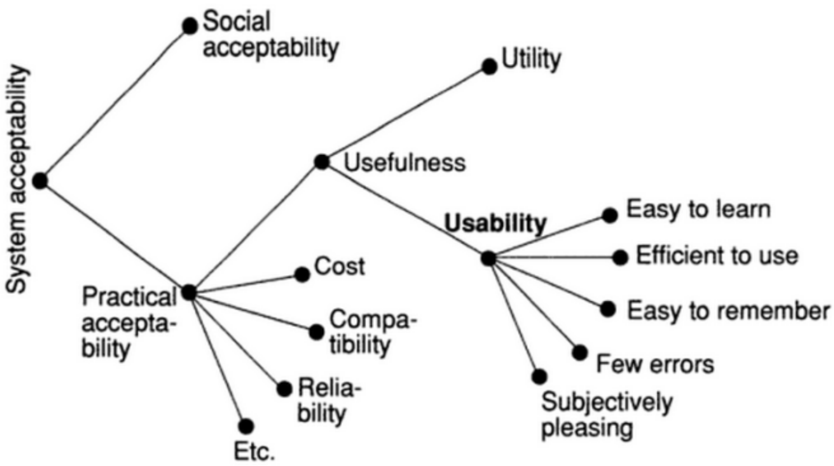


Figure 3.2: System acceptability and its components (Nielsen, 1993).

Nielsen (1993) identifies five attributes of usability:

- Learnability: Users can learn the system easily and quickly start working with it;
- Efficiency: Users can increase productivity by using this system (speed of performance);
- Memorability: A casual user can remember how to work when he/she returns to the system after a period of time;
- Errors: The system has an acceptable rate of error and users can easily recover from them; and
- Satisfaction: Users should enjoy using the system.

Other types of usability factors have been defined in the literature. Jokela *et al*. (2006) explained usability in terms of task performance effectiveness (completing tasks using the system while considering the quality of output), efficiency (utilising resources for completing the tasks) and satisfaction (user's attitude to the system).

Brooke (1996) developed a low-cost usability scale which can be used to evaluate the usability in systems. The System Usability Scale (SUS) is a ten-item, 5-point Likert scale (figure 3.3) covering aspects such as need for support, training, and complexity.

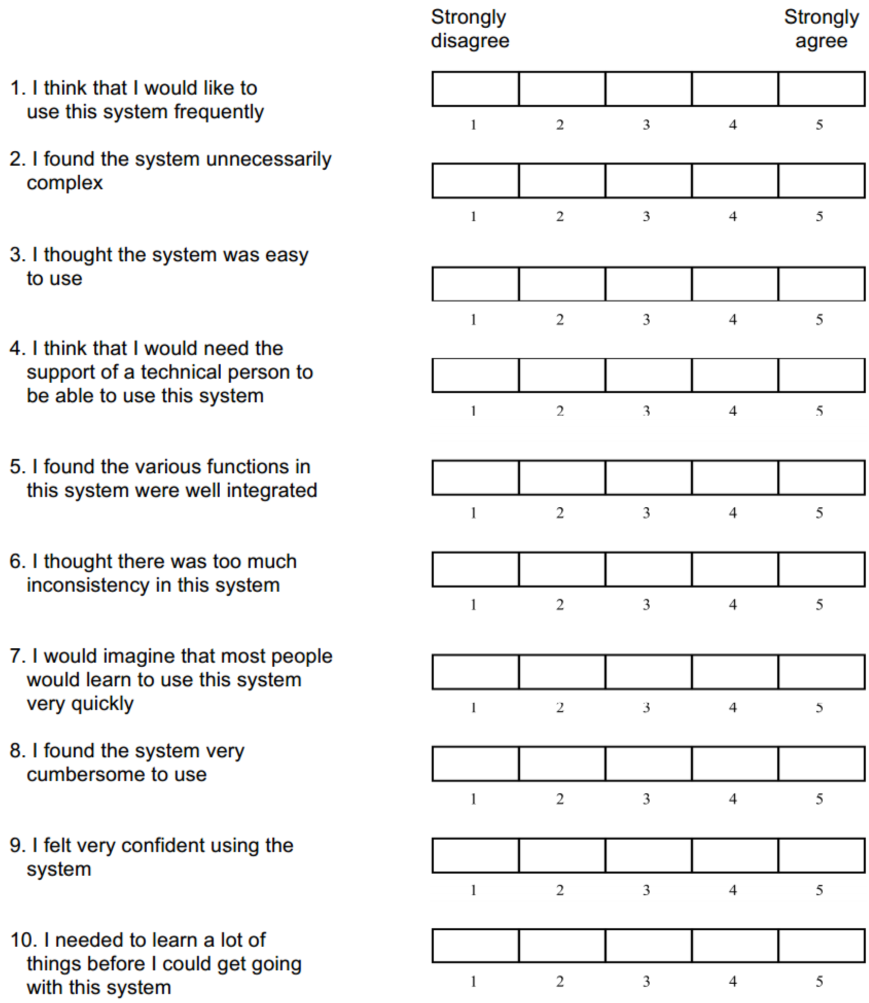


Figure 3.3: The System Usability Scale which covers a variety of aspects of system usability (Brooke, 1996).

The main advantages of this approach were addressed by Bangor *et al*. (2008) as:

- SUS is technology agnostic;
- SUS is flexible enough to assess various types of interfaces;
- SUS is relatively quick and easy to be utilised;
- It gives a single score on a scale which is easily understandable by various people; and
- SUS is not commercial which makes it a very cost-effective tool.

This method was selected for evaluating prototype system usability in this research.

3.3.3 Data Collection Methods

This section describes various methods for data collection, such as case study, interviews, participant observation, and questionnaires. The reasons for selecting each method are also discussed.

3.3.3.1 Case Study

A case study is an in-depth study on one or more individuals (Jackson, 2008). It is an empirical inquiry in which the focus is on a contemporary phenomenon within its real-life context (Yin, 1994). Case studies look at examples and processes and relations in a period of time rather than taking a single snapshot of individuals (Feagin *et al*., 1991). It is suitable for answering questions like "how" and "why" (Yin, 1994). Case studies look at real cases and are suitable when types of evidence such as interviews, questionnaires, reports, brochures, procedures, and strategic plans are available (Yin, 1994).

Two advantages of case study research are that it often suggests hypotheses for future work and assists the study of rare phenomena such as diseases. It may also provide empirical support for a theory and has an important role in evaluation. However, it has some disadvantages. Generalisation of results is problematic. Researchers may be biased in their interpretations, paying more attention to the results that support their theories and ignoring other data. Therefore, case studies should be utilised with caution (Jackson, 2008).

Case studies can be qualitative, quantitative or mixed (Yin, 1994). They provide a suitable approach for studying how people, processes and technology interact in the case of information systems development and engineering (Aien, 2013). There are three types of case studies, namely explanatory, exploratory and descriptive (Yin, 1994). Explanatory studies define casual relationships among variables. Exploratory studies are suitable for finding and discovering what is happening and evaluating new phenomena leading to new theories. A descriptive study provides an accurate description of phenomena or situations (Yin, 1994).

Case studies, particularly descriptive and exploratory, are considered highly relevant for this research, as:

- Case studies can precisely describe the situations in 3D cadastral registration and visualisation;

- They help to realise the issues clearly as they present new phenomena and highlight many hidden corners; and
- Various data sources can be utilised as evidence, including interviews and literature.

Case study designs can be single-case or multiple-case designs. The single-case design is appropriate when testing a well-formulated theory or when a case addresses an extreme or unique situation. Multiple-cases designs are often considered more compelling, and the overall study is more robust. However, conducting several cases needs extensive resources and time (Yin, 1994).

In this research, a single-case design, focused on the Melbourne metropolitan area in the state of Victoria, Australia (figure 3.4) was used. This region was selected as the case study for undertaking this investigation for a number of reasons:

- Victorian legislation supports 3D ownership registration;
- Victoria has a paper-based (PDF) cadastre which allows registration of overlapped ownership information;
- Victoria provides an easily accessible legal system to investigate legal documents;
- The opportunity for industry placements and suitable access to cadastral data, provided by Land Registry in Victoria (Land Victoria) and the City of Melbourne;
- Land Victoria is one of the industry partners of the Land and Property Information in 3D Project and this research is one part of this project;
- Land Victoria and the City of Melbourne have interest in the implementation of a full digital 3D cadastre;
- The easy access to specialists in Victoria from the University of Melbourne;
- Victoria is in the process of moving to a digital submission of cadastral data and interested parties are familiar with the issues and challenges in moving to a new type of data submission (Shojaei *et al.*, 2012);
- Similar to the Land Registry in Victoria, the City of Melbourne provided easy access to the required data and documents; and
- Melbourne, the capital of the State of Victoria, has attracted many people and many high rises are erected every year, meaning that the problem of efficient management of ownership information in overlapped properties is getting

more attention. Therefore, Victoria can be considered as an extreme case which can be extended to many jurisdictions in the world.

Selecting Melbourne as a case study limits the result of this research to the requirements of users in this region. However, utilising other data collection methods helped to have a general list of requirements to cover the needs of other jurisdictions. Also, in order to avoid bias, international investigations and expert opinions (through questionnaires and meetings) were considered in this research. Although the case study concentrates on Victoria, it can be used as an example of how to develop similar case studies for other jurisdictions.

Within this research, two case modules (mini case studies) (Hilburn *et al.*, 2006) were defined within this region to develop requirements for various scenarios. Each mini case study relates to a scenario involved in the development of requirements. In addition, each one is considered as part of requirement development by considering characters that might be part of an actual scenario in the future.

Figure 3.4: Melbourne metropolitan area in Victoria is chosen as a case study.

3.3.3.2 Interviews

Interviewing is a common method for collecting research data. In interviews, questions are asked face to face or over the phone and interviews can be conducted anywhere. The advantage of interviewing is that not only verbal responses, but also facial responses are recorded (Jackson, 2008). However, this method of data collection requires time for arranging meetings with interviewees and conducting the interviews. There are two main types of interview, namely in-depth, and focus group interviews.

In the first type, the interviewer can ask about the fact of a matter and also the interviewee's opinion about it. The interview may take place over a single meeting or a period of time. The interviewee can suggest other persons for interview or other sources of information (Yin, 1994).

Focus group interviews are conducted for a group of 6 to 10 persons at the same time and place. The questions are often open-ended questions and the whole group can participate. The main disadvantage of this type of interview is that one or two participants may dominate the conversation (Jackson, 2008).

In this research, both types of interviews (qualitative approach) were selected as participants could give their opinion and have in-depth discussions in the topic to further clarify their needs and expectations from a 3D cadastral visualisation application.

3.3.3.3 Participant Observation

Participant observation is a qualitative method of data collection in which researchers *"participate in the situation in which the research participants are involved"* (Jackson, 2008, Page 82). This method has been used widely in anthropological studies of different cultural or social groups. There may be some topics for which there are no other methods of data collection. Participant observation also allows researchers to understand a topic from the point of view of someone dealing with it in their daily life. However, the main drawback is the potential biases which might be produced because of close involvement with the people (Yin, 1994).

As part of this research, participant observation was chosen to closely identify the tasks of cadastral users and understand processes and requirements. Participant observation was conducted at two main organisations to study the current processes and understand the issues and shortcomings in representing land and property information (see section 3.4.3).

3.3.3.4 Questionnaire

A questionnaire or survey is a common approach for collecting data from individuals. Questions should be as clear as possible and minimise confusion. There are various methods for writing questions including open-ended, closed-ended, partially open-ended and rating-scale questions (Jackson, 2008). Open-ended questions have no predefined answers and participants describe their answers using their own words. However, these do not usually provide quantitative data. Closed-ended questions have predefined answers from which participants select the best answer. Partially open-ended questions are like closed-ended questions; but allow room for adding other possible answers. In rating-scale questions, participants choose a number to describe their ideas about the questions. One popular version of this type of question uses a Likert rating scale. Brooke (1996) developed a rating-scale method for evaluation of usability in systems.

Questionnaires (both qualitative and quantitative) were used in this research as responses were required from many cadastral users with different backgrounds. Also, questionnaires could verify the results from other data collection approaches quickly and cheaply. It is easy to monitor the progress of a survey based on the number of responses, and responses can be captured electronically which makes analysis faster.

3.3.4 Mixed Methodologies

Mixed methods involve both qualitative and quantitative approaches. According to Leech and Onwuegbuzie (2009, Page 1) mixed methods involve "*collecting, analysing, and interpreting quantitative and qualitative data in a single study or in a series of studies that investigate the same underlying phenomenon.*" Mixed methods add more meaning and content to numbers for further analysis and examination (Hesse-Biber, 2010) and draw on the strengths of both approaches. The following five reasons were identified for using mixed methods by Greene *et al*. (1989):

- Triangulation is the most commonly cited reason which mixed methods use to help answer the research questions. Triangulation refers to mixing more than one method in order to examine a research problem. This method is able to converge various data collected in a study to validate research findings;
- Complementarity provides researchers with a better understanding of the research problem and results. This is acquired by combing both qualitative and quantitative data and not just statistics or explanation alone;
- Development: for instance, the results of quantitative methods can help to shape the questions in the interviews; and
- Mixed methods can expand the inquiry.

In addition, Tashakkori and Teddlie (2003) identified the following advantages for using mixed methods instead of single methods:

- Mixed research methods can answer research questions which other single methods cannot; and
- More robust inferences are provided with mixed methods.

In the context of this research a mixed method of qualitative and quantitative studies was considered the most appropriate, as the questions identified in this research could not be answered using a single method.

Various data collection methods such as participant observation, case study, and questionnaires were required to answer the "why" and "how" questions. For example, how does the land registry currently represent cadastral data? However, in addition to qualitative approach, a quantitative method was more appropriate to evaluate the usability of developed prototype systems (Brooke, 1996) or the importance of identified requirements. Utilising all these evidences required a mixture of both qualitative and quantitative methods.

3.3.5 Choosing a Mixed Methods Design

After choosing a mixed methods approach, the next step was deciding the specific design that could address the research problem appropriately. There are various designs of mixed methods. Important factors for choosing designs are *"knowing the intent, the procedures, and the strengths and challenges associated with each design"* (Creswell and Plano Clark, 2011, Page 58).

Various models of triangulation methods exist. In the convergence model quantitative (QUAN) and qualitative (QUAL) data are collected and analysed separately and the results are converged for interpretation. This method is mainly used when the aim is *"to compare results, or to validate, confirm, or corroborate quantitative results with qualitative findings"* (Creswell and Plano Clark, 2011, Page 65). In a multilevel research design, different methods (qualitative and quantitative) are utilised in different levels in a phenomenon and the overall interpretation is based on merging the findings from each level (Creswell and Plano Clark, 2011). Figure 3.5, represents these two triangulation designs.

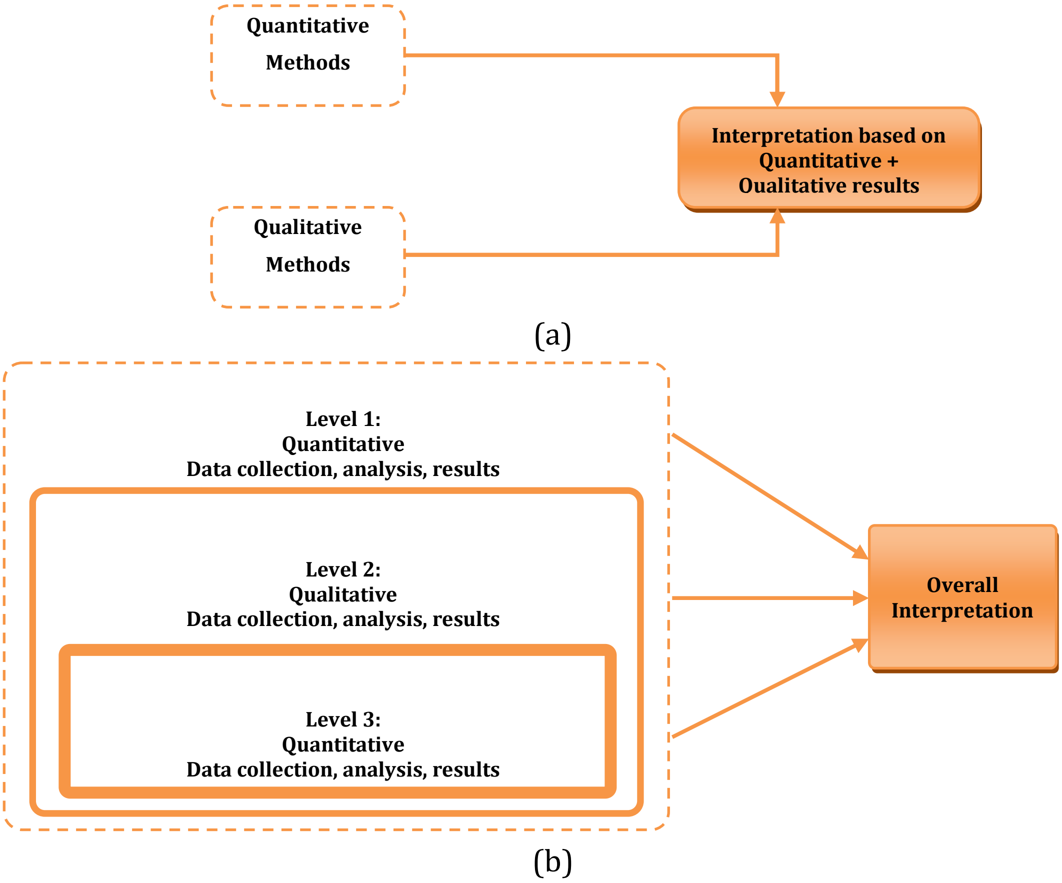


Figure 3.5: (a) Triangulation Design: the convergence model; (b) Triangulation Design: the multilevel model adapted from (Creswell and Plano Clark, 2011).

Among various triangulation methods, the multilevel model was chosen, as Creswell and Plano Clark (2011, Page 84) suggested *"If different types of data are collected to represent different levels of analysis within a system, with the intent of forming an overall interpretation of the system, then the choice of design is the Triangulation Design–multilevel model"*. The research design associated with this research is addressed in the next section.

3.4 Research Design

The research design consists of one main task (requirements engineering) and three interrelated levels (according to the mixed triangulation multilevel methods). Figure 3.6 represents this design, associated levels, steps and their relations.

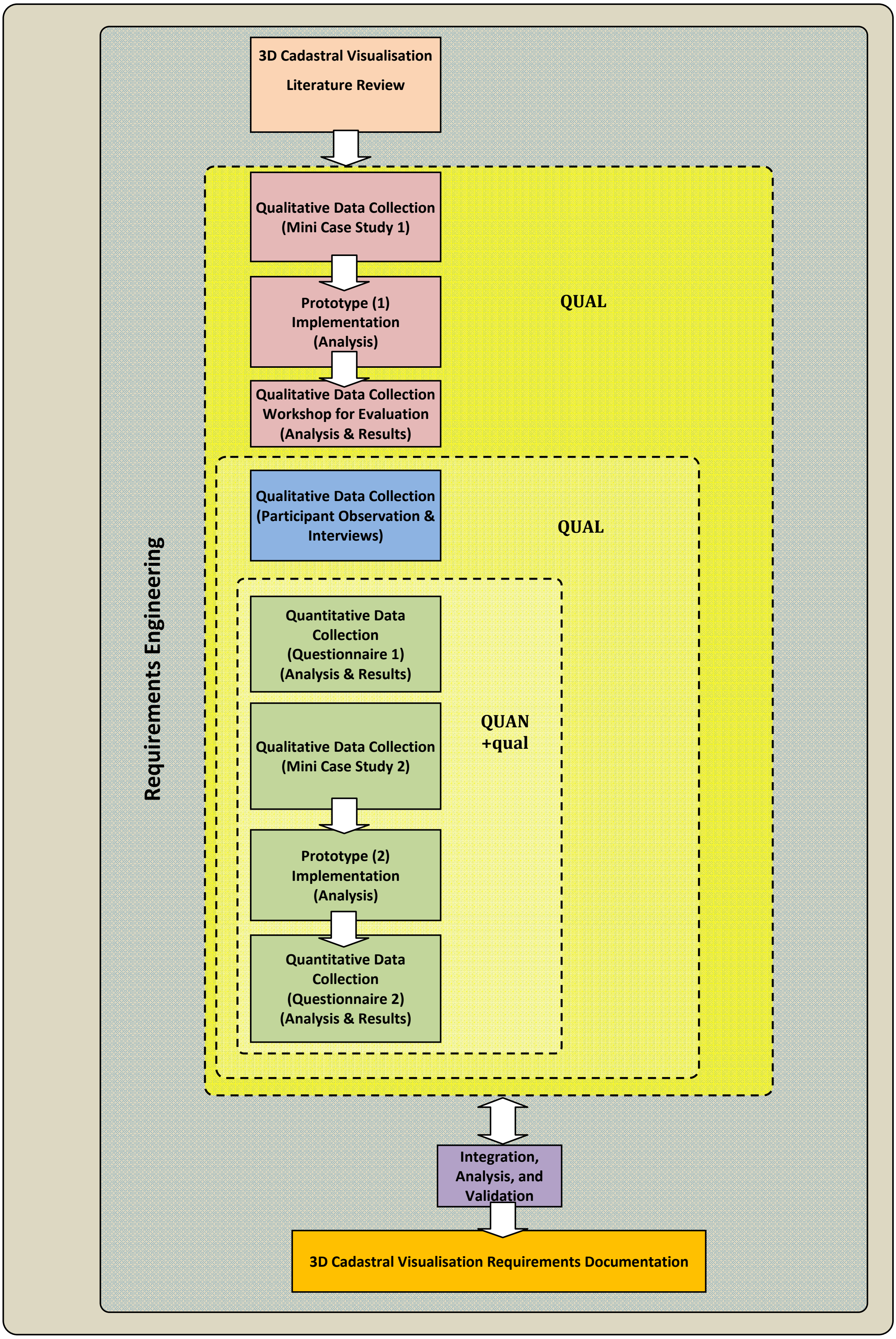


Figure 3.6: The research design, associated levels, steps and their relations.

As shown in figure 3.6, the mixed triangulation multilevel methods were used [QUAL, QUAL, QUAN+qual]. The approach was adapted from a similar design by Lisle (2011). This method includes three levels, which are described below.

In the first level, a mini case study (QUAL) was conducted and followed by implementation of the first prototype system, and the findings were analysed and evaluated in a workshop using a group discussion with open-ended questions. In this level, various requirements were identified and the main challenges in 3D cadastral visualisation were recognised.

In the second level, a qualification method [QUAL] was chosen and two methods of data collection were developed, including interviews and two industry placements (participant observation). In this level, a large number of requirements were elicited. In addition, the requirements from the first level were verified again in this level.

In the third level, a QUAN+qual approach was developed and implemented. Firstly, the identified requirements from previous levels were validated using a questionnaire (QUAN). Secondly, in order to provide a real case and assess the second prototype in real conditions, a mini case study (qual) was defined and the prototype was evaluated using a questionnaire (QUAN).

Finally, the results of all levels were integrated for overall interpretation and documentation of the requirements. All these levels were considered to support requirements engineering, as described further in section 3.5.

It is worth noting that, in the multilevel approach (figure 3.5), the whole process is iterated (data collection, analysis, and results). Therefore, repetitive objectives are seen in each level and the overall interpretation is based on merging the results from each level. Chapter 7 describes the results of each level and the methods used for integrating and analysing them.

As shown in figure 3.6, the following research activities were conducted and associated research objectives were addressed in each level.

3.4.1 Literature Review

The following objectives were considered in literature review:

- To study and understand 3D cadastral concepts;
- To study and understand 3D visualisation concepts for cadastral purposes;

In order to achieve these objectives, a comprehensive literature review was undertaken on 3D cadastral visualisation and 3D visualisation. Various resources were utilised to collect a wide range of information in cadastral visualisation. These resources include books, journals, international standards, organisation reports, conference proceedings, 3D visualisation applications, and information published on the internet. The results of the literature review were discussed in chapter 2.

3.4.2 Level 1 of the Research Design

Level 1 looks at the following research objectives:

- To identify and develop 3D visualisation requirements for cadastres; and
- To validate and showcase the developed 3D cadastral visualisation requirements.

In Level 1, a case study was selected and a prototype was developed and evaluated.

- Case Study Selection

The case study approach was chosen to investigate the current status of cadastral visualisation in Victoria and identify the issues and challenges in representing ownership information.

- Requirements Validation Using Prototyping Approach

In this research, the main output is 3D cadastral visualisation requirements. As part of the requirements engineering process, the requirement validation controls the requirements documents in terms of completeness, consistency and accuracy.

To evaluate the requirements identified in the literature, the prototyping approach (Kotonya and Sommerville, 1998) was used. Prototypes allow practitioners to quickly and easily assess the usability of the proposed visualisation requirements.

Prototyping is a solution for bridging the communication gaps in requirements identification and illustrates something concrete to the stakeholders (Kimmond, 1995). A prototype is a preliminary version of a software system developed to elicit and validate the system requirements. A prototype is not an end-product and it may lack some functionality. The developed prototype is discussed in chapter 6.

In Level 1, a prototype was developed to represent the identified requirements. The prototype was presented in a workshop with the project's industry partners and feedback was received.

3.4.3 Level 2 of the Research Design

Level 2 looks at the research objective to

- o Identify and develop 3D visualisation requirements for cadastres.

In this level, participant observation (Jorgensem, 1989) was conducted in two main organisations in Victoria which have a high level of interest in land and property information: the Department of Transport, Planning and Local Infrastructure (DTPLI) and the City of Melbourne.

As described in chapter 1, this research is part of the Land and Property Information Project in 3D[23] and these organisations have an important role in land administration in Victoria. Land Victoria, as part of DTPLI is responsible for registering land and property information in Victoria. The City of Melbourne is a local government area in Victoria located in the central business district of Melbourne. As part of the land administration processes, the City of Melbourne is responsible for urban development.

Investigation of both organisations was essential for this project and research. Therefore, two separate placements were conducted for a period of 4 months in each of these organisations. In addition to participant observation, several interviews were conducted with staff in these organisations and various issues were discussed. The following achievements were attained in the placements:

- o The subdivision process was documented;
- o The current status of representing ownership information was analysed and the challenges were identified;
- o The visualisation requirements of users in these two organisations were identified and documented;
- o Various valuable resourses such as reports, plans, and other types of document were studied which were not available online; and
- o Many meetings and open-ended interviews were conducted with staff and many important points were identified in these meetings.

The results of this activity are presented in chapter 4.

[23] csdila.unimelb.edu.au/projects/3dwebsite

3.4.4 Level 3 of the Research Design

Level 3 was designed based on the following research objectives:

- To identify and develop 3D visualisation requirements for cadastres; and
- To validate and showcase the developed 3D cadastral visualisation requirements.

In Level 3, the following activities were conducted:

3.4.4.1 Questionnaire Design and Implementation

In order to examine and validate the visualisation requirements of cadastral users, a quantitative questionnaire was designed and conducted. The questionnaire targeted land registry and land surveyors, however, those involved in land administration processes such as building managers, developers, and architects were invited to participate. The questionnaire is called *"Questionnaire 1"* in the rest of this thesis and is accessible in Appendix 2.

- Distributing and Selecting Participants

The questionnaire aimed to examine and validate cadastral users' requirements. For this reason, the snowball sampling technique was utilised as it has been widely used (Biernacki and Waldorf, 1981). In this approach, researchers can control who receives the questionnaire and can follow up for further investigations.

The questionnaire was distributed at 3 levels, inVictoria, Australia, and internationally. Many specialists in cadastre and related fields who were identified as important in this research received the questionnaire directly by email. In addition, the questionnaire was distributed by the Institution of Surveyors Victoria, the peak professional association for land surveyors in Victoria.

On a bigger scale, many other experts in other states in Australia received the questionnaire. Also, the questionnaire was posted to the website of the FIG joint commission 3 and 7 Working Group on 3D Cadastres[24] to receive international responses. A link to the questionnaire was also posted in related groups on LinkedIn[25].

In order to choose appropriate participants, working with high-rise developments was considered the main factor in establishing the sample population. In Victoria, there are only a selected number of organisations that are involved in such developments. From these

[24] http://www.gdmc.nl/3DCadastres/
[25] http://www.linkedin.com/

organisations, approximately 30 people have been identified as appropriate participants for this research (using a snowball approach). In light of the small population size, 28 responses were required to achieve a confidence level of 95% and a 5% margin for error, and due to close collaboration and relationships with these organisations, a high response rate was received. However, due to the high interest of other stakeholders, organisations and experts, the questionnaire was distributed on a broader scale. A total of 197 responses were received. However, only 93 responses were completed and the rest were partially answered. As such, the response rate was higher than the scope of the research.

- Designing Questionnaire

The questionnaire was designed including the following four sections:

Section (1): Introduction

This section introduced both research and questionnaire.

Section (2): Participant's information

This section collected the names of organisations which participants come from, their level of experience in cadastre, and area of expertise.

Section (3): Organisational spatial data characteristics

This section focused on collecting organisation's activities regarding cadastral data, such as kind of visualisation media, the current challenges and issues associated with visualising 3D models, and the drivers and motivations to move to 3D.

Section (4): Visualisation requirements identification.

Section four had five parts, which sought information on required data elements, analytical requirements, user interface and system requirements, technical requirements, and visualisation requirements.

The questions were multiple-choice selections or required only short answers; however, in some instances an option for further comment was also provided.

- Questionnaire Refinement

The questionnaire was checked internally and externally to avoid any misinterpretations. A draft version of the questionnaire was prepared in digital format and distributed to the members of the Land and Property Information in 3D Project at the Centre for SDIs and Land Administration (CSDILA) in the Department of Infrastructure Engineering at the University of Melbourne. In addition, two people external to the University of Melbourne with backgrounds in cadastre were invited to examine the questionnaire to check various aspects such as terminology and understanding of questions. The questionnaire was updated reflecting the feedback received. Then, the on-line questionnaire was generated in SurveyGizmo and tested internally to ensure that the on-line questionnaire was accessible and also that responses were being recorded at the server.

The link to the on-line questionnaire was sent by email to the participants and their responses were recorded at the server.

- Ethics Considerations

In order to distribute the questionnaire, an appropriate ethical approval was gained from the Human Research Ethics Committee at the University of Melbourne. The collected data is kept in a secure environment during and after the collecting period.

3.4.4.2 Prototype Implementation and Evaluation

In this Level, the second prototype system was designed and implemented for 3D cadastral visualisation. To evaluate the requirements identified in previous Levels, the prototyping approach was utilised. In order to evaluate the usability of the second prototype, a questionnaire was designed and distributed among users after presenting the prototype. The implementation and evaluation of the prototype are explained in chapters 6 and 7 respectively.

These levels are part of the big picture of the requirements engineering process, which is the main activity in developing 3D cadastral visualisation requirements. The requirements engineering process is explained in the next section.

3.5 Requirements Engineering

This section describes the process of requirements engineering for 3D cadastral visualisation.

Requirements engineering is getting more and more attention in recent years (Escalona and Koch, 2004) and many methods for requirements engineering are discussed in the literature (Alford, 1977, Gause and Weinberg, 1989, Thomas, 1996, Kotonya and Sommerville, 1998, Berenbach *et al.*, 2009). Requirements engineering assists in the process of software development to enhance the efficiency of the final product.

A requirement is defined as *"A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standards, specification, or other family imposed documents"* (IEEE Standard, 1990, Page 62). Requirements engineering is "*all of the activities involved in discovering, documenting and maintaining a set of requirements for a computer-based system*" (Kotonya and Sommerville, 1998, Page 8) and requirements definition is the process of carefully developing of the needs of a system. Ross and Schoman (1977, Page 6) stated that a requirements definition *"must say why a system is needed, based on current or foreseen conditions, which may be internal operations or an external market. It must say what system features will serve and satisfy this context. And it must say how the system is to be constructed"*.

Requirements engineering process includes inputs and outputs according to figure 3.7.

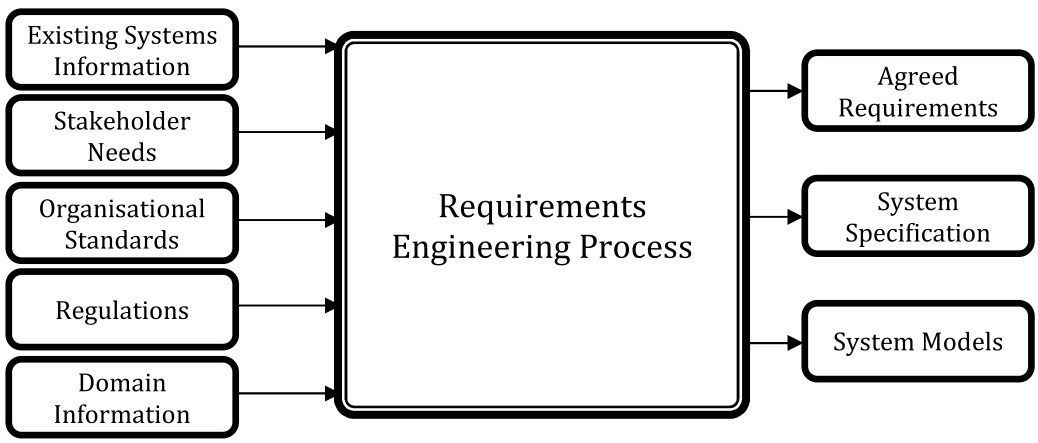


Figure 3.7: Inputs and outputs of the requirements engineering process (Kotonya and Sommerville, 1998).

Inputs are often information about existing systems and their functionality or limitations. Stakeholder needs are what they expect in the system to fulfil their tasks. Organisational standards and regulations are the agreed documents from the stakeholders which define conditions and affect the system. Domain information is information about the context of the developing system.

Agreed documents are finalised and approved by stakeholders. System specification is a detailed document of the system's functionality. System models describe the system from various views such as data flow model or process model.

The activities in requirements engineering depends on the context of system development and may include (Kotonya and Sommerville, 1998):

1- Requirements elicitation;

2- Requirements analysis and negotiation;

3- Requirements documentation; and

4- Requirements validation.

In the requirements elicitation process, system requirements are identified through related existing system documents, discussion with stakeholders, contextual knowledge and existing systems in the market. Lloyd and Dykes (2011) investigated human-centred approaches, following ISO13407, to elicit requirements for geo-visualisation application design in crime management. They concluded that a common understanding of the context of use, domain, and visualisation options are very important to achieve a successful design. In the next step, identified requirements are analysed in more detail in order to verify the requirements. This process is necessary in order to avoid conflicts in the requirements. The finalised requirements are documented with details that can be understood by all stakeholders. At the final stage, requirements are validated for completeness and consistency (Kotonya and Sommerville, 1998). Figure 3.8 illustrates a commonly used type of process model for requirements engineering, called the coarse grain activity model, which represents the main activities in requirements engineering and gives an overall picture (Kotonya and Sommerville, 1998).

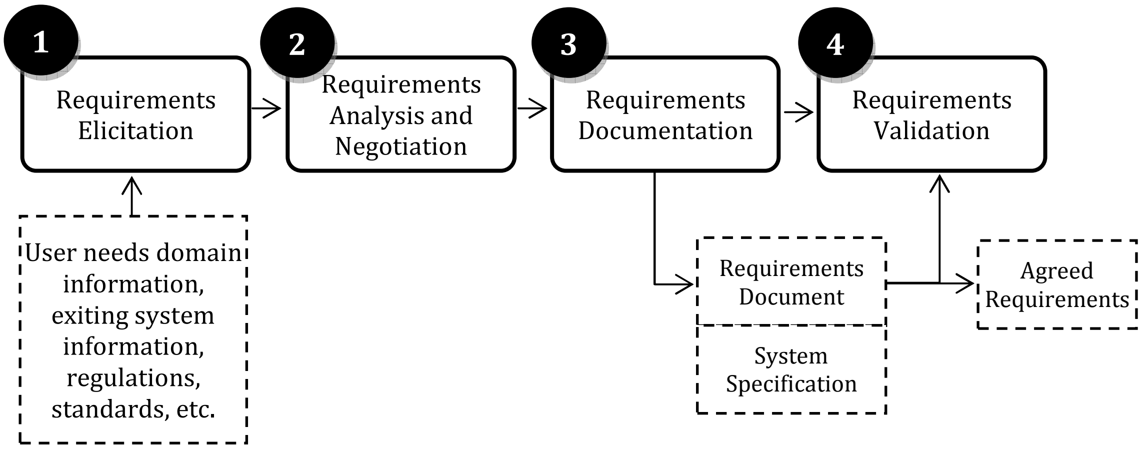


Figure 3.8: The activity model of the requirements engineering process (Kotonya and Sommerville, 1998).

3.5.1 Requirements Elicitation

Discovering requirements is the first step towards developing a computer-based system. In this activity, system developers and associated specialist interact with the end users, stakeholders or customers in order to identify various aspects of a system including the existing problems, the system domain, and the required efficiency (Kotonya and Sommerville, 1998). Various techniques are used to elicit the requirements. The main sources of information are existing documents and system users. Some of the other important methods are:

- Interviews

Interviews are a traditional and common approach in requirements elicitation. Requirements engineers talk to the stakeholders in order to understand the problems and define the objectives of the application. Interviewing includes four steps, namely stakeholder identification, preparing the interview, conducting the interview, and documentation of the interview (Escalona and Koch, 2004). There are two types of interview: closed interviews with pre-defined questions; and open-ended interviews with no predefined questions.

- Joint Application Development (JAD) and Brainstorming

In this approach, all stakeholders participate in several meetings and requirements are analysed and documented in each session. JAD saves time as it concludes the requirements quickly. Brainstorming is similar to JAD as it is a group meeting from all stakeholders in order to collect non-evaluated ideas (Escalona and Koch, 2004).

- Scenarios

Several scenarios are developed and users are asked to interact with a computer application (Weidenhaupt *et al*., 1998). During the interaction, requirements are discovered by monitoring the users and documenting their interactions with the system (Kotonya and Sommerville, 1998).

- Participant Observation and Social Analysis

This is passive observation in which observers spend time with a group in order to carefully document their interaction and activities (Kotonya and Sommerville, 1998).

- Questionnaire

This is an important approach which includes preparing some questions for the stakeholders. The questionnaire can be administered in a meeting or sent directly to the participants. Preparing the questions requires good knowledge about the domain (Escalona and Koch, 2004).

- Prototyping

Prototyping illustrates something concrete to the stakeholders, and can thus fill communication gaps in requirements identification (Kimmond, 1995). A prototype is a preliminary version of a system used to elicit and validate the system requirements. A prototype is not an end-product and may lack some functionality. Obvious requirements need not be implemented in the prototype. There are two main types of prototypes. “Throw-away” prototypes are ignored after developing the main system, while evolutionary prototypes are extended and converted into the final product (Kotonya and Sommerville, 1998). The requirements which are clear, should not be developed through throw-away prototypes (Saqi and Ahmed, 2008).

3.5.2 Requirement Analysis and Negotiation

A requirements analysis should develop an agreed list of requirements which is complete and consistent. This requires skilled and experienced people to check the requirements and resolve the conflicts or remove overlapping requirements. Requirements negotiation is important to discuss the issues and problems in the requirements in order to resolve conflicts among stakeholders and finalise the requirements acceptable by all stakeholders (Kotonya and Sommerville, 1998).

3.5.3 Requirements Documentation

This phase is usually conducted during the previous phases and the findings are reviewed and finalised along with the progress of the project. Specification can be generated as the output of requirements engineering. *"Specification [...] means ensuring that the requirements documents represent a clear description of the system for design and implementation and is a final check that the requirements meet stakeholders' needs"* (Kotonya and Sommerville, 1998, Page 89).

Various organisations, such as the US Department of Defense and the IEEE, have developed standards for requirements documentation. One of the best is "IEEE Recommended Practice for Software Requirements Specifications [SRS]" (IEEE Std 830, 1998), which suggests a template for documenting the requirements.

Based on the IEEE Standard, developing a specification should help in the following ways (IEEE Std 830, 1998):

a) System users can accurately explain what they wish to obtain;

b) System developers understand exactly what the users need;

c) Others can also benefit from this standard to:

1) Develop requirements specification for their organisations; and

2) Develop a template and content of their specific software requirements specifications.

The following template (figure 3.9) was suggested by IEEE (IEEE Std 830, 1998) which represents an outline for writing an SRS.

Table of Contents
1. Introduction
1.1 Purpose
1.2 Scope
1.3 Definitions, acronyms, and abbreviations
1.4 References
1.5 Overview
2. Overall description
2.1 Product perspective
2.2 Product functions
2.3 User characteristics
2.4 Constraints
2.5 Assumptions and dependencies
3. Specific requirements (External interfaces, Functions, Performance requirements, Logical database requirements, Design constraints, Organising the specific requirements, and Additional comments)
Appendixes
Index

Figure 3.9: An outline for writing an SRS suggested by IEEE (IEEE Std 830, 1998).

3.5.4 Requirements Validation

Requirements validation controls the requirements documents in terms of completeness, consistency, redundancy, comprehensibility, and ambiguity (Kotonya and Sommerville, 1998). In this process, organisational standards, acts, regulations and domain knowledge are used by professionals in order to validate the requirements document.

There are different kinds of requirements validation techniques available in the literature some of them are as follows (Kotonya and Sommerville, 1998, Saqi and Ahmed, 2008):

- Requirements Reviews;
- Requirements Inspections; and
- Requirements Prototyping.

A traditional technique in requirements validation is requirements review (See figure 3.10). A group of specialists review the requirements and discuss the problems in order to finalise the list of requirements. In the process they monitor ambiguities, missing information, requirements conflicts and unrealistic requirements (Kotonya and Sommerville, 1998).

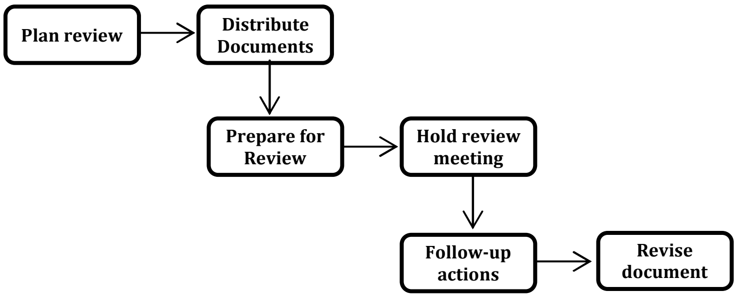


Figure 3.10: The requirements review process (Kotonya and Sommerville, 1998)

Requirement inspection is similar to requirements review, but includes inspecting software to find the defects of a product. Inspection is a costly and time consuming process as a large number of software artifacts need be analysed, searched and sorted for this purpose (Saqi and Ahmed, 2008).

Prototyping is another way to validate the documented requirements. In some cases, it is very difficult to imagine how written requirements can be converted to a computer system. Therefore, developing a prototype demonstrating the requirements to the stakeholders makes it easier for them to find the issues and problems and suggest how to enhance the efficiency of the final system (Kotonya and Sommerville, 1998).

In this research, requirement review and prototyping techniques were used for requirements validation as these techniques were most feasible and quick approaches. Chapter 7 describes these processes and results.

3.6 Chapter Summary

This chapter explained the research design and described the methods utilised in this research. Firstly, the conceptual design framework was described and the research problem and objectives were explained. Various research methods (qualitative and quantitative) were then discussed and the most suitable approach for this research was chosen and justified.

As part of the research design, Melbourne metropolitan area in Victoria was selected as a case study to investigate 3D visualisation requirements. Two prototypes were designed and various methods were considered for evaluation and validation of the results and finding.

In addition, due to the importance of requirements engineering in this research, various steps in requirements engineering were discussed along with the developed conceptual framework (figure 3.6). In this multi-level approach, various steps of requirements engineering were conducted in the context of 3D cadastral visualisation.

In the next chapter, the current practice of RRRs representation in Victoria, Australia is discussed based on the participant observations, interviews, and two mini case studies conducted in this research.

CHAPTER 4

CURRENT PRACTICE OF RRRs REPRESENTATION: VICTORIAN CASE STUDY

"Visualize this thing that you want, see it, feel it, believe in it. Make your mental blue print, and begin to build."

–ROBERT COLLIER

4 Current Practice of RRRs Representation: Victorian Case Study

4.1 Introduction

This chapter discusses the results of the qualitative case study investigations to identify the current practice of visualising RRRs in Victoria, mainly in the case study region of the Melbourne metropolitan area in Australia. The aim is to identify the current practice and challenges in representation of RRRs for the case study region.

To understand these challenges, firstly Victorian land administration systems and the land registry organisation are introduced. The current practice of RRR presentation is then explained using two cases in Melbourne. Next, the challenges in visualisation of RRRs are described. Figure 4.1 presents the structure and discussions in this chapter.

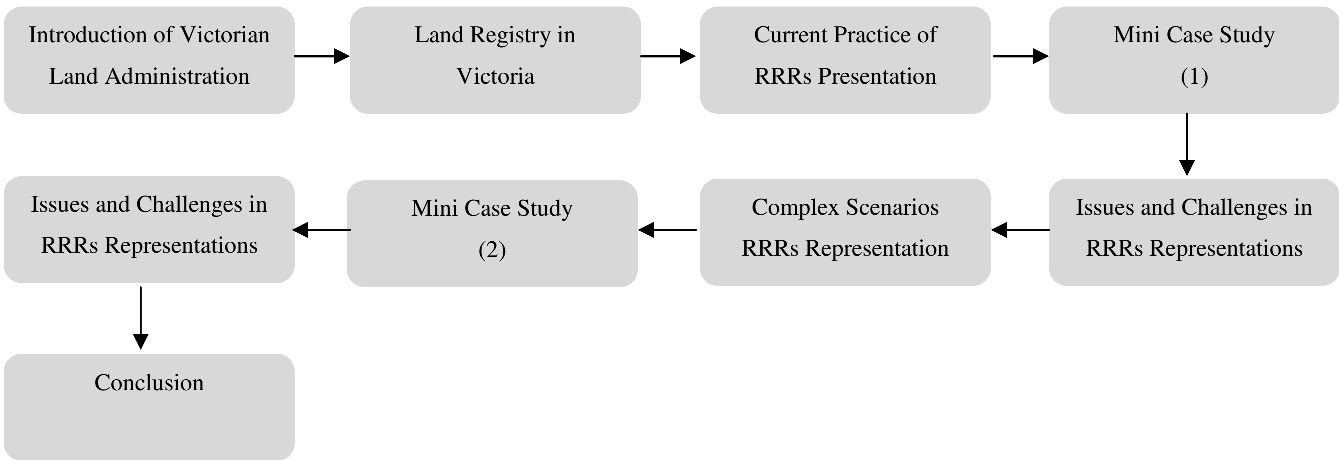


Figure 4.1: Topics and their relations in this chapter.

4.2 Victorian Land Administration Systems and Land Registry

There are three levels of government in Australia, namely federal, states and local governments. Each level has different tasks. Defence, foreign affairs, trade and commerce, taxation, customs and excise duties, pensions, immigration and postal services are duties of the Federal Government. States and local governments are responsible for health, education, state transport networks, town and planning and land administration (Dalrymple *et al.*, 2003).

Land administration is performed under a range of government departments such as environment, planning, lands or land administration (Aien, 2013).

Land administration systems provide an infrastructure for implementing land policies and land management strategies. In modern administration, 'land' includes resources, the marine and its environment, buildings, and all things on, above and under the ground surface (Williamson *et al*., 2008).

Land administration monitors development proposals and change in land use according to adopted planning regulation and land-use laws. It also determines land ownership boundaries based on building regulations (Williamson *et al*., 2010).

Land administration systems differ according to laws and regulations in each jurisdiction. However, the overall aim of land administration is managing land efficiently to achieve sustainable development.

The role of land management in delivery of sustainable development is based on using the land management paradigm to use various tools to manage common land related processes. One of the fundamental tools is cadastre, the vital information layer of a land management system (Williamson *et al*., 2010).

In Victoria, the Department of Transport, Planning, and Local Infrastructure (DTPLI)[26] is responsible for land administration. DTPLI has different sections with various tasks. Land Victoria is the section responsible for managing land titles and property information, valuations, surveying, geodesy, and naming places.

Before introducing the Land Registry in Victoria, a background is necessary.

4.2.1 Geography, Population, and History of Victoria

Australia has eight jurisdictions which all operate under a system of Australian government (Kalantari, 2008). This provides each state a high level of autonomy (Karki *et al*., 2013a). Australia is a developed country in south hemisphere with the area of 7,692,024 square kilometres[27] and it has the position of sixth in big countries in the world. The capital is Canberra and has eight states and territories. Melbourne is one of the big cities which is located in Victoria state (See figure 4.2).

[26] http://www.dtpli.vic.gov.au/

[27] http://www.ga.gov.au/education/geoscience-basics/dimensions/area-of-australia-states-and-territories.html

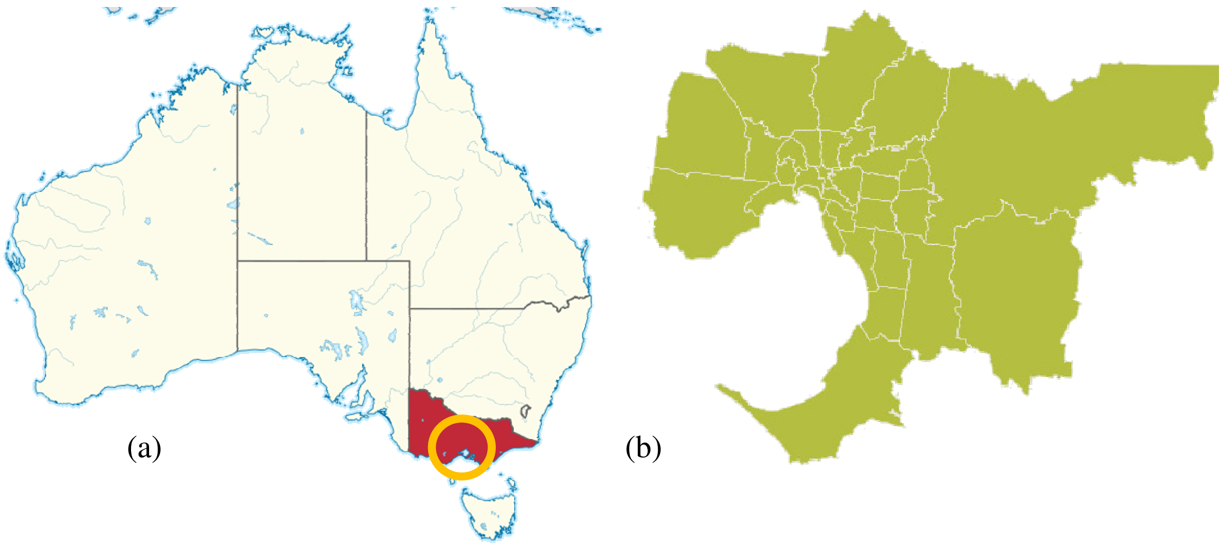


Figure 4.2: Australia and Victoria state. (a) Australia, Victoria, Melbourne; (b) Melbourne metropolitan area.

The Australian population is over 23,000,000 and Victoria's population is more than 5,000,000 (ABS, 2014). Although land administration in all states is based on the Torrens Titling System (Williamson *et al.*, 2010), the systems in each jurisdiction are different. Before the Torrens System, a general law title system operated in Victoria. For seventy years after European settlement in Australia, the English general law was used for deeds registration (Dalrymple *et al.*, 2003).

A general law title included a chain of title deeds to guarantee and enable transferring a property. The problem was that it included many deeds which were handwritten and not clear. Missing deeds could create difficulties in transferring a property (Land Victoria, 2012a).

In the mid-1850s, Robert Torrens introduced a new system to simplify land transfer, as the general law system was expensive, complicated and inefficient (Williamson, 1984). After two decades, all states adopted the Torrens System, with some changes according to local systems and their needs (Dalrymple *et al.*, 2003).

This system was adopted based on successful implementation of the system in South Australia in 1858. It was the modern method of registration at that time (DTPLI, 2014b), and has an important role in developing a secure and reliable land titling system in Victoria.

The Torrens System plays a significant role in land administration in Victoria, used to register ownership rights and interests on land. This system only introduces the current owner and does not provide long complicated documents, such as title deeds. In addition, the government guarantees to provide compensation in case of loss of land or a registered interest (DTPLI, 2014b).

With the progress of computer technology, computerised cadastral systems have been improved over the past decade to enhance land registry services. In addition, legislation is being updated to accommodate new types of needs and expectations, such as vertical subdivision and apartment ownership (Dalrymple *et al.*, 2003). Table 4.1 summarises some of the Acts and regulations in Victoria since the 1940s.

Table 4.1: Acts and regulations in Victoria (Land Victoria, 2012b).

Legislation and regulations	Period
Company Shares	1940s
Stratum Act	1950's-1967
Strata Act	1967-1988
Cluster Titles Act	1974-1988
Subdivision Act	1988-Present
Subdivision (Procedures) Regulations 2011	2011-Present
Building Subdivision Guidelines	2012-Present

In company shares, a company owns the land and buildings and sellers have a block of company shares entitling them to sell it.[28] In the other words, the owner has a part of the building rather than owning a separate disposable title (Land Victoria, 2012b). In these cases, there is no subdivision and only one parcel is presented.

The need for apartments increased significantly after World War II and this demand led to the creation of stratum title (Paulsson, 2007). Under stratum title, property is subdivided into lots. The owner of each unit (lot) holds a shared right in a company which owns and manages common property (Consumer Affairs Victoria, 2013). The service company is responsible for managing the building and there is an agreement between the owners and the service company to clarify the rights, restrictions and responsibilities. The interesting point of the Stratum Act was measuring and recording heights on the plans[29].

Due to some disadvantages of stratum title, such as finding a company to be involved, difficulty in getting financing, and an increase in the number of documents, subdivision plans

[28] http://news.domain.com.au/domain/real-estate-news/the-other-titles-of-ownership-20130815-2rxix.html
[29] (J. Matthews, personal communication, November 20, 2012)

became more complex (Paulsson, 2007). Therefore, stratum title converted to strata title. In the 1967 Strata Titles Act, a body corporate was introduced to manage common property and there was no need to involve a service company.

In strata title, a certificate is issued for the lot and parking lot and there is no need to issue it for common property areas. Like a service company, a body corporate is assigned for maintenance of the apartment. The Strata Act also allowed boundaries to be defined by buildings, including upper and lower boundaries. However, easements could not be created and part lots were not allowed (Land Victoria, 2012b).

The Cluster Titles Act combined elements of the Transfer of Land Act Plans and Strata Act Plans. In this Act, easements, reserves, and restricted lots (e.g. car park) were allowed (Land Victoria, 2012b). However, the subdivision process was considered complex, costly and time consuming.

The Subdivision Act 1988 approved the subdivision process at the earliest stages with minimal expenses. It also combined the subdivision approval process with the planning process (Paulsson, 2007).

The Subdivision Act came into force in 1988 and changed some of the existing Act and processes. For example, if a common property exists on the plan, a body corporate will be automatically created. Following an amendment to the Subdivision Act 1991, no title is issued to the common property and those already issued may be recalled by the land registry (Paulsson, 2007).

The Subdivision Act had additional benefits for developers, such as that planning permits could be issued at any time, stamp duty was minimised, cancellation of restrictive easements was made easier, and the staging process was simplified (Paulsson, 2007).

In October 2011, the Subdivision (Registrar's Requirements) Regulations 2011 came into effect (LandVictoria, 2012) with the aim of narrowing the interpretation of building boundaries. The Building Subdivision Guidelines (LandVictoria, 2012) have also been developed to guide the preparation of subdivision plans for surveyors.

4.2.2 Land Registry Organisation in Victoria

As mentioned above, Land Victoria is responsible for land administration in Victoria. Specifically, it manages land titles and records, the Victorian water registrar, property valuation, surveying, online property information and services, electronic conveyancing, SPEAR (Streamlined Planning through Electronic Applications and Referrals) and geographic place names.[30]

There are about 3.2 million titles recorded in databases in Land Victoria. After using the Torrens System for more than 150 years, many technological changes have been made and more computer systems (such as Victorian Online Titles System (VOTS)) are used for titling. There are many countries using this system such as England and Wales, Ireland, Malaysia, Singapore, Iran, Canada and Madagascar (DTPLI, 2014b).

Land Victoria has several sections and each section is responsible for different tasks. Figure 4.3 illustrates the organisation structure of Land Victoria.

[30] (Land Registry, personal communication, November 5, 2012)

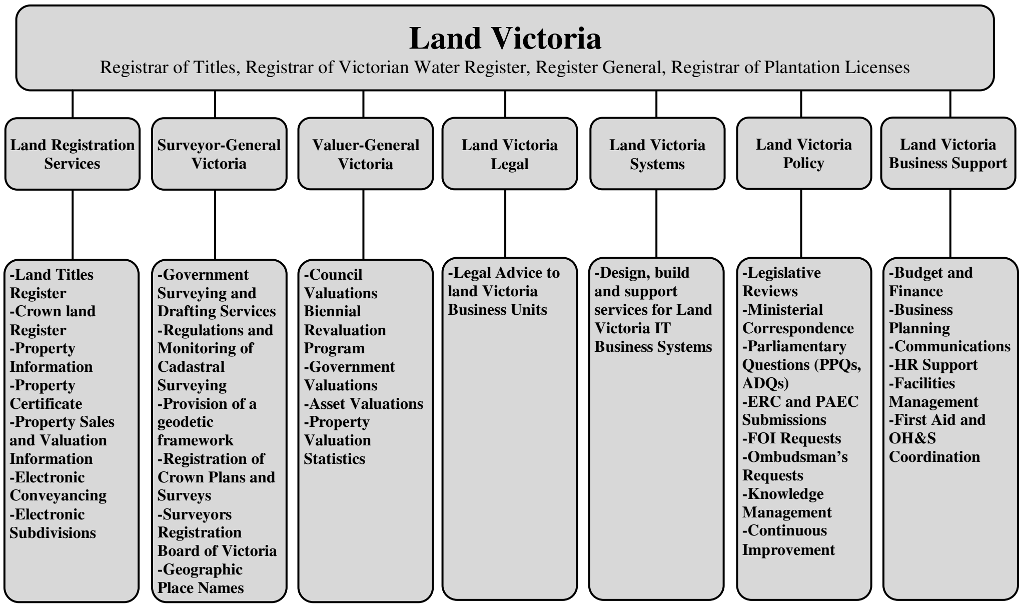


Figure 4.3: Land Victoria organisation structure (DTPLI, 2014a).

- **Land Registration Services**

Land Registration Services provide users with secure, accurate and guaranteed authoritative data or services for property, plan and water share transactions through various solutions to enhance the property and development industries (DTPLI, 2014a).

- **Surveyor-General Victoria**

The Surveyor-General of Victoria is the primary government authority on surveying and the cadastre. The Surveyor-General's roles include a diverse range of Acts and Parliament regulations, with responsibilities including land administration, planning, surveying, the electoral system, geographic place names, regulation, geodetic infrastructure and survey control network, protection of the cadastre, providing technical advice and guidelines for surveying, developing standards for surveys, and industry leadership (DTPLI, 2014a).

- **Valuer-General Victoria**

The Valuer-General oversees valuations for State Government property transactions and the making and return of council rating valuations. The Valuer-General also estimates government assets for departments and authorities to complete their financial reporting requirements (DTPLI, 2014c).

- **Land Victoria Legal**

The Land Victoria Legal office provides legal advice to the land registry and other Land Victoria branches.

- **Land Victoria Systems**

Land Victoria Systems provides design, build and maintenance services for Land Victoria's business systems.

- **Land Victoria Policy**

The Land Victoria Policy Section provides legislative reviews, ministerial correspondence, ombudsman's requests, knowledge management and continuous improvement.

- **Land Victoria Business Support**

Land Victoria Business Support provides Land Victoria with various services such as supporting budget and finance, business planning, communications, HR Support, facilities management, and first aid and OH&S coordination.

After describing the land registry organisation in Victoria, the current practice of presenting RRRs is discussed in the following section.

4.2.3 Current Practice of RRRs Representation-Mini Case Study (1)

As the importance of 3D cadastre is highly significant in dense populated areas, the focus of this research is limited to visualisation of RRRs in urban areas. Therefore, Melbourne metropolitan area was selected for the first mini case study in to investigate the current approach to visualisation of RRRs and identify the issues and challenges.

4.2.3.1 Mini Case Study (1) – the University Square Underground Car Park

The University of Melbourne has an underground car park in the south part of the Parkville Campus (figure 4.4). The reason for choosing this location for the mini case study was to investigating the issues and challenges for representing ownership boundaries. This car park was an interesting case as it is located under several land parcels and road segments.

- **Mini Case Study Description**

This car park has two main entrances from Bouverie Street and Berkeley Street. Drivers and passengers can have access to the car park using elevators located on Grattan Street. Figure 4.4 (c) shows the location of the car park and its extend.

Figure 4.4: Mini case study (1) location; (a) Australia, Victoria, Melbourne; (b) The University of Melbourne Campus; (c) University Square Underground Car Park, (Google Maps, 2012).

The DCDB of Victoria has the equivalent map for representing this car park. Figure 4.5 represents the existing geometrical representation on DCDB. In this figure, 6 boxes show the location of existing infrastructure (elevators and air conditioners) of the car park.

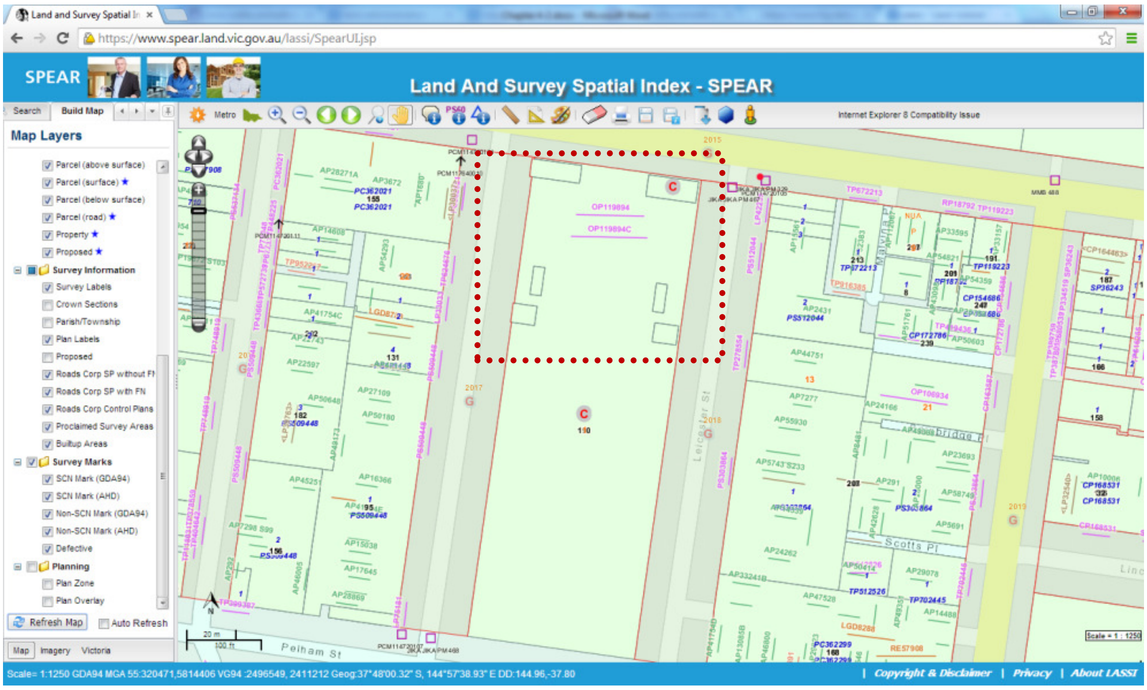


Figure 4.5: The existing geometrical information in DCDB[31].

In addition to the DCDB, the survey plan of this car park is presented in figure 4.6, which shows the extent of the car park below multiple parcels and road segments.

[31] https://www.spear.land.vic.gov.au/lassi/SpearUI.jsp

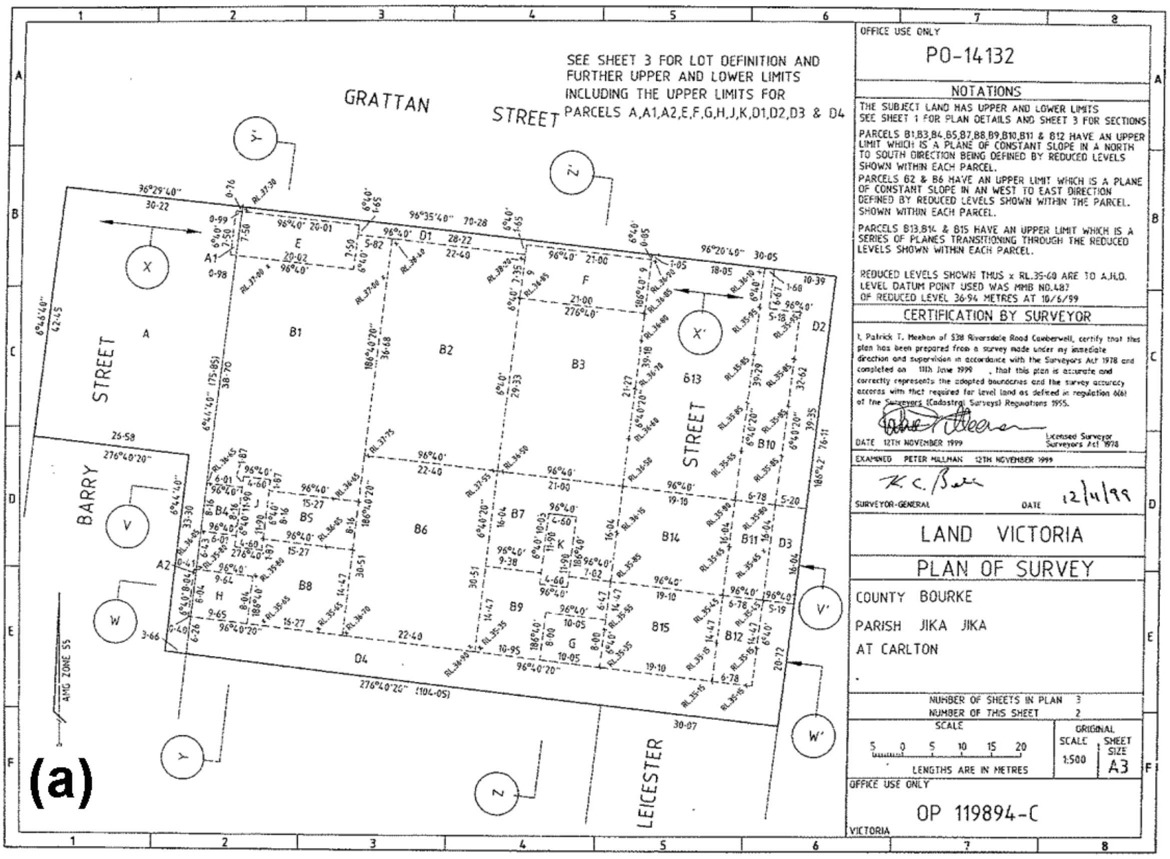


Figure 4.6: (a) OP plan representing the crown land.

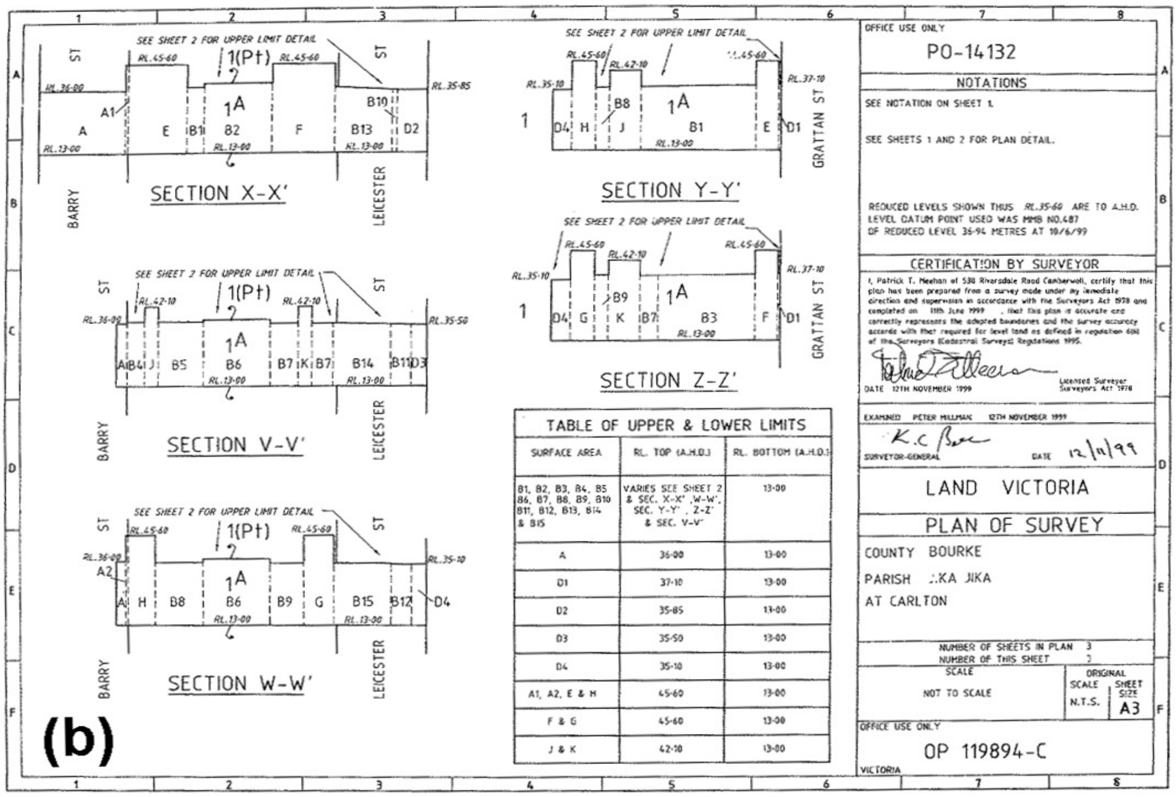


Figure 4.6: (b) cross-sections show the height information using RL (Reduced Level).

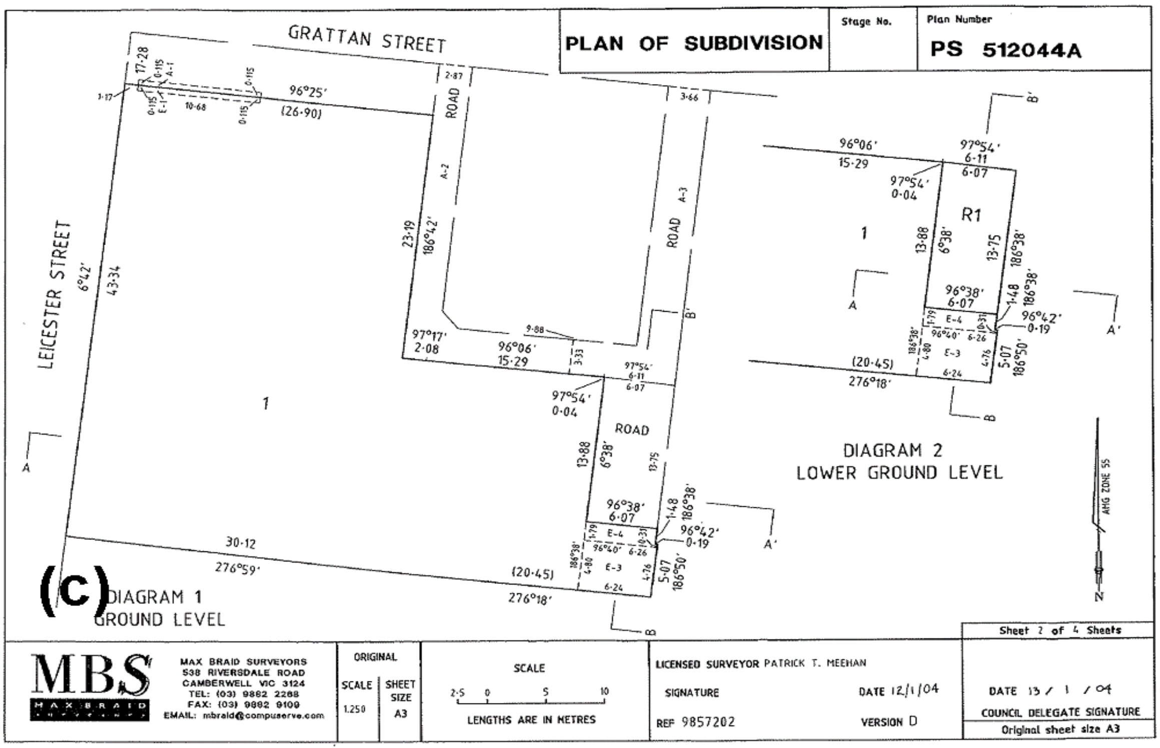


Figure 4.6: (c) Plan of subdivision of the left wing of the car park.

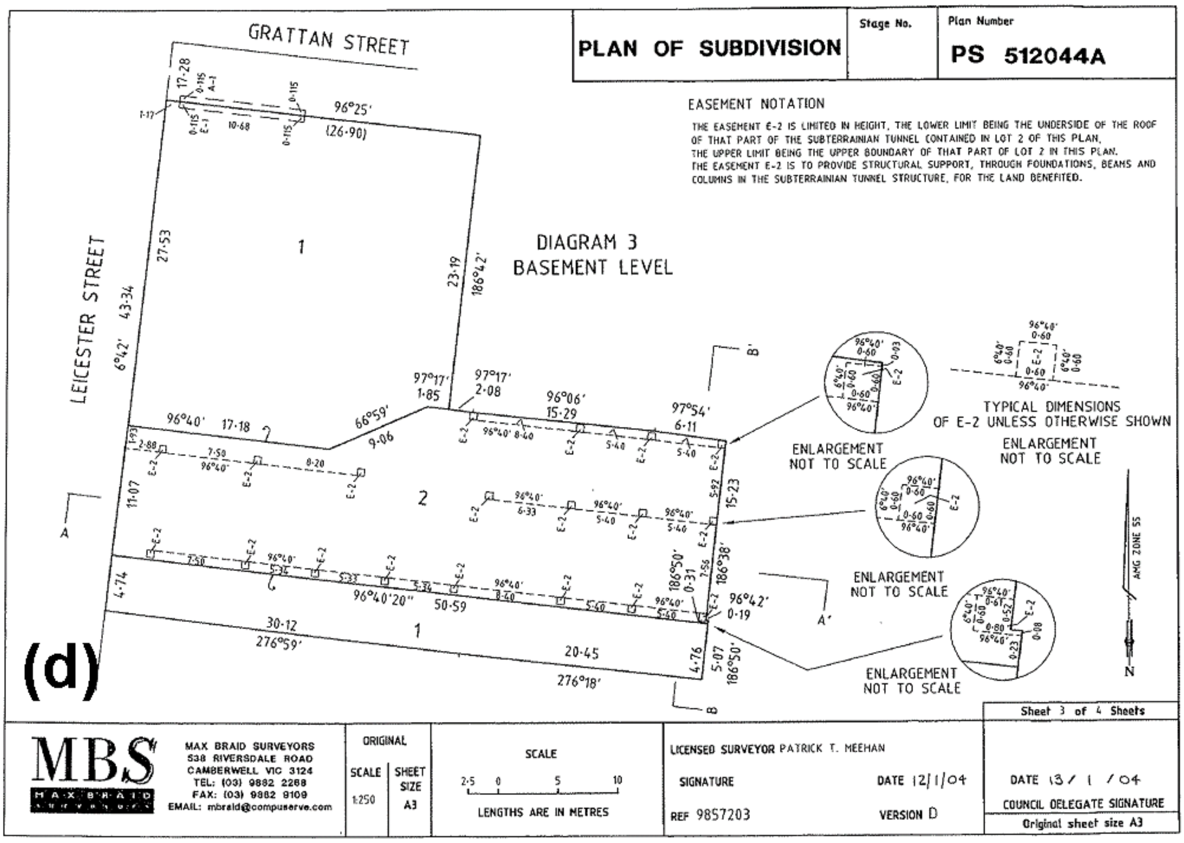


Figure 4.6: (d) Plan of subdivision of the right wing of the car park.

Figure 4.6 (a) represents the OP plans, which stand for Original Plans (Crown). This figure shows the survey observations including bearings, distances and reduced levels (RL) of roofs and ceilings. Reduced levels are represented in plans are based on the AHD (Australian Height Datum). Figure 4.6 (b) represents some cross-sections from different directions, including height and depth limitations. Figure 4.6 (c) shows the subdivision plan of the west wing and figure 4.6 (d) shows the east wing, which is the entrance ramp to the car park. Easements also can be seen in this figure.

The survey plans were back-captured using AutoCAD Map 3D to provide a digital and accurate 2D map. Then, field work was conducted to measure the heights of different parts which had not been recorded on the plans. Finally, the 2D map was converted to a 3D model using SketchUp. All information about the ownership rights such as lots, easements, cadastral observations (bearings and distances) were extracted from the survey plan for prototype development. A 3D model of the car park was generated and illustrated on figure 4.7. The 3D model only shows the physical view of this car park.

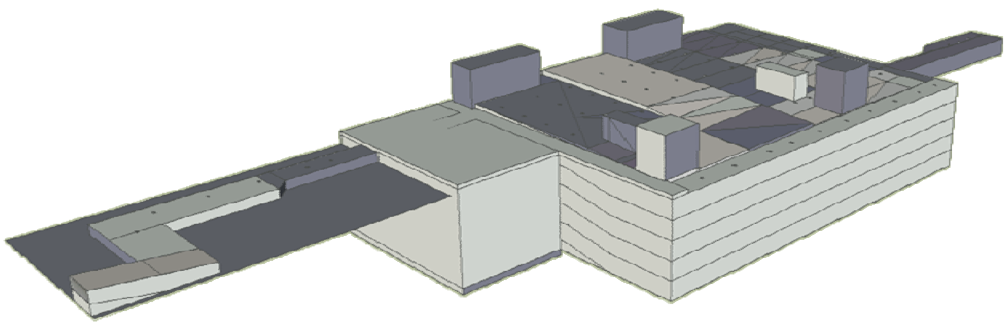


Figure 4.7: 3D model of the car park. A physical view represents the whole structure and entrances.

- **Analysing the issues and challenges in representing RRRs in mini case study 1**

By analysing this mini case study as a sample of the current approach in representing RRRs in Victoria, several challenges are identified:

- Some of the height and depth limitations are not represented geometrically in the plan, only described by text;
- The car park is located underneath several land parcels which are not visualised in the plan. Therefore, understanding the current status using the plan is not simple;
- Notations on the plan are sometimes difficult to read particularly in old survey plans;
- In case of complex scenarios, multiple plans and cross-sections are required to illustrate the ownership boundaries;

- There is not enough and clear information regarding adjacent land parcels on the plan;
- Due to the restrictions on the paper-based plans, enlargement methods were utilised to describe the detail of small easements (figure 4.6 (d));
- Interpretating the plans is very time-consuming;
- Understanding of the plans requires a high level of expertise and only expert users can understand them;
- Interaction and real 3D property objects cannot be seen easily and any overlap or clash cannot be detected easily; and
- There is no information about physical objects in this plan.

These results show that representing ownership boundaries in a 2D approach is not efficient and even experienced land surveyors require time to understand the situation in complex scenarios.

This mini case study was an introduction to the current practice of visualising RRRs in urban areas. Currently RRRs are registered under the Subdivision Act 1988 In land administration processes, the subdivision process represents the largest economic value and is of vital importance to the economy of land registries (Zevenbergen and Stubkjær, 2005). Therefore in the next section, the subdivision process in Victoria is studied in more detail to identify how RRRs are represented for various users in this process. What are the issues? And how data is collected and visualised?

4.2.3.2 Subdivision Process in Victoria

Researchers have documented the subdivision process in various jurisdictions (Zevenbergen and Stubkjær, 2005, Paulsson, 2007). Paulsson (2007) identified four main stages: issuing the planning permit, a certified plan of subdivision, a statement of compliance, and issuing titles in the subdivision process.

Dalrymple *et al.* (2003) outlined the involvement of professionals in the subdivision processes (table 4.2). They identified the major players in the land administration as land owners, land developers and planners, land surveyors, conveyancers (lawyers and others), real estate agents, and financial institutions.

Table 4.2: Subdivision of Land Process and related professionals (Dalrymple *et al.*, 2003).

Procedure	Who
Purchase/own a parcel of land and the certificate of title	Land owner
Prepare subdivision design – refer to council and state regulations	Surveyor/Planner
Apply for subdivision permit – submit plan	Surveyor/Planner Referral Authorities
Discuss subdivision design – review by independent authorities	Client, Council, Surveyor/Planner, Referral Authorities (Water, Sewerage, Gas, Electricity and Telecommunications)
Conduct Final survey – re-establish the boundary, connect to AMG	Licensed Surveyor
Full plan of subdivision – establish new individual parcels	Client submission Council approval
Issue Titles	Land Registry

In the case of dividing land into two or more new parcels, subdivision plans are required. Various types of new parcels, including lots, roads, reserves and common property, can be created by subdivision. Subdivision plans are lodged under Section 22 of the Subdivision Act 1988. In addition to subdivision plans, consolidation plans are created for consolidating two or more parcels of land into one parcel which are based on Section 22 of the Subdivision Act 1988 (DTPLI, 2014b).

The subdivision process may start with an owner(s), who may approach real estate agents, land surveyors, or architects to start the subdivision process. Figure 4.8 illustrates a snapshot of the subdivision process and professionals involved.

Real estate agents give market advice to the owner and land surveys to establish the boundaries, and architects start designing the building. In this process, developers can assist in giving advice for designing the building from an engineering point of view.

After finishing the design phase, a plan of subdivision is prepared by a licensed land surveyor. The licensed surveyor uses surveying techniques and existing documents such as architectural plans to prepare the subdivision plans. This is a very time-consuming process as many meetings are conducted to consider the advice of developers, architects, and owners' corporations.

The agreed and finalised subdivision plan is submitted as part of an application to the relevant council in person, post, or online (SPEAR) to obtain a planning permit and to certify the plan. The number of applications for subdivisions varies in each council. For example, one of the councils in Victoria receives about 100 subdivisions every year.[32]

The vast majority of applications need a planning permit. Aplanning permit is required to give permission for a use or development on a particular piece of land. For example, a planning permit is required for "*constructing or altering a building, starting a new use on land, displaying a sign, subdividing land, and clearing native vegetation from land*" (DTPLI, 2013) .[33]

In most subdivisions, the application is advertised by either signage on site, mailing to affected owners, and/or by public notice in the local paper (CoM, 2010).

On receipt of the formal application, the responsible council refers the application to all the relevant referral authorities within 7 days of receipt of the application. Referral authorities then have 21 days to respond with their conditions and requirements. In some cases, referral authorities may request further information (CoM, 2010). Referral authorities include:

- Electricity and Gas
- Environment
- Fire
- Heritage and Culture
- WorkSafe Victoria
- Roads and Transport
- Water
- Industry
- Telecommunication
- Planning and Land

The council monitors the subdivision plan against the Planning and Environment Act 1987, the Planning Scheme and the Subdivision Act 1988 for any inconsistency. Inconsistencies include whether the plan meets the requirements of the planning scheme and other regulations related to the boundaries of roads, lots, common property and reserves and the form and plan content (DSE, 2003).

[32] (City Council, personal communication, October 31, 2013)
[33] More information about the Planning Permit can be found: http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0018/41274/Chapter_3_Planning_Permits.pdf

In case of any restrictions to the plan, this must be provided in writing on the plan and certified by the council. Referral authorities can specify conditions on the planning permit through the council.

If the plan conforms to the Subdivision Act, the plan is certified by the council. The certified plan is valid for five years. Any disputes for the plan can be sent to the Victorian Civil and Administrative Tribunal (VCAT)[34].

VCAT can review an application for the following reasons (DPCD, 2012):

- If an authority does not make a decision within the time frame;
- A responsible authority refuses a permit application; and
- In case of any conditions on the permit.

As part of the subdivision process, the responsible council issues a property address according to regulation 11 (Subdivision Regulations 2011), which gives notification of the allocated address for each lot on the plan of subdivision. The address is also used by all Service Authorities to update their own databases (CoM, 2012a).

Each department in a council has a checklist in the subdivision process. For example, shadow analysis, planning schemes, comparison with architectural plans, engineering plans, photos, building information (Regulation 503 Building Surveyor), compliance with parent title, car parks, easements, common property areas, lot and common property boundaries, light and air easements, accessibility of all lots and car parks are all controlled manually (CoM, 2012b).

After issuing the planning permit, construction is started. When construction is finished, if the applicant met all the requirements specified in the planning permit and the Subdivision Act, a Statement of Compliance is issued by the responsible council. After construction, land surveyors often check the consistency of the as-built construction with the plan[35].

In the case of very large developments of more than 25 000 square meters, the State Planning department is responsible for issuing the planning permit.[36] Due to the importance of big developments, more factors are checked through their checklists. For instance, wind modelling is conducted to investigate the effect of wind after construction in the location of the building.[37] Currently, wind modelling is conducted using wind tunnels with a scaled

[34] https://www.vcat.vic.gov.au/
[35] (Land Registry, personal communication, November 12, 2012)
[36] (State Planning, personal communication, October 16, 2013)
[37] (State Planning, personal communication, October 29, 2013)

model of the building. Also, State Planning asks the applicants to provide them with a 3D digital model of the building in an accepted format. The 3D models are imported into the 3D modelling software (Urban Circus[38]). The software is based on GIS and game engines and is used for the following functions (DPCD, 2010):

- Strategic planning, which includes calculating density, floor areas and site capacity for projects;
- Assessing planning applications, including controlling the impact of building heights and setbacks on other buildings and public realm, accurate shadow and skyline analysis; and
- Maintaining a database of Planning Permits' history, modelling permits issued by the planning minister.

State Planning has provided the following technical specifications for submitting the 3D models (DPCD, 2010):

- The file format should be FBX or SKP;
- Base units should be in metres;
- Models should be geo-referenced to the MGA Projection[39];
- Height should be in absolute units;
- The maximum total combined texture size for a single building is 2048 x 2048 pixels;
- Internal and external surfaces must be split into two separate files for improved performance, smaller file sizes, and the ability to only load external surfaces where internal surfaces are not required.

After issuing the statement of planning permit by councils or the minister of planning, the GIS team in the council is responsible for updating the parcel map, and they are notified when a new submission is received in SPEAR.[40]

The Subdivision Act also allows for apartment units to be pre-sold from a certified, and in some cases uncertified, plan even before any work started on the ground (DPCD, 2012).

After issuing the Statement of Compliance, the subdivision plan can be lodged with Land Victoria. The Subdivision Act 1988 defines the requirements for registration of a plan of subdivision. Any plan of subdivision lodged to Land Victoria needs to provide the Statement of Compliance from the responsible council, surveyor's report, abstract of field records, street address, and certificate of title. If the application includes an owners' corporation, some

[38] http://www.urbancircus.com.au/
[39] Map Grid Australia
[40] (City Council, personal communication, October 31, 2013)

additional documents (such as owners' corporation lodgement checklist, limited and unlimited owners' corporation forms) need to be provided with the application (DSE, 2012).

Large subdivisions may be conducted in more than one stage, and they are certified and registered in various stages. In each stage, the processes are repeated.

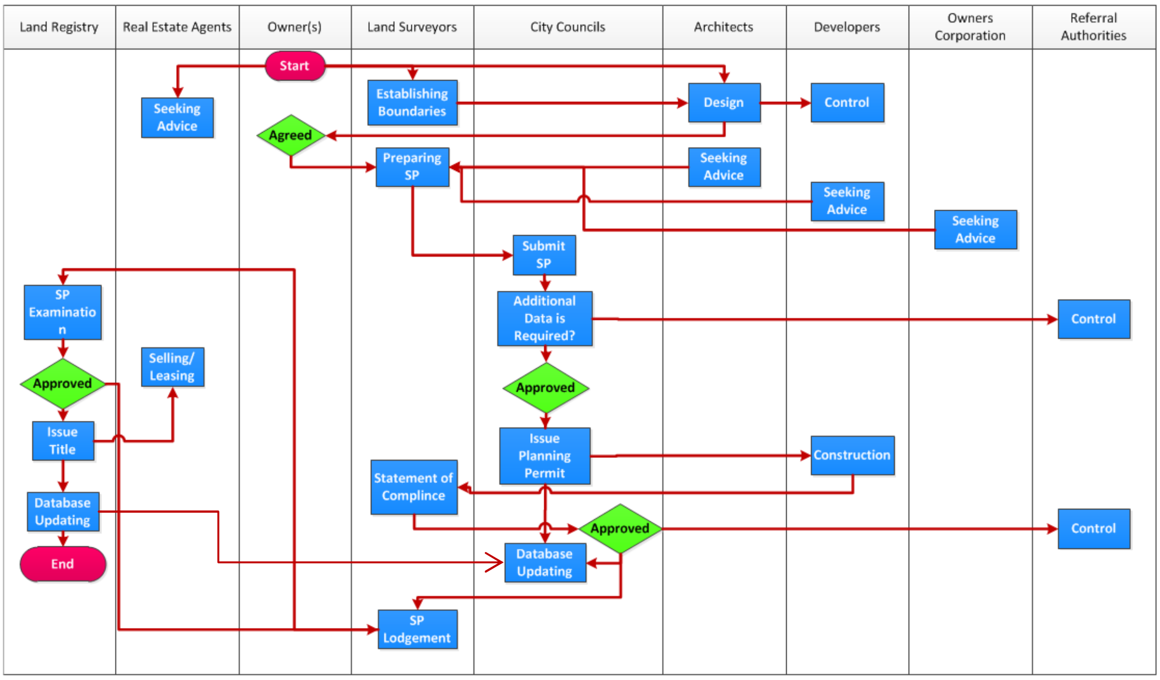


Figure 4.8: The subdivision process and involved professionals.

Survey plans can be submitted in PDF format to the land registry through SPEAR, or in paper-based format in person to Land Victoria.

Land Victoria ensures the provided survey plans are based on standards. In the registration process, survey plans are examined. In the examination process, examiners[41] evaluate the survey plans to be based on defined standards and regulations and correct in surveying calculations. Examination takes between 5 days for simple and low complex buildings to 15 days[42].

The examination process covers the following items (DSE, 2010b):

- Check plan header;
- Check plan number;
- Check land description panel;

[41] Some examiners are licensed surveyors and 3 of 40 are land surveyors (Land Registry, personal communication, November 20, 2012).

[42] (Land Registry, personal communication, April 3, 2013)

- Check notations panel;
- Check plan executions panel;
- Check vesting table;
- Check easements table;
- Check restrictions;
- Check owners corporation schedule;
- Perform plan diagram checks on:
  - Parcel identification;
  - Boundary definitions;
  - Check area;
  - Check roads and reserves;
  - Full easement check;
  - Check title connections;
  - Closures;
  - Check north point scale and orientation datum;
- Perform survey checks:
  - Perform currency checks;
  - Check datum;
  - Check abstract of field records;
  - Check surveyor's report.

In some cases, plans need to be referred to the land surveyors to amend and resubmit.

After examination, plans are registered and become a legal document, when a title will be issued and cadastral databases are updated. The related council and referral authorities are also informed regarding the result of registration. The GIS team in councils replaces the old titles.

The subdivision process in Victoria, as described here, engages various professionals to work together to start a development and subdivide the land in question. Different professionals use different data and have different needs.

Land Victoria developed Building Subdivision Guidelines in 2012 to guide the preparation of subdivision plans for surveyors. These guidelines describe the location of boundaries in case of building subdivisions. Due to the importance of visualising ownership boundaries accurately, some important points in the preparation of building subdivision plans are described below.

4.2.3.3 Ownership Boundaries in Subdivision Plan Preparation

In general, there are two main types of 3D property; unbounded and bounded (Stoter and van Oosterom, 2006). In unbounded 3D parcels, the ownership right of land may extend above (air space) and below the ground level vertically, and there is no clear boundary in at least one part of the 3D property. For example, the air space can be an unbounded right and extends into the sky. However, in case of any restriction to the right (e.g. height limitations), the extent of the right is limited based on the restriction. For instance, the depth limitation for a land parcel in Victoria is fifty feet since 1892 (Paulsson, 2007).

Bounded 3D parcels usually have limited and fixed boundaries, and ownership rights are defined clearly in plans. A subdivision plan may use the structure of a building to show the location of boundaries (LandVictoria, 2012). However, ownership boundaries must be clear to the owners, buyer, surveyors, land registry organisations, councils, solicitors and owners corporation managers.

In case of apartments, defining the ownership boundaries is very important, as walls, roofs, and ceilings have thicknesses. Land Victoria has developed Building Subdivision Guidelines (LandVictoria, 2012) for these cases, which define various types of ownership boundary locations as "*interior face*", "*exterior face*", and "*median*". The location of ownership boundaries are usually decided by land surveyors, bodies corporate, and developers. Some symbols are used on the plan to show the locations. For example, "*M*" is used for median boundaries and "*E*" is used for exterior faces.

- **Interior Face**

In interior face boundaries, ownership boundaries are located along the interior faces of walls, floors, ceilings, windows, or doors. Any additional internal coverings, such as water-proof membranes and fixtures attached to walls, floors, and ceilings are considered inside the parcel (LandVictoria, 2012). The interior face excludes the parcel from the ownership of building structures (See figures 4.9).

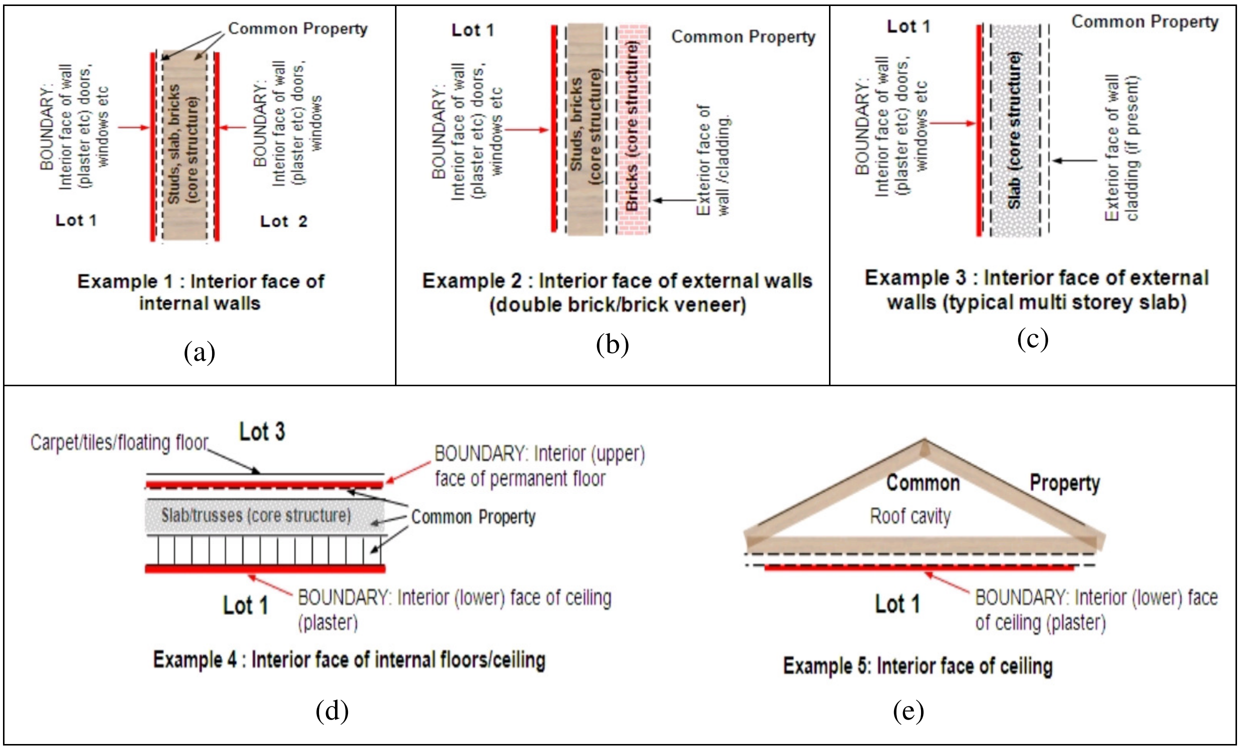


Figure 4.9: Interior face examples in section views (LandVictoria, 2012).

In figure 4.9 (a), two neighbouring units are shown and the ownership boundary is considered interior. Therefore, the thickness of the wall between two apartments is considered as common property. In figure 4.9 (b & c), the wall thickness is located outside of the lot and is considered common property. In figure 4.9 (d & e), ownership boundaries are defined horizontally. In these cases, interior boundaries define the location of ownership rights in roofs and ceilings. Figure 4.10 (a & b) represents the interior face interpretation from a plan view and section view.

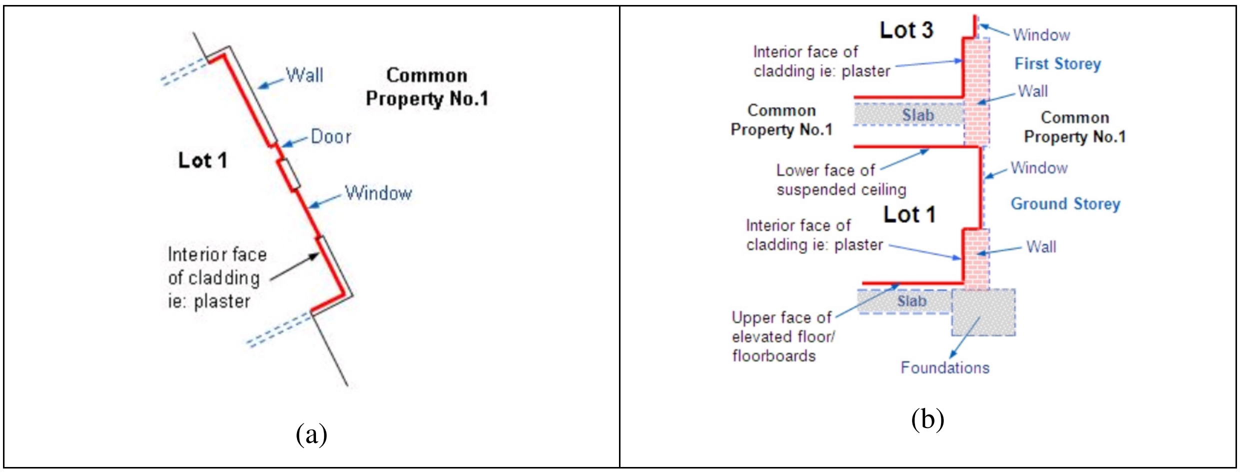


Figure 4.10: (a) Interior face examples in plan view; (b) Interior face examples in section views (LandVictoria, 2012).

- **Exterior Face**

Exterior faces are located along the exterior face of walls, doors, windows, foundations, roofs, eaves or guttering of the building. Exterior face boundaries include the parcel in the building structure. Floor plans and cross sections show the exterior face of building boundaries in subdivision plans. Figure 4.11 (a, b, c & d) represent some examples of exterior faces in various views and situations.

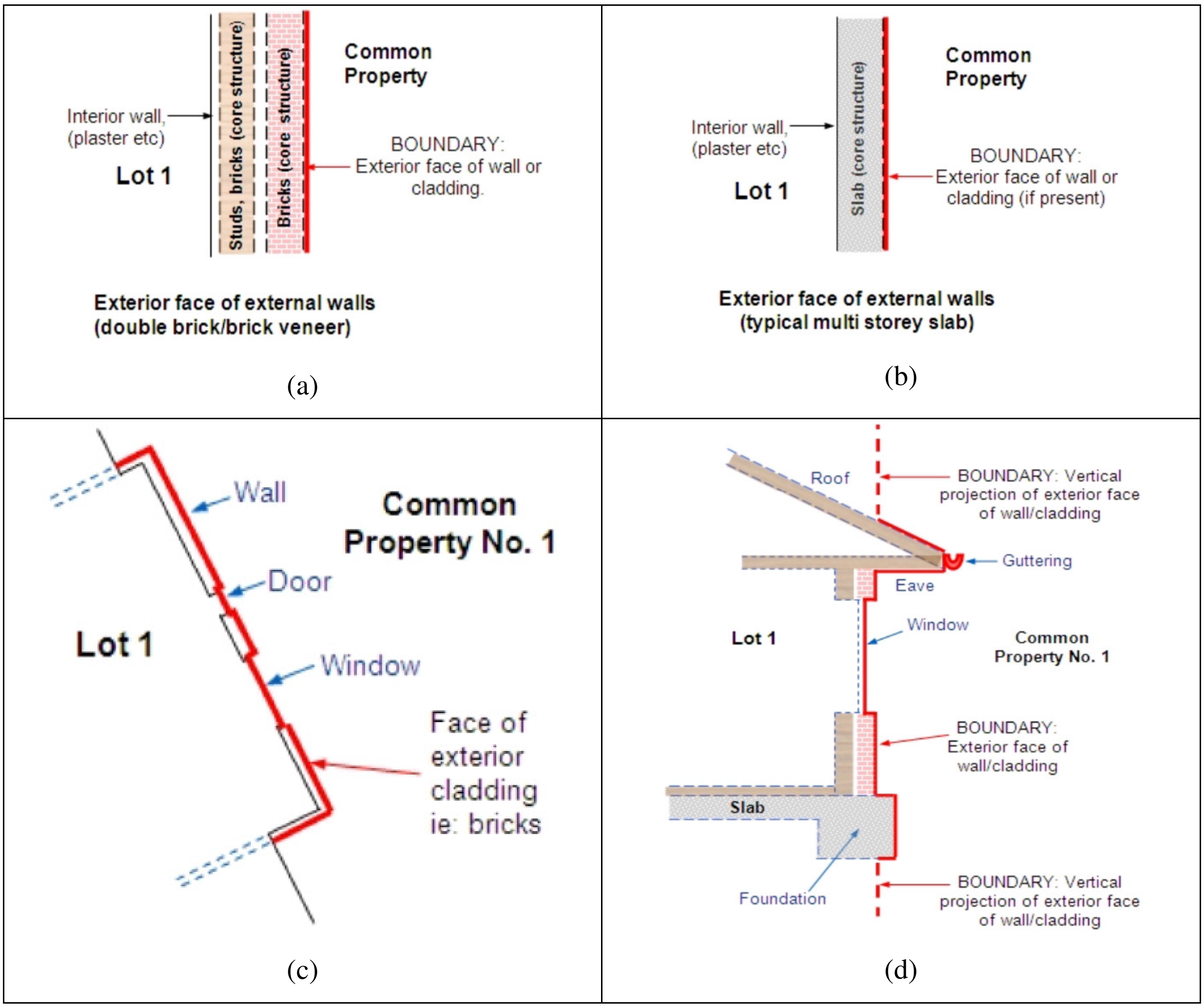


Figure 4.11: (a) Exterior face example (double brick/brick veneer); (b) Exterior face example (typical multi storey slab); (c) the location of exterior face on the plan; (d) a section view representing the ownership boundary (LandVictoria, 2012).

The horizontally and vertically projections of the red line are presented on figure 4.11 (c & d).

- **Median Boundaries**

The location of building boundaries defined as median lies along the midpoint of walls, windows, doors or any building part. Any building part outside of this boundary does not belong to the parcel. Median boundaries are usually marked as "*M*" on the plan (figure 4.12).

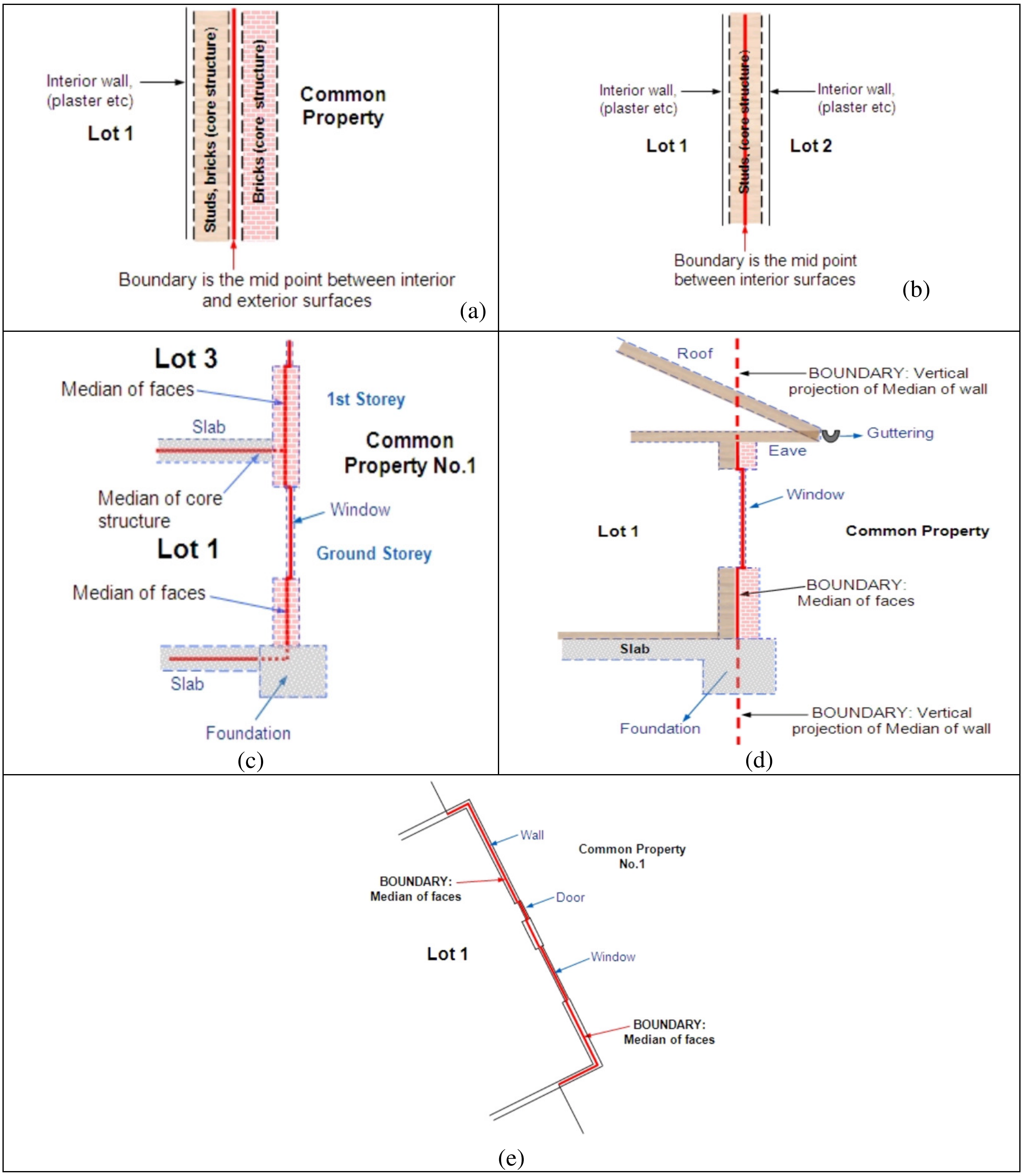
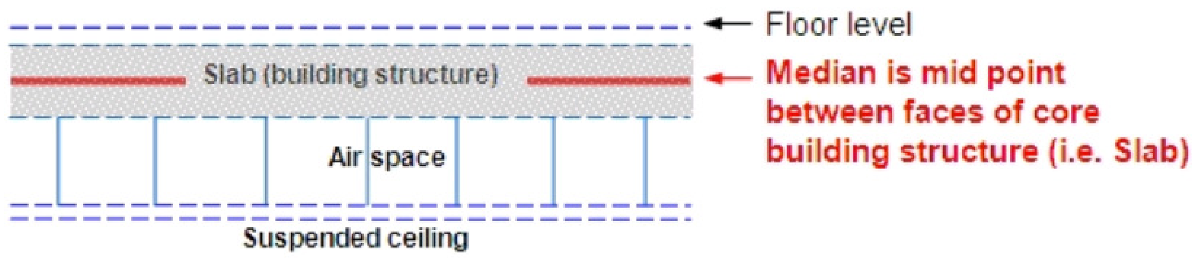
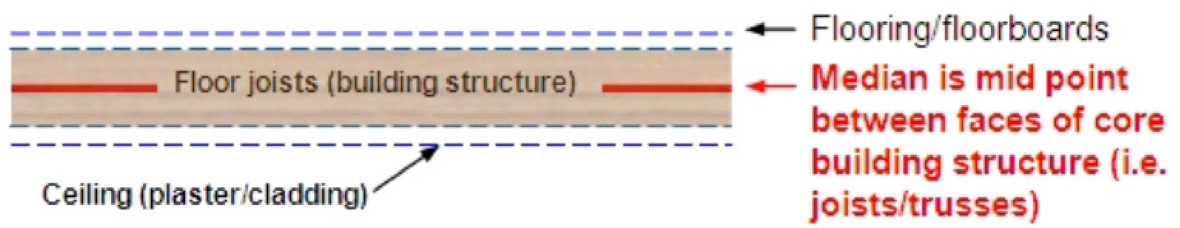


Figure 4.12: (a) Median boundary example of external walls (double brick/brick veneer); (b) Median boundary example of internal walls (double studs/plaster); (c) Median boundary in a section view in case of apartment units; (d) Median boundary location in a section view; (e) Plan view of the location of median boundary location (LandVictoria, 2012).

The median boundary location in horizontal building parts (roofs and ceiling) is different from vertical building parts (walls, doors, and windows). In the case of median boundaries for floors and ceilings, the ownership boundaries lie in the middle of the building structures and any elevated floors or suspended ceilings are not included in the building structure. The horizontal median boundaries are depicted in cross-sections as illustrated in figure 4.13 (a & b) (LandVictoria, 2012).



(a)



(b)

Figure 4.13: The horizontal median boundaries in two examples; (a) Median boundary in suspended ceiling; (b) Median boundary without suspended ceiling (LandVictoria, 2012).

According to the situation, a plan may specify other types of ownership boundary locations. In these cases, notations and diagrams are necessary to describe the boundary locations accurately (LandVictoria, 2012).

Where interior faces are used for locating ownership boundaries, all building services are located in common property areas. Therefore, notations are written on the plan to clarify the spaces among interior faces (See figure 4.14).

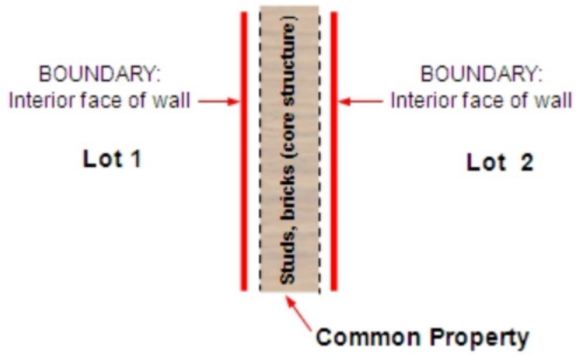


Figure 4.14: An example of two ownership boundaries as interior face. The space between two interior faces is common property (LandVictoria, 2012).

For clarification of ownership rights, notations are written on the first page of subdivision plan. Here is an example:

> *"Common Property No.# is all the land in the plan except the lots (and Roads and /or Reserves) and includes the structure of all wall, floor, ceiling, window, door, balustrade (other) which define boundaries except where indicated otherwise"* (LandVictoria, 2012).

In addition to the common property areas, easements, if they exist, are shown on the plan clearly. More information about the type of easements and the benefited party are provided in the first page of subdivision plans.

The land parcel corners are defined by bearings and distances from control points, which are based on the MGA.[43] However, the building boundaries are not defined by measurements but are referenced to the physical building parts. Therefore, there is no type of information for re-establishing the boundaries.

In order to understand the issues and challenges in representing RRRs in complex scenarios, a mini case study was chosen to investigate the method of representing RRRs in a high-rise in Victoria, described in the following section.

[43] The Map Grid of Australia 1994, http://www.dtpli.vic.gov.au/__data/assets/pdf_file/0010/111043/The_Map_Grid_of_Australia_1994_Computational_Manual.pdf

4.2.3.4 Mini Case Study (2) - ILK South Yarra[44]

ILK South Yarra is a new high rise building located about 3.4 kilometres from Melbourne Central Business District (CBD). This high rise was selected as a mini case study for the following reasons:

- o It includes various types of 3D property rights such as easements, lots, common property areas which brings a high level of complexity to this case;
- o A mixed land use including shops, residential area, and underground car park exists in this building; and
- o The land surveying company of this building is one of the industry partners of the 3D Land and Property Information Project. Therefore, the required information and experience were provided by this partner.

In the following section, more information about this mini case study is provided.

- **Mini Case Study Description**

This high rise has twenty-six levels and three basements. It has 401 lots and six common property areas. The location of the high rise is shown in figure 4.15.

[44] 227 Toorak Road, South Yarra, Victoria

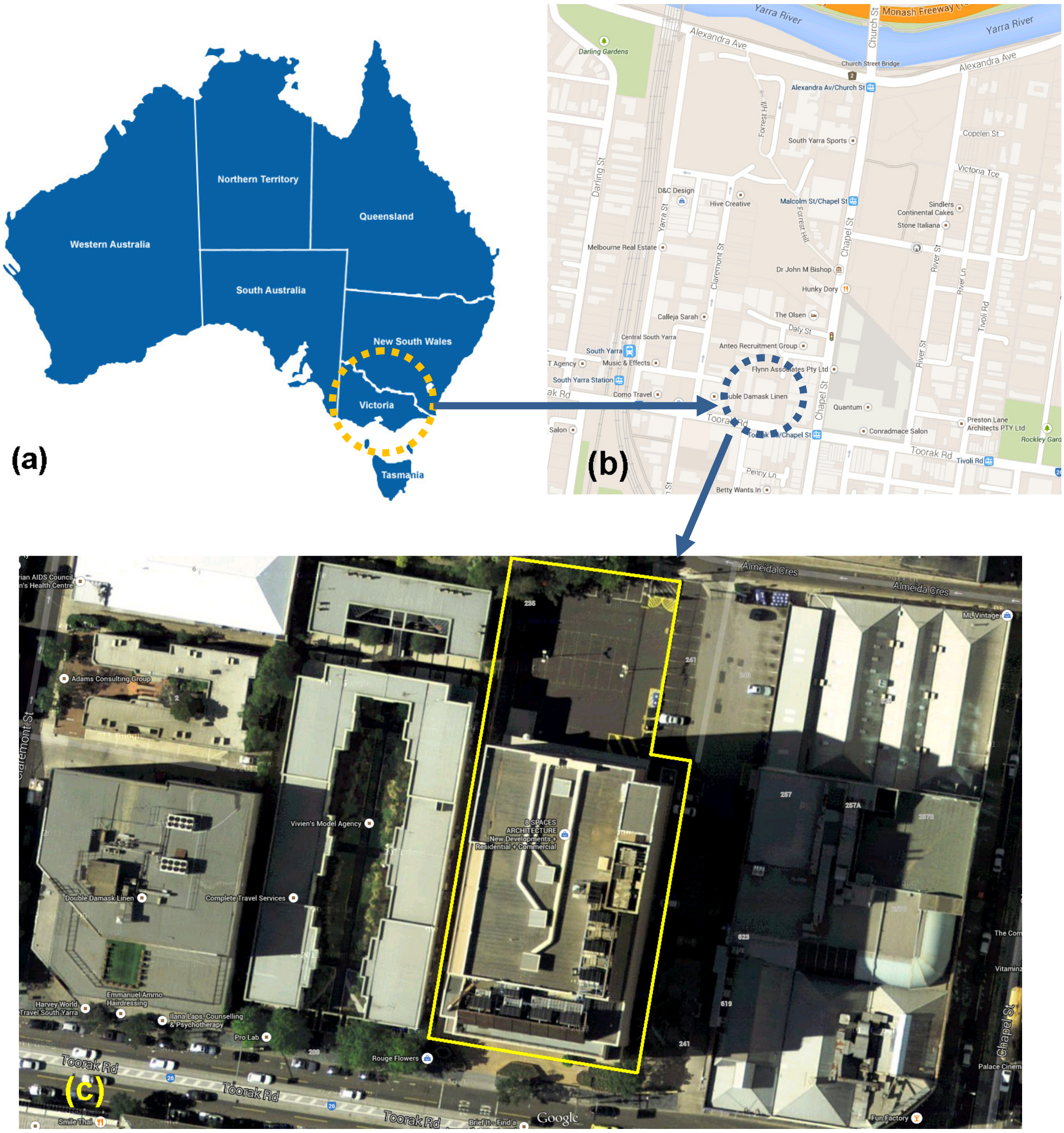


Figure 4.15: Mini case study (2) location; (a) Australia, Victoria, Melbourne; (b) The location of the building on Google Maps; (c) An aerial image of the building with the parcel boundary (Google Maps, 2014).

The associated land parcel on DCDB is shown in figure 4.16.

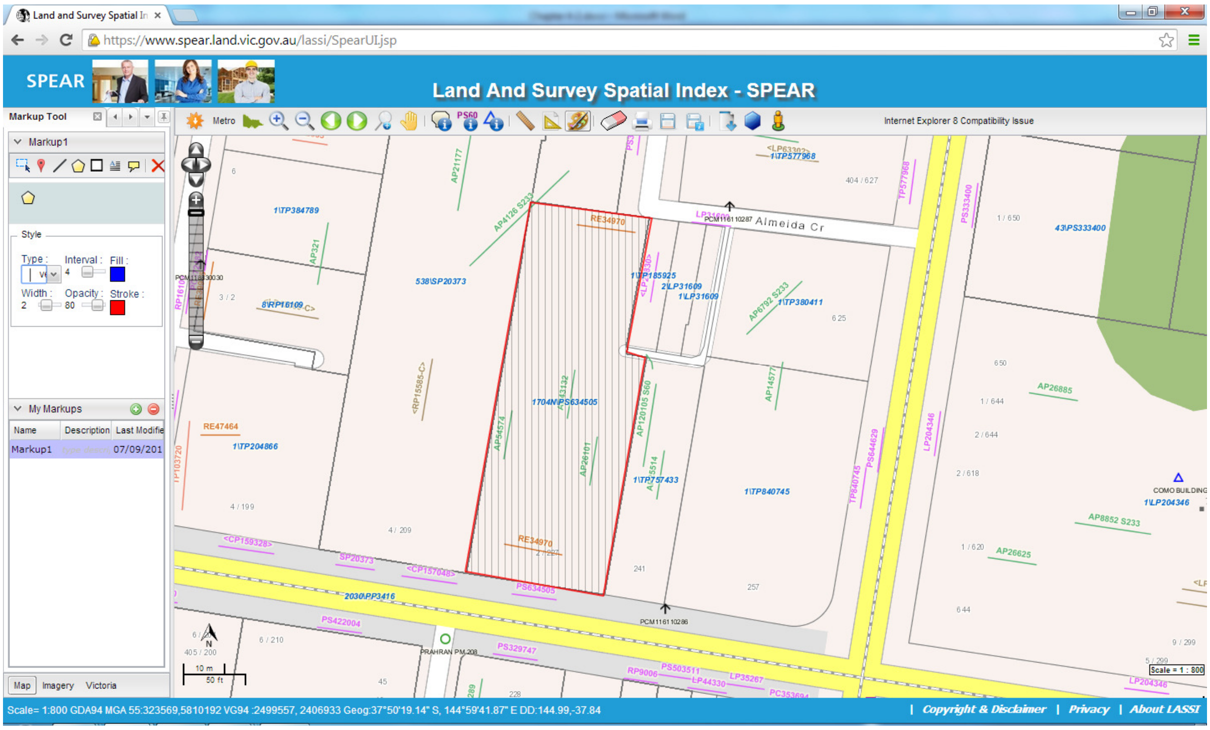


Figure 4.16: The geometrical description of the ILK land parcel on DCDB.

The survey plan (subdivision plan) of this high rise represents the ownership boundaries in more detail. The subdivision plan has 56 pages and includes many floor plans, sections and notations to explain the ownership boundaries. Some parts of the plan are shown in figure 4.17.

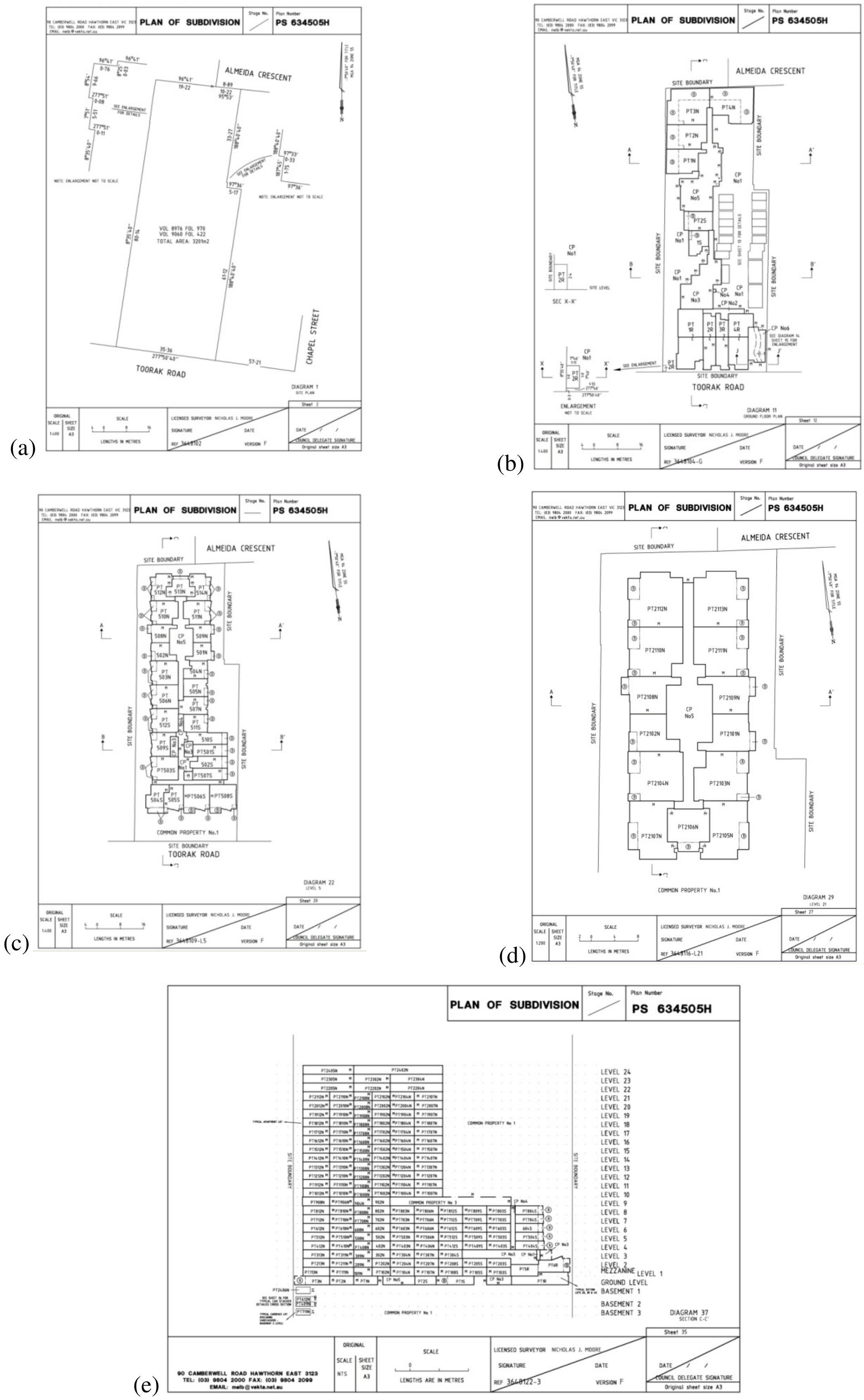
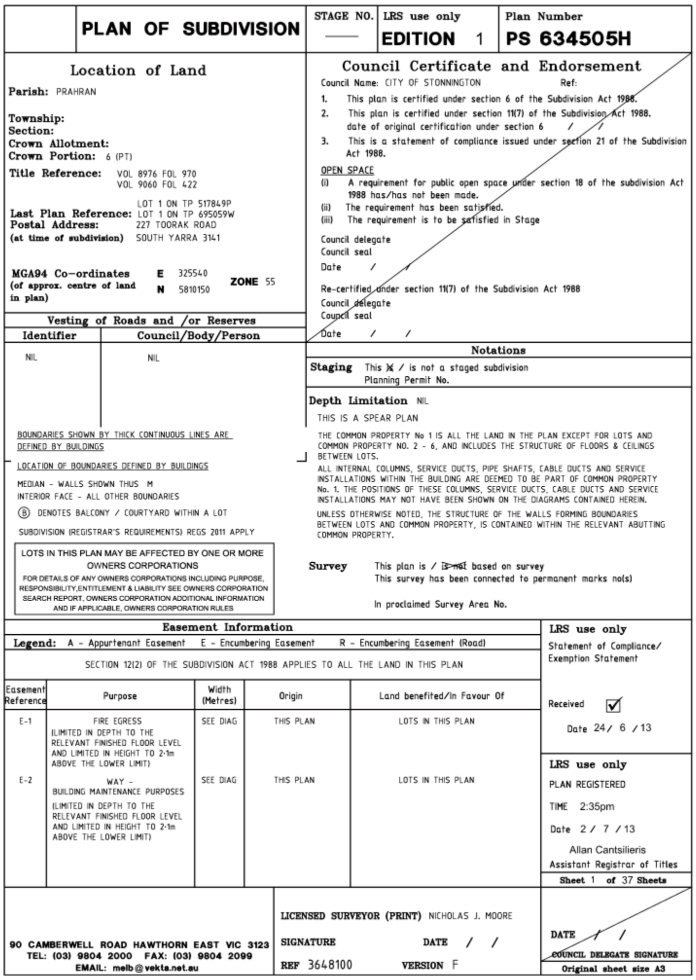


Figure 4.17: Some pages of the subdivision plan of the ILK South Yarra; (a) Land parcel boundaries; (b) Ground floor plan; (c) Level 5 floor plan; (d) Level 21 floor plan; (e) Cross-section C-C'.

In the following section, this plan of subdivision is described in detail.

- **Analysing the Mini Case Study**

This building is located in the jurisdiction of Stonnington City Council, in an area where there are many high rises. The first page of the plan of subdivision provides information about the building, including the following items (figure 4.18):



PLAN OF SUBDIVISION | STAGE NO. — | LRS use only EDITION 1 | Plan Number PS 634505H

Location of Land

Parish: PRAHRAN
Township:
Section:
Crown Allotment:
Crown Portion: 6 (PT)
Title Reference: VOL 8976 FOL 970, VOL 9060 FOL 422
Last Plan Reference: LOT 1 ON TP 517849P, LOT 1 ON TP 695059W
Postal Address: (at time of subdivision) 227 TOORAK ROAD SOUTH YARRA 3141
MGA94 Co-ordinates (of approx. centre of land in plan) E 325540 N 5810150 ZONE 55

Council Certificate and Endorsement

Council Name: CITY OF STONNINGTON Ref:
1. This plan is certified under section 6 of the Subdivision Act 1988.
2. This plan is certified under section 11(7) of the Subdivision Act 1988. date of original certification under section 6 / /
3. This is a statement of compliance issued under section 21 of the Subdivision Act 1988.

OPEN SPACE
(i) A requirement for public open space under section 18 of the subdivision Act 1988 has/has not been made.
(ii) The requirement has been satisfied.
(iii) The requirement is to be satisfied in Stage

Council delegate
Council seal
Date / /

Re-certified under section 11(7) of the Subdivision Act 1988
Council delegate
Council seal
Date / /

Vesting of Roads and /or Reserves

Identifier	Council/Body/Person
NIL	NIL

Notations

Staging This ~~is~~ / is not a staged subdivision
Planning Permit No.

Depth Limitation NIL

THIS IS A SPEAR PLAN

BOUNDARIES SHOWN BY THICK CONTINUOUS LINES ARE DEFINED BY BUILDINGS

LOCATION OF BOUNDARIES DEFINED BY BUILDINGS
MEDIAN - WALLS SHOWN THUS M
INTERIOR FACE - ALL OTHER BOUNDARIES

(B) DENOTES BALCONY / COURTYARD WITHIN A LOT

SUBDIVISION (REGISTRAR'S REQUIREMENTS) REGS 2011 APPLY

LOTS IN THIS PLAN MAY BE AFFECTED BY ONE OR MORE OWNERS CORPORATIONS
FOR DETAILS OF ANY OWNERS CORPORATIONS INCLUDING PURPOSE, RESPONSIBILITY,ENTITLEMENT & LIABILITY SEE OWNERS CORPORATION SEARCH REPORT, OWNERS CORPORATION ADDITIONAL INFORMATION AND IF APPLICABLE, OWNERS CORPORATION RULES

THE COMMON PROPERTY No 1 IS ALL THE LAND IN THE PLAN EXCEPT FOR LOTS AND COMMON PROPERTY NO. 2 - 6, AND INCLUDES THE STRUCTURE OF FLOORS & CEILINGS BETWEEN LOTS.
ALL INTERNAL COLUMNS, SERVICE DUCTS, PIPE SHAFTS, CABLE DUCTS AND SERVICE INSTALLATIONS WITHIN THE BUILDING ARE DEEMED TO BE PART OF COMMON PROPERTY No. 1. THE POSITIONS OF THESE COLUMNS, SERVICE DUCTS, CABLE DUCTS AND SERVICE INSTALLATIONS MAY NOT HAVE BEEN SHOWN ON THE DIAGRAMS CONTAINED HEREIN.
UNLESS OTHERWISE NOTED, THE STRUCTURE OF THE WALLS FORMING BOUNDARIES BETWEEN LOTS AND COMMON PROPERTY, IS CONTAINED WITHIN THE RELEVANT ABUTTING COMMON PROPERTY.

Survey This plan is / ~~is not~~ based on survey
This survey has been connected to permanent marks no(s)
In proclaimed Survey Area No.

Easement Information

Legend: A - Appurtenant Easement E - Encumbering Easement R - Encumbering Easement (Road)

SECTION 12(2) OF THE SUBDIVISION ACT 1988 APPLIES TO ALL THE LAND IN THIS PLAN

Easement Reference	Purpose	Width (Metres)	Origin	Land benefited/In Favour Of
E-1	FIRE EGRESS (LIMITED IN DEPTH TO THE RELEVANT FINISHED FLOOR LEVEL AND LIMITED IN HEIGHT TO 2·1m ABOVE THE LOWER LIMIT)	SEE DIAG	THIS PLAN	LOTS IN THIS PLAN
E-2	WAY - BUILDING MAINTENANCE PURPOSES (LIMITED IN DEPTH TO THE RELEVANT FINISHED FLOOR LEVEL AND LIMITED IN HEIGHT TO 2·1m ABOVE THE LOWER LIMIT)	SEE DIAG	THIS PLAN	LOTS IN THIS PLAN

LRS use only
Statement of Compliance/ Exemption Statement
Received ☑
Date 24/ 6 /13

LRS use only
PLAN REGISTERED
TIME 2:35pm
Date 2/ 7 /13
Allan Cantsilieris
Assistant Registrar of Titles
Sheet 1 of 37 Sheets

90 CAMBERWELL ROAD HAWTHORN EAST VIC 3123
TEL: (03) 9804 2000 FAX: (03) 9804 2099
EMAIL: melb@vekta.net.au

LICENSED SURVEYOR (PRINT) NICHOLAS J. MOORE
SIGNATURE DATE / /
REF 3648100 VERSION F

DATE / /
COUNCIL DELEGATE SIGNATURE
Original sheet size A3

Figure 4.18: The first page of subdivision plan.

- **Stage No**: describes the stage number of this plan. Some parcels are subdivided in more than one phase, called staged subdivision. However, in this plan, the parcel is subdivided in one stage and there is no stage for future subdivision;
- **Plan Number**: This number is a unique code which is used for searching and identifying plans on online services (e.g. LASSI, SPEAR) or databases. The number starts with two characters, PS, PC, LP, CP, CS, TP, RP, or OP which show the type of plan. In this case, PS stands for Plan of Subdivision. In addition to plan number, other numbers and codes are used in the processes, such as Volume Folio number which refers to title documents;

- **Location of Land**: This part represents the location of the building including the parish, township, title references, postal address, the last plan reference, and coordinate of an approximate centre of the land parcel. The last item, the coordinate, is based on MGA94;
- **Vesting of Roads and /or Reserves**: This section refers to the established (new) roads or reserves which are created by the plan;
- **Council Certificate and Endorsement**: This part describes council name, council certificates, and public open spaces;
- **Notations**: This section provides information about height and depth limitations, ownership boundary types, and surveying information. Boundaries shown by thick continuous lines are defined by building parts. Some characters are used in the plan to show the location of boundaries defined by buildings. "*M*" stands for Median and refers to the location of ownership boundaries in the middle of a building structure. Otherwise, boundaries are interior in this plan. "*B*" refers to the balcony or courtyard within a lot;
- **Easement Information**: This part describes the easements on the plan. In this plan, there are two types of easements, fire egress and building maintenance.
- **Surveying Company**: This section provides information about the surveying company and the licensed surveyor details.

There are several pages besides the first page which describe ownership boundaries. The parcel boundary is represented using bearings and distances (See figure 4.17 (a)). The area of the parcel is also shown in this page. The adjacent roads and streets are depicted in the plan to clarify the location of the parcel and its orientation. In this building, all three basements were considered for car parks. Due to the large number of units, car stackers were designed to give more car spaces, comprising two car spaces in one parking lot (See figure 4.19). There are different types of car stackers, and this method complicates the registration of rights. In this case, they are considered as part of the lot (apartments).

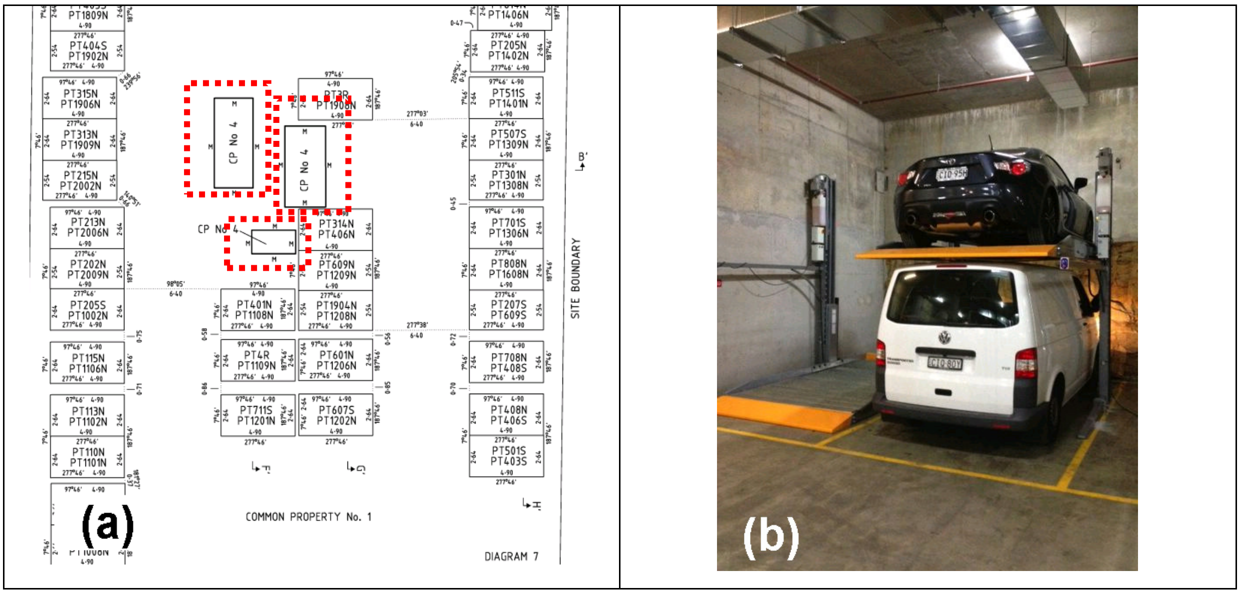


Figure 4.19: (a) Parking lots on basement two. There are two car spaces in each locations which shows there is a car stacker system; (b) This shows a sample of car stackers (Copyright Going Up Lifts).

According to the notations on this plan (figure 4.18), Common Property Number one is "*all the land in the plan except for lots and common property NO. 2 – 6, and includes the structure of floors and ceilings between lots. All internal columns, service ducts, pipe shafts, cable ducts and service installations within the building are deemed to be part of Common Property NO. 1. The positions of these columns, service ducts, cable ducts, and service installations may not have been shown on the diagrams contained herein. Unless otherwise noted, the structure of the walls forming boundaries between lots and Common Property, is contained within the relevant abutting common property*".

This clarifies that common property number 1 covers all spaces outside of defined lots and other common property areas. Therefore, Common Property No. 1 is written on figure 4.19 (a) to show the rights of spaces in the car park between parking lots.

In figure 4.19 (a), Common Property No. 4 is shown and the boundary is specified as "*M*". In this case, the ownership boundaries between Common Property No. 4 and No. 1 are defined as median. Therefore, the wall belongs to both Common Property areas.

Figure 4.20 represents the ground floor plan and includes several lots, common property areas and one easement. According to this plan, easement 1 is located in the middle of common property No. 6 and it gives access to the fire exit. Other lots are defined as median and interior.

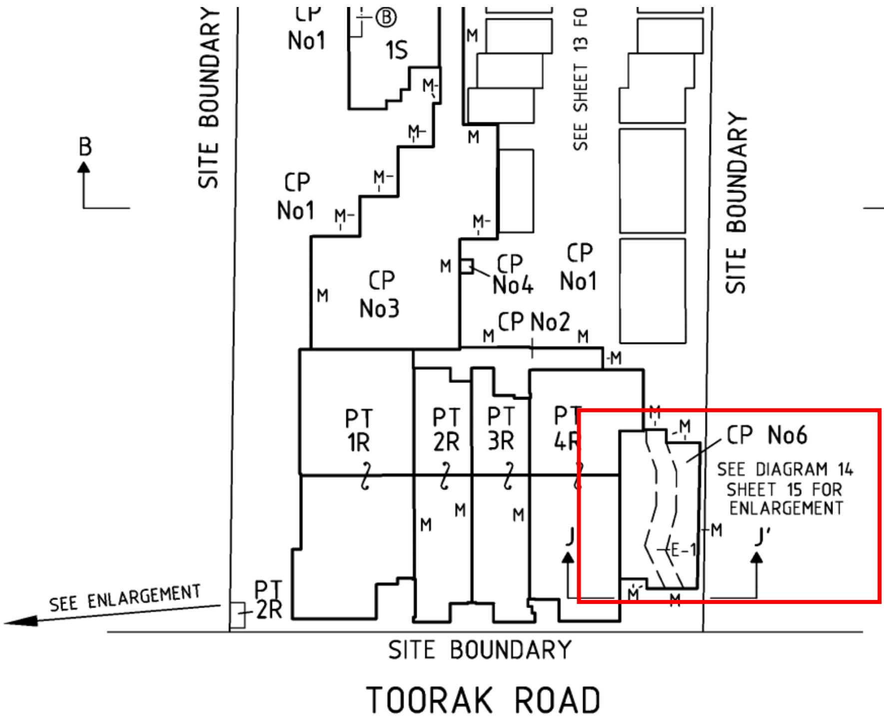


Figure 4.20: The ground floor of the subdivision plan which shows an easement.

As indicated in figure 4.20, there are vincula on this plan. Symbols (~) represent the height differences in these lots, which can be seen in cross-sections.

Figure 4.17 (e) shows a cross-section of the high rise and as can be seen in this figure, there is no height information. All boundaries are referenced relative to the building structure. In addition, in this figure, "*M*" symbol shows that slabs are considered as median.

In addition to the plan, there is an Owners Corporation Report which gives information about liability and entitlement. This report clarifies the liability and entitlement if an owner has the right of access to common property areas (figure 4.21).

Department of Sustainability and Environment

Owners Corporation Search Report

Produced: 02/07/2013 04:47:07 PM

OWNERS CORPORATION 1
PLAN NO. PS634505H

The land in PS634505H is affected by 6 Owners Corporation(s)

Land Affected by Owners Corporation:
Common Properties 1 - 6, Lots 1N, 1R, 1S, 2N, 2R, 2S, 3N, 3R, 4N, 4R, 5R, 6R, 101N, 101S, 102N, 102S, 103N, 103S, 104N, 104S, 105N, 105S, 106N, 106S, 107N, 107S, 108N, 108S, 109N, 109S, 110N, 111N, 112N, 113N, 114N, 115N, 201N, 201S, 202N, 202S, 203N, 203S, 204N, 204S, 205N, 205S, 206N, 206S, 207N, 207S, 208N, 208S, 209N, 209S, 210N, 211N, 212N, 213N, 214N, 215N, 301N, 301S, 302N, 302S, 303N, 303S, 304N, 304S, 305N, 305S, 306N, 306S, 307N, 308N, 309N, 310N, 311N, 312N, 313N, 314N, 315N, 401N, 401S, 402N, 402S, 403N, 403S, 404N, 404S, 405N, 405S, 406N, 406S, 407N, 407S, 408N, 408S, 409N, 409S, 410N, 410S, 411N, 411S, 412N, 412S, 413N, 414N, 501N, 501S, 502N, 502S, 503N, 503S, 504N, 504S, 505N, 505S, 506N, 506S, 507N, 507S, 508N, 508S, 509N, 509S, 510N, 510S, 511N, 511S, 512N, 512S, 513N, 514N, 601N, 601S, 602N, 602S, 603N, 603S, 604N, 604S, 605N, 605S, 606N, 606S, 607N, 607S, 608N, 608S, 609N, 609S, 610N, 610S, 611N, 611S, 612N, 612S, 613N, 614N, 701N, 701S, 702N, 702S, 703N, 703S, 704N, 704S, 705N, 705S, 706N, 706S, 707N, 707S, 708N, 708S, 709N, 709S, 710N, 710S, 711N, 711S, 712N, 712S, 713N, 714N, 801N, 801S, 802N, 802S, 803N, 803S, 804N, 804S, 805N, 805S, 806N, 806S, 807N, 807S, 808N, 808S, 809N, 809S, 810N, 810S, 811N, 811S, 812N, 812S, 813N, 814N, 901N, 902N, 903N, 904N, 905N, 906N, 907N, 908N, 909N, 910N, 1001N, 1002N, 1003N, 1004N, 1005N, 1006N, 1007N, 1008N, 1009N, 1010N, 1011N, 1012N, 1013N, 1101N, 1102N, 1103N, 1104N, 1105N, 1106N, 1107N, 1108N, 1109N, 1110N, 1111N, 1112N, 1113N, 1201N, 1202N, 1203N, 1204N, 1205N, 1206N, 1207N, 1208N, 1209N, 1210N, 1211N, 1212N, 1213N, 1301N, 1302N, 1303N, 1304N, 1305N, 1306N, 1307N, 1308N, 1309N, 1310N, 1311N, 1312N, 1313N, 1401N, 1402N, 1403N, 1404N, 1405N, 1406N, 1407N, 1408N, 1409N, 1410N, 1411N, 1412N, 1413N, 1501N, 1502N, 1503N, 1504N, 1505N, 1506N, 1507N, 1508N, 1509N, 1510N, 1511N, 1512N, 1513N, 1601N, 1602N, 1603N, 1604N, 1605N, 1606N, 1607N, 1608N, 1609N, 1610N, 1611N, 1612N, 1613N, 1701N, 1702N, 1703N, 1704N, 1705N, 1706N, 1707N, 1708N, 1709N, 1710N, 1711N, 1712N, 1713N, 1801N, 1802N, 1803N, 1804N, 1805N, 1806N, 1807N, 1808N, 1809N, 1810N, 1811N, 1812N, 1813N, 1901N, 1902N, 1903N, 1904N, 1905N, 1906N, 1907N, 1908N, 1909N, 1910N, 1911N, 1912N, 1913N, 2001N, 2002N, 2003N, 2004N, 2005N, 2006N, 2007N, 2008N, 2009N, 2010N, 2011N, 2012N, 2013N, 2101N, 2102N, 2103N, 2104N, 2105N, 2106N, 2107N, 2108N, 2109N, 2110N, 2111N, 2112N, 2113N, 2201N, 2202N, 2203N, 2204N, 2205N, 2206N, 2301N, 2302N, 2303N, 2304N, 2305N, 2306N, 2401N, 2402N, 2403N, 2405N, 2406N.

Limitations on Owners Corporation:
Unlimited

Postal Address for Service of Notices:
"ENGINE PROPERTY GROUP" SUITE 201 126 WELLINGTON PARADE EAST MELBOURNE VIC 8002
OC018671A 02/07/2013

Rules:
Model Rules apply unless a matter is provided for in Owners Corporation Rules. See Section 139(3) Owners Corporation Act 2006

Owners Corporation Rules:
1. OC018677M 02/07/2013

Additional Owners Corporation Information:
OC018671A 02/07/2013

Notations:
Only the members of Owners Corporation 2 are entitled to use Common Property No. 2.
Only the members of Owners Corporation 3 are entitled to use Common Property No. 3.

LAND VICTORIA, 570 Bourke Street Melbourne Victoria 3000
P.O. Box 500 East Melbourne Victoria 3002, DX 250639
Telephone: (03) 8636 2010 Facsimile: (03) 8636 2005
ABN 90719052204
Page 1 of 18

Figure 4.21: Owners Corporation Report showing the liability and entitlement of each lot.

By analysing this mini case study, more details were found which show the limitations of current practice. Many of the same challenges can be seen as in mini case study (1).

- **Analysing the issues and challenges in representing RRRs in mini case study 2**

The challenges identified in analysing the second mini case study are:

  - Height and depth limitations are not represented geometrically in the plan, are only described as notation;
  - The parking lots are located on top of each other, which makes it difficult to determine who owns which lot;
  - In this case, 56 sheets of paper are required to show the ownership boundaries;
  - There is not enough or clear enough information on the plan regarding adjacent land parcels;
  - Due to the restrictions on the paper-based plans, enlargement methods were utilised to describe the detail of small easements (figure 4.17 (b));

- Interpreting the plans is very time-consuming;
- Understanding of the plans requires a high level of expertise and only expert users can understand them;
- Interaction and real 3D property objects cannot be seen easily and any overlap or clash cannot be detected easily; and
- There is no clear information about physical objects in this plan.

In addition to paper-based (PDF) plans, some applications have been developed in Victoria to facilitate the land administration processes.

4.2.3.5 Current Visualisation Applications in Land Administration

Land Victoria has provided users with various online applications to visualise authoritative data related to land and property information. These applications are used widely in land administration in Victoria.

- **Land and Survey Spatial Information (LASSI)**[45]

LASSI is a web-based application for visualising the boundary of land parcels stored in DCDB in Victoria. This application has some basic functionalities such as zoom, pan, distance measurement, identify, print, save image, drawing mark-up tools (point, line, polygon, rectangle, callout, text). The default data layers in this system are parcel maps, parcel numbers, localities and roads. Various layers are accessible through this application. Figure 4.22 illustrates a snapshot of this application.

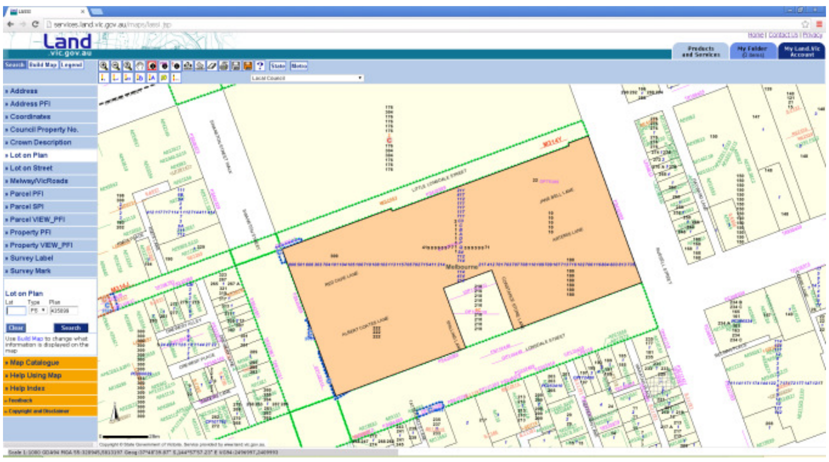


Figure 4.22: LASSI application, a viewer for visualising land parcels stored in DCDB.

There are some visualisation issues associated with this application:

[45] http://services.land.vic.gov.au/maps/lassi.jsp

- This application is very slow to retrieve data and visualise the land parcels;
- The cartography of data is not suitable. Text and labels overlaps and colours are not appropriately selected.

LASSI has a legend for defining various ownership boundaries (table 4.3).

Table 4.3: Legend in LASSI for various ownership boundaries.

Parcel Type	Symbol
Below surface parcel	
Above surface parcel	
Surface parcel	
Parcel	

In this application, several overlapped parcels in Melbourne were studied, which are further described here. Figure 4.23 visualises some surface parcels and one above-ground parcel on a street. The green parcels are surface parcels and the blue parcel shows an above surface parcel.

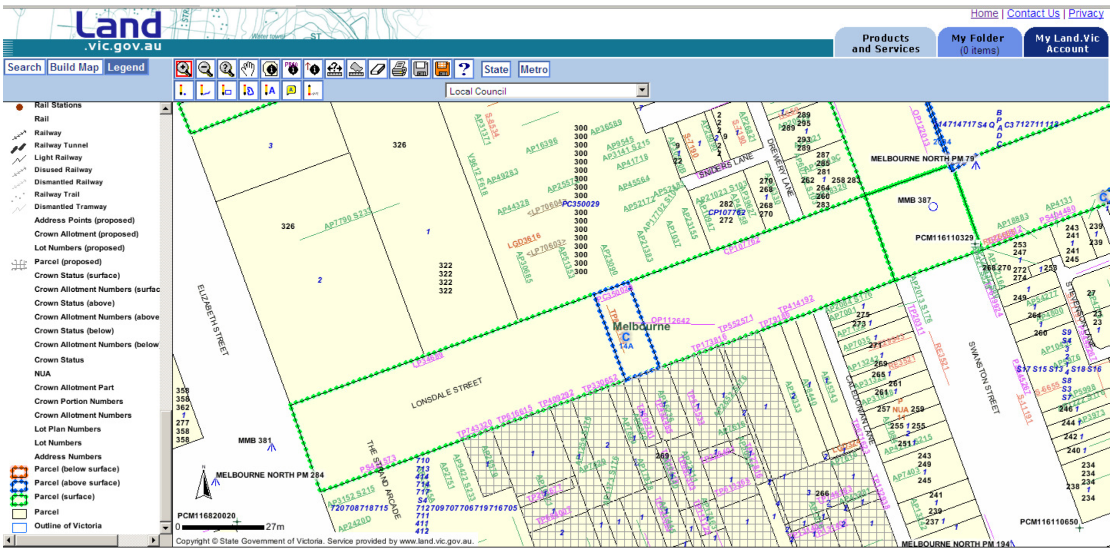


Figure 4.23: Several surface parcels and an above surface parcel located on top of a street.

Figure 4.24 shows the above mentioned case, called a skywalk.

Figure 4.24: A skywalk connects two buildings on top of a street in Melbourne.

An example of three overlapped parcels is shown in figure 4.25.

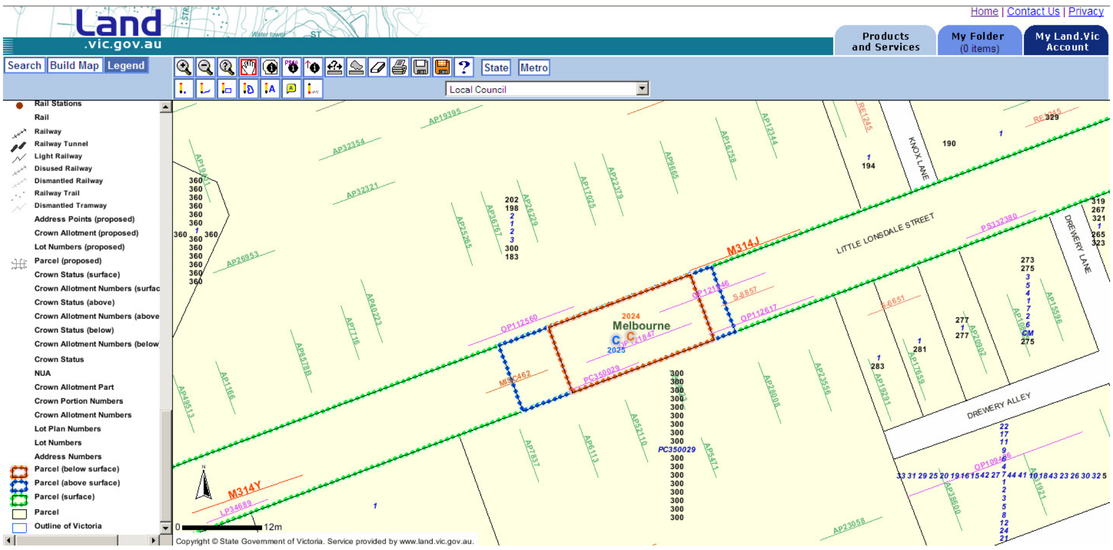


Figure 4.25: Three overlapped parcels located on top of each other.

Figure 4.26 shows a photo of the above case, a skywalk connecting two buildings.

Figure 4.26: A skywalk connects two buildings over a street. There is an underground parcel which is shown in figure 4.25.

In these cases, due to the limitations of 2D visualisation, cartography approach is used for representing overlapped parcels. Recently, a new version of LASSI has been developed by Land Victoria, called LASSI-SPEAR. Figure 4.27 shows a snapshot of this application.

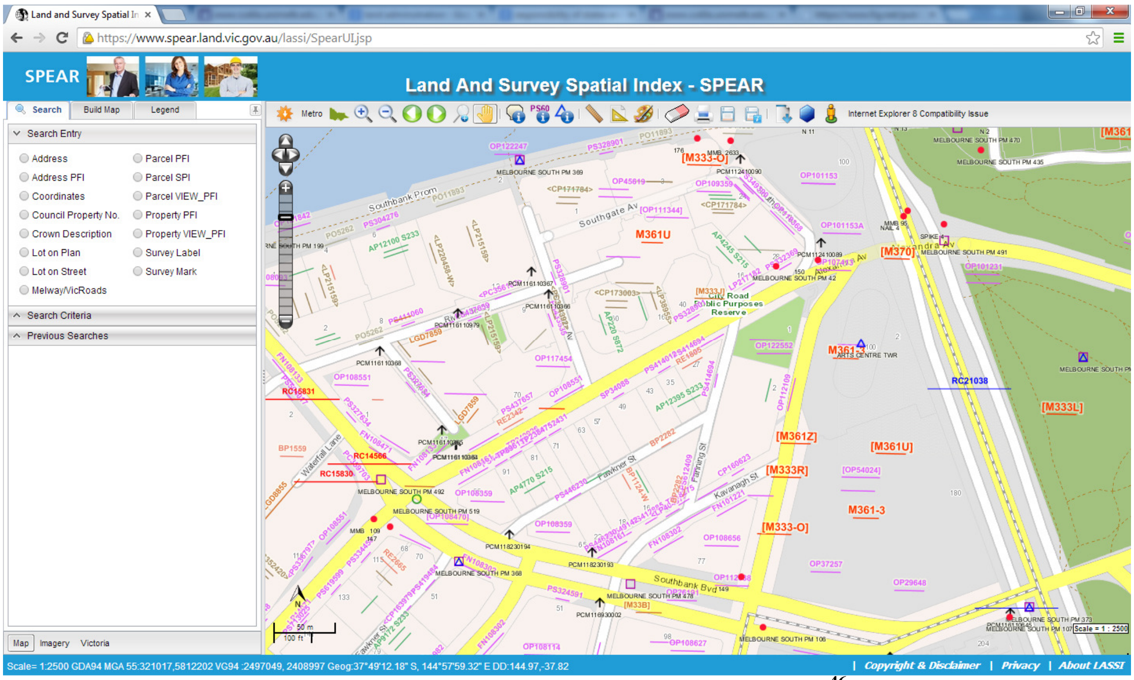


Figure 4.27: A snapshot of LASSI-SPEAR[46].

[46] https://www.spear.land.vic.gov.au/lassi/SpearUI.jsp

- **Vicmap API**[47]

Vicmap API (figure 4.28) is a JavaScript mapping Application Programming Interface (API) for delivering Victorian data (Vicmap) and other spatial data. Vicmap Property is a property map base (cadastre) and includes spatial information at various scales (Ho and Rajabifard, 2012b). It contains information on parcels and property identifiers, local government reference numbers, both registered and proposed parcels, Crown and freehold land, roads, easements, unique features and geometric information to visualise the information as polygons in geographic information systems[48].

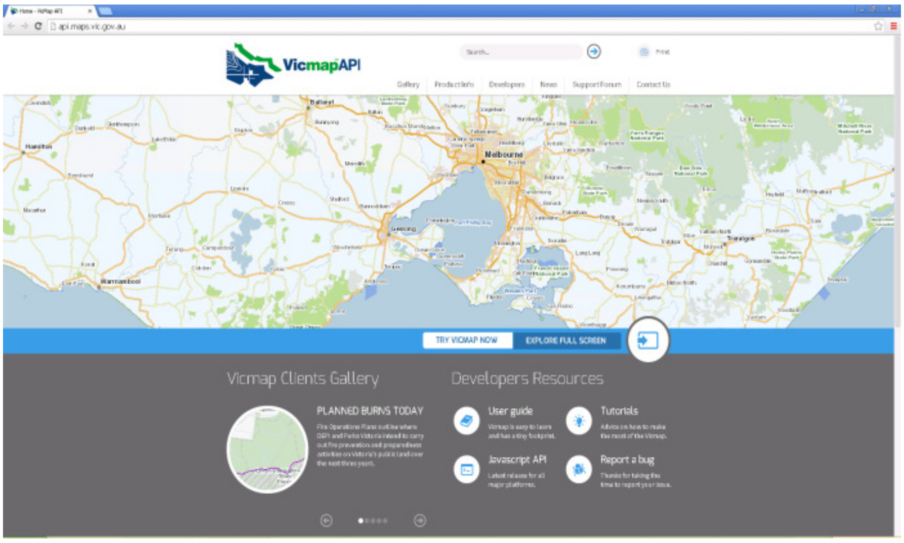


Figure 4.28: Vicmap API for representing main datasets in Victoria.

These two applications are mainly used for the following main purposes (SKM, 2011):

- To provide an index map of crown and private land parcels;
- To assist the land administration process;
- To provide information about each land parcel;
- To support urban and regional development; and
- To provide an infrastructure map of Victoria.

Many authorities, such as local governments, use Vicmap in the land administration process. This data is mainly used to issue planning permits and building permits. Table 4.4 represents a list of users of Vicmap API.

---

[47] http://api.maps.vic.gov.au/

[48] http://services.land.vic.gov.au/SpatialDatamart/dataSearchViewMetadata.html?anzlicId=ANZVI0803002683&extractionProviderId=1

Table 4.4: Sample of Vicmap API users (SKM, 2011).

Sector	**Example uses**
Facility and infrastructure managers	Infrastructures (e.g. cable) providers use Vicmap data to improve services
Utility companies	Planning and service supply, billing, and maintenance
Developers	To understand existing tenure, planning, asset location, and parcel location to facilitate development
Dial before you Dig	This free service is based on Vicmap data to identify the location of underground assets to prevent them being damaged during construction process
Local governments	Controlling land use, zoning, subdivision, asset management and service delivery
Emergency planning and response organisations (VicSES, VicPol, AV, MFB, CFA)	Vicmap is used for emergency management including planning, response, recovery, and compensation.
State Government	• Managing environmental and natural resources including State Forests, parks and other public land, water resources and catchments; • For understanding land boundary information to assist in the planning and design of projects; • Urban planning; • Land tenure management, including the management of Crown land - for weeds, fire and flood; • Disaster management and responses; • Quarantining – e.g. utilising Vicmap to identify the properties within a set distance of the affected area.
Property conveyancing and real estate sector	To identify land tenure and size and position of land parcels
Lending institutions, banks	Controlling the current tenure and title identification of properties
Australia Post	To locate property addresses
Insurance companies	To control current tenure and title of properties

Investigation of these two applications could help identify the current approaches to visualisation of cadastral data. In addition, the types of users and their needs were identified through this investigation.

4.3 Summary of Findings

In this section, findings from the case study and interviews are provided to show the main challenges.

The Victorian land administration system currently registers ownership information in overlapped scenarios. However, there are some issues which need updating in the Subdivision Act. The current legislation dates from 1988. The type of legislation was prepared for that period and cannot cope with some new types of issues (e.g. car stackers) easily.[49] Multiple owners' corporations is another challenge. In addition, there are some gaps in the land administration process. For example, owners' corporations need to be notified in case of any change in the ownership of apartment units,[50] which are not currently included in the process.

The owners (or tenants) are not aware of their rights and pets, parking, noise, and defects are significant issues in owners' corporations.[51]

According to the interviews with a wide variety of users, the current registered plans are limited to only a small community in Victoria. The value of this data is decreased when data is not recorded digitally. Due to the existing limitations in the current registration system and visualisation, building managers have their own approaches to managing ownership rights. As an example, in a very complex high-rise in the centre of the City of Melbourne, a building manager had prepared a spreadsheet of car park locations in order to search and find the car park for each apartment.[52]

The land registry is interested in implementing a digital 3D cadastre in the current process as it would help to register ownership information in 3D and also provide property information accessible for many users.[53] One of the main challenges in implementing a digital 3D cadastre is the cost of preparation of 3D data. Based on findings in this research, architectural drawings are a good source of 3D data.

By implementing a digital 3D cadastre, more applications can be developed for various users. For instance, 3D models of buildings can significantly help in disasters (e.g. fires) to help fire fighters to accurately locate the fire in a building.

Also, building managers believe that 3D visualisation is an added value for ownership boundaries interpretation as they need to know where the services and utilities are.[54] Currently building managers need to go to the site in order to understand the situation. If a 3D model exists for that building, building managers can get more information from that.[55]

[49] (Land Registry, personal communication, April 3, 2013)
[50] (Building Manager, personal communication, May 9, 2013)
[51] (Building Manager, personal communication, April 24, 2013)
[52] (Visit, QV Building, May 2, 2013)
[53] (Land Registry, personal communication, November 14, 2012)
[54] (Building Manager, personal communication, May 9, 2013)
[55] (Building Manager, personal communication, May 15, 2013)

Real estate agents are interested to have 3D visualisation applications to assist them to sell or rent the properties. Therefore, marketing requirements in 3D visualisations must be considered.

Many people do not understand the terms and surveying drawings on the plans. However, understanding plans is very important to know liability and entitlement. For this reason, Strata Community Australia has conducted some seminars and published many handbooks to teach the public how to understand, use, and interpret plans.[56] Owners are now getting more informed about their rights and more educated.

4.4 Chapter Summary

In this chapter, land administration systems in Victoria were explained and Land Victoria was introduced, including the organisational structure, and Acts and regulations. The first mini case study was introduced and issues and challenges were discussed. The subdivision process in Victoria was described and various ownership boundaries in the subdivision plan were discussed. Then, the second mini case study was introduced and various issues were highlighted. Current visualisation applications in land administration in Victoria were introduced.

At the end of the chapter, findings from the case study (including two mini case studies), and interviews were provided to show the main challenges. According to this assessment, the Victorian land registry is able to register RRRs in unit/apartment level. However, the registered data is currently recorded in a paper format not in a digital format.

The next chapter presents the identified 3D visualisation requirements for representing RRRs in 3D for cadastral users.

[56] (Building Manager, personal communication, April 24, 2013)

CHAPTER 5

REQUIREMENTS FOR 3D CADASTRAL VISUALISATION APPLICATIONS

Information Visualisation Mantra
"Overview first, zoom and filter, then details on demand"-
–BEN SHNEIDERMAN

5 Requirements for 3D Cadastral Visualisation Applications

5.1 Introduction

This chapter details the user requirements for 3D visualisation applications for cadastral purposes. These requirements were identified through the process of requirements engineering, as described in chapter 3. Due to the different cadastral law and regulations in each jurisdiction, providing a widely accepted comprehensive and unique list of requirements is not possible. Therefore, these requirements are mainly based on the needs and expectations of users in Victoria, but they can also be considered as initial requirements for other jurisdictions and extended based on their needs. Therefore, it is significant to consider a scalable and flexible solution which can incorporate future needs and expectations.

The identified requirements are classified, based on their similarity, into the following five main categories:

- Data Requirements;
- User Interface and System Requirements;
- Technical Requirements (Non-functional Requirements);
- Visualisation Requirements; and
- Analytical Requirements.

The following sections further describe each category and relevant requirements. At the end of some sections, some features which are useful for specific users are recommended to be included in the visualisation applications. The users of each requirement are introduced and analysed in chapter 7. There is no priority or relative importance in the order of requirements listed below.

5.2 Data Requirements

Understanding cadastral data is vital to choosing the best method of visualisation. Software developers need to know the characteristics of data to be visualised. For visualising 3D cadastres, three main types of data were found to be significant: physical data, legal data and administrative information. Physical data refers to physical objects such as buildings and utilities, on, above or under the ground surface. Physical data has two main purposes in visualisation of cadastral data: (a) to give context, and (b) to identify legal boundaries that are explicitly linked to physical entities. Legal data is defined as property ownership rights, restrictions, and responsibilities. Administrative information includes non-spatial information such as attributes of RRRs and documents. These data requirements and their characteristics are described in detail in the following sections.

5.2.1 Legal Data

Legal data represent rights, restrictions and responsibilities which are abstract; that is, conceptual and cannot be seen in the real world. However, in some cases, a physical object can be a representative for a legal object. For example, a wall is a physical object but may also represent the edge of a property. In this case, the physical and legal entities are coincident and the same data may represent both. However, the data may be ambiguous as ownership boundaries could be located at the exterior or interior face, or even in the middle of the wall. Often such ambiguities are resolved by textual description (e.g. "the interior of the wall") on the plan of subdivision. This section describes legal data and the method of visualisation for cadastral purposes.

5.2.1.1 Parcel

Parcel is a very important legal entity in cadastral applications. According to FIG Commission 7 Statement on the Cadastre,[57] the basic spatial unit in a cadastre is known as a parcel. Examples of parcels in Victoria include a lot, Crown allotment, road, and common property. In Victoria, individual parcels of land are described in a folio of the registrar, in the case of Crown land, a Crown Land Status Report[58].

Name
Parcel
Description
A land parcel is an individual piece of land for which a land title has been issued[59]. Land parcel can be a (Victorian ePlan, 2012): • Lot; • Common property; • Road; • Easement; • Restriction; • Owners corporation; • Stage lot; • Depth limitations;

[57] https://www.fig.net/commission7/reports/cadastre/statement_on_cadastre.html
[58] Victorian Cadastre Terminologies, 2013, unpublished report, Land Victoria.
[59] http://www.dtpli.vic.gov.au/property-and-land-titles/land-titles/about-land-titles/common-terms-land-titles#parcel

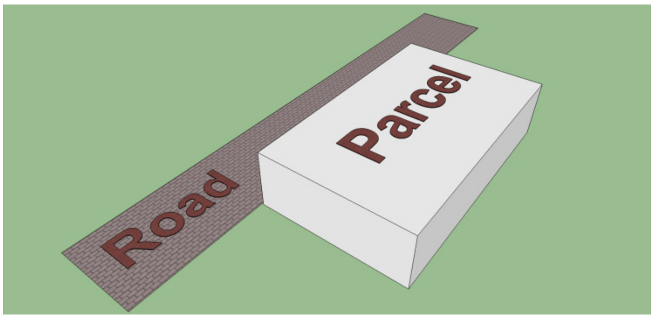
- Crown parcel;
- Crown allotment; and
- Crown portion.

Possible attributes

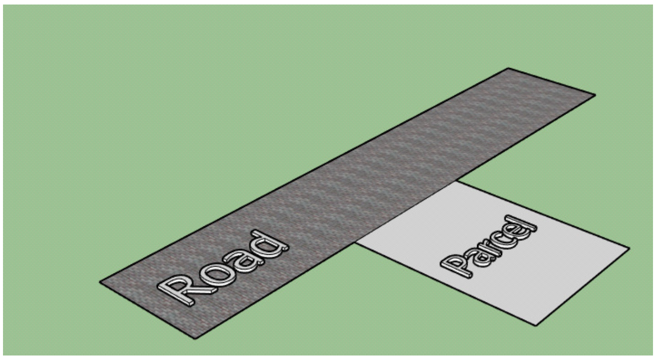
Plan number, LGA, parish, township, municipality, crown portion, title reference (parent title), last plan reference, postal address, MGA- co-ordinates (approximate coordinate of the centre of land in plan), zone, depth limitation, staging, planning permit number, survey, land surveyor's name, signature, surveyor's reference, date and version, company name and address, purpose of survey report, description of land, instrument and calibration details, permanent mark connections, vesting of roads and or reserves, appurtenant easements, road and abuttals, encumbrance.

Visualisation

The following figure represents an example of visualising a land parcel. A land parcel has ownership rights above and below the ground. However, this right might be limited in height and depth; in this case a volume object best represents the ownership boundaries. Otherwise, the right is unlimited in vertical extent above and below the ground surface.



In this case, due to the limitation of representing unbounded volumes, just a 2D boundary is visualised and the extent of rights is attached to the 2D boundary (Shojaei *et al*., 2013) (figure below).

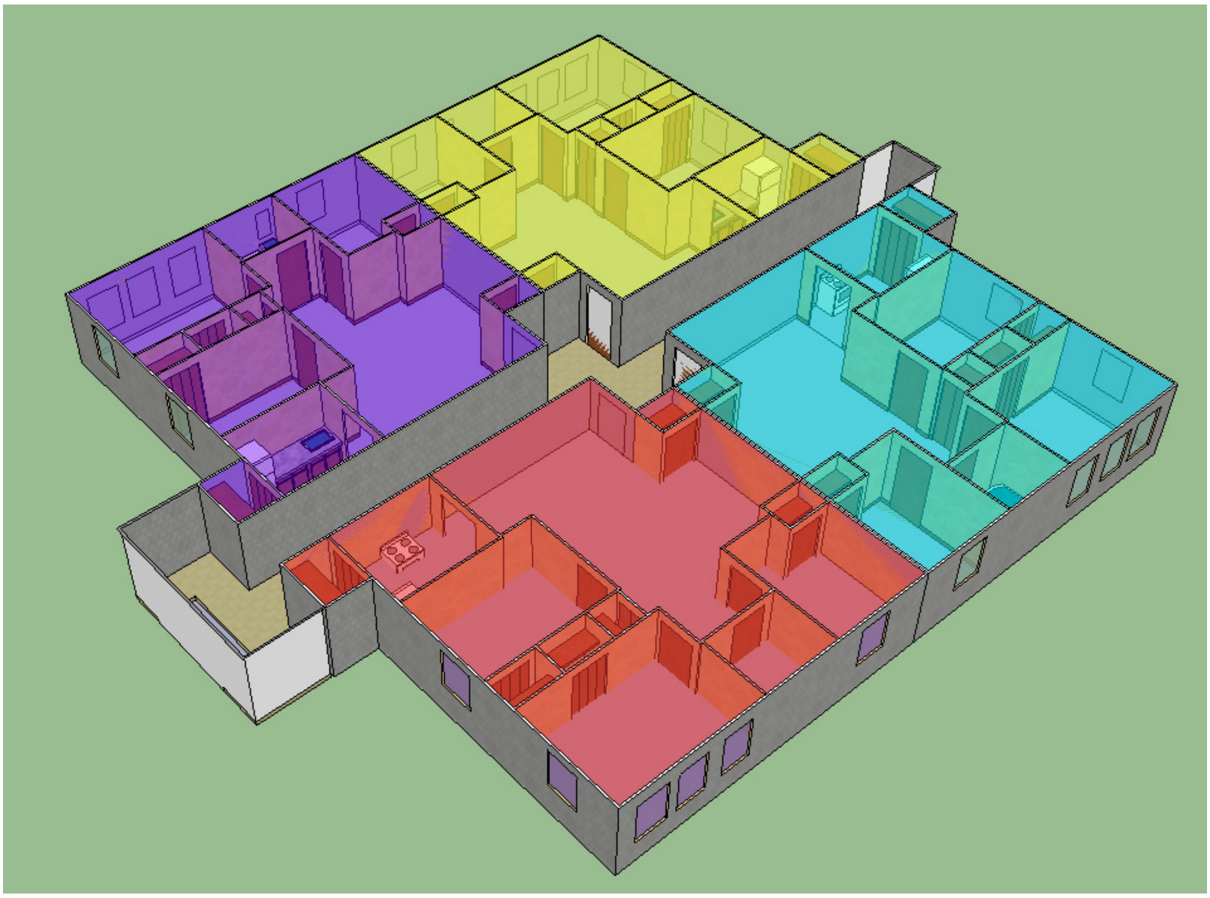


Most 2D cadastral applications, which visualise DCDB, represent 2D land parcels and associated attributes. As an example, LASSI[60] in Victoria can visualise land parcels in Victoria.

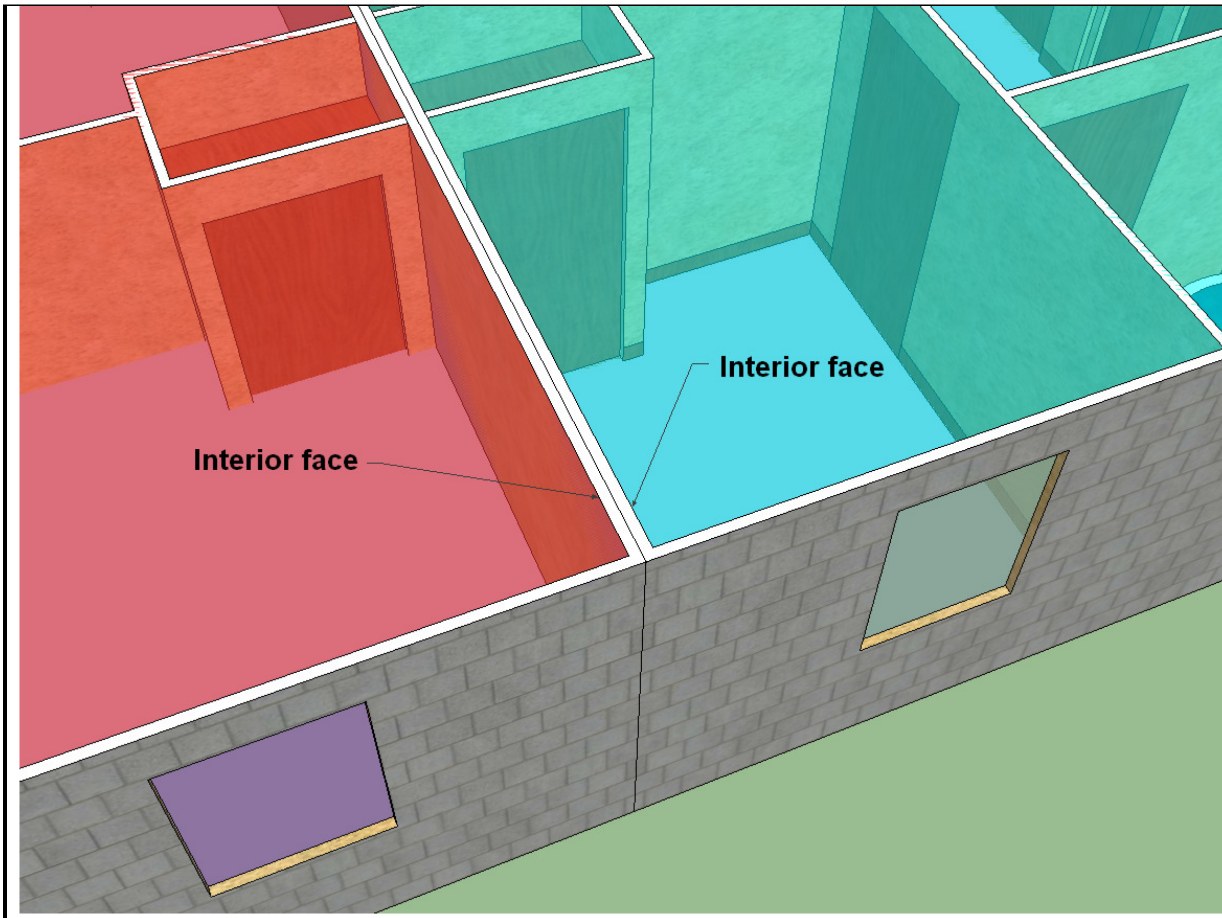
[60]https://www.spear.land.vic.gov.au/lassi/SpearUI.jsp

5.2.1.2 Lot

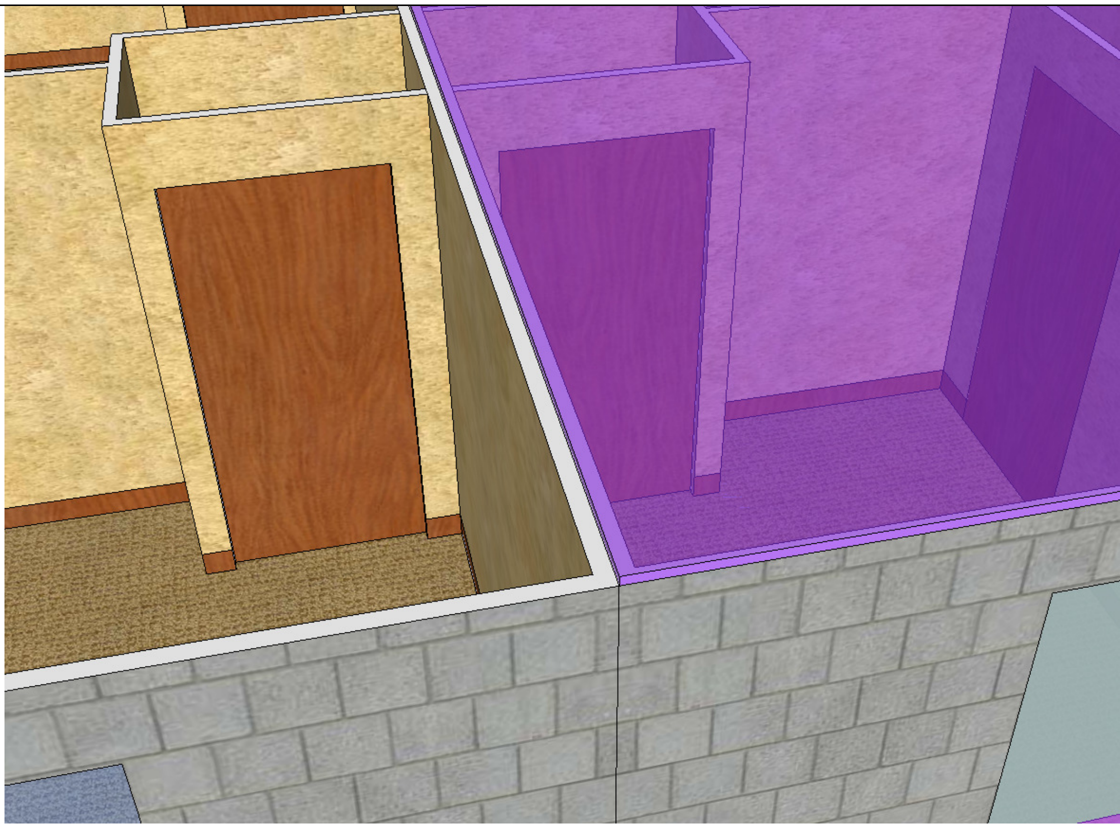
A land parcel may have one or more lots. Each lot must be visualised and its extent must be clear.

Name
Lot
Description
One piece of land which can be sold separately, or in other words, an individual piece of land for which a land title has been issued[61].
Possible attributes
Lot number, area, etc
Visualisation

The above figure presents four lots, each an apartment unit, located on one floor of a building. Each lot is limited to the ownership boundary of the associated apartment unit. Ownership boundary locations (e.g. exterior face, interior face or median of wall) of each lot must be clearly presented. For example, in the following figures, different types of ownership boundary location are visualised.

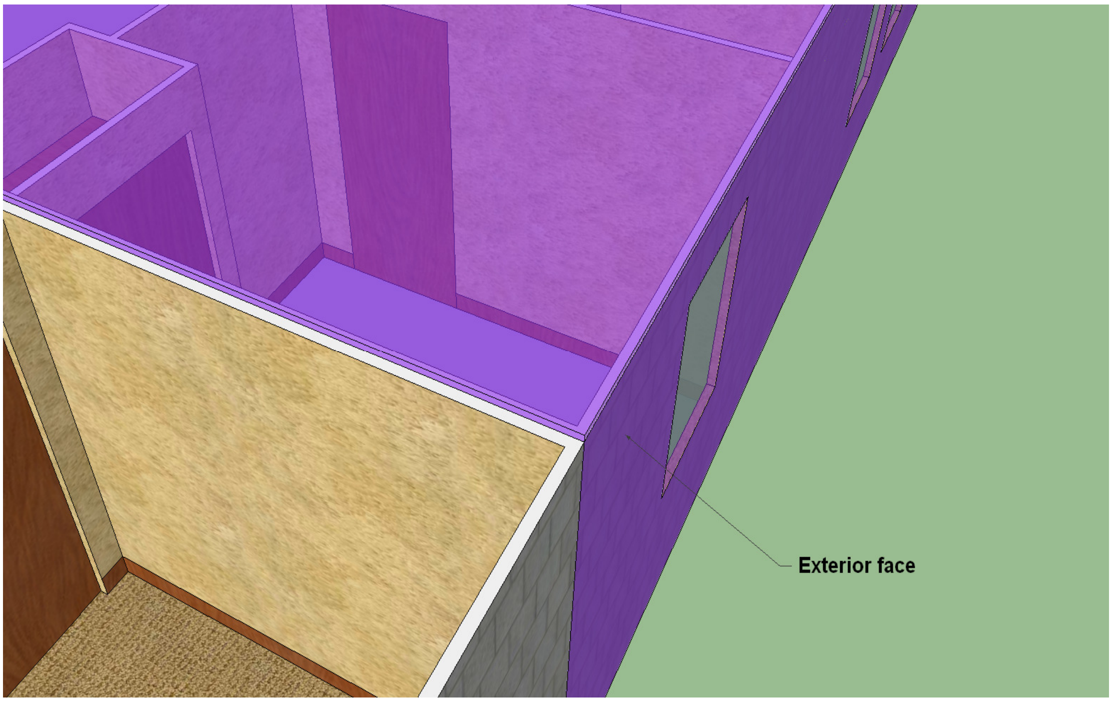
[61] http://www.dtpli.vic.gov.au/property-and-land-titles/land-titles/about-land-titles/common-terms-land-titles#parcel



Interior face: The red and blue lots both have interior face as ownership boundary rights. Therefore, the wall between them is common property.



Median face: The ownership boundary right is defined as median face for the purple lot. Therefore, half of the wall belongs to the purple lot.

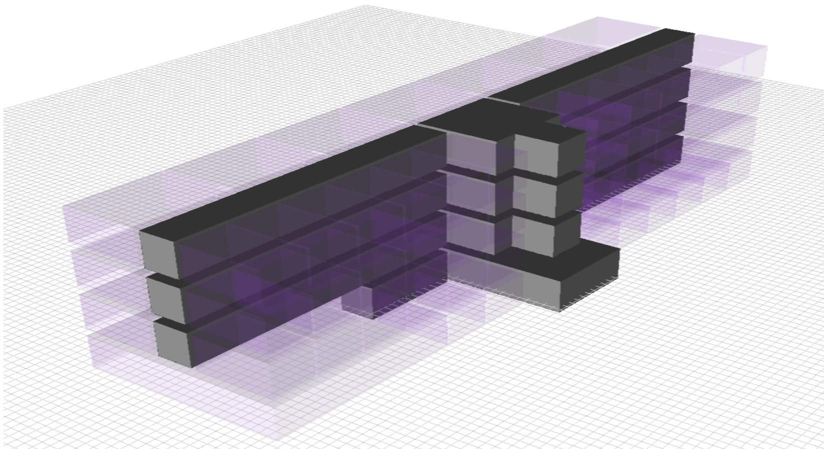


Exterior face: The ownership boundary right of the purple lot is defined as exterior face. The external wall belongs to the purple lot.

Lots can be apartment units or a piece of land. In any case, the ownership boundary of lots must be clearly described in the visualisation application. Lack of fully describing the boundaries may result in disputes.

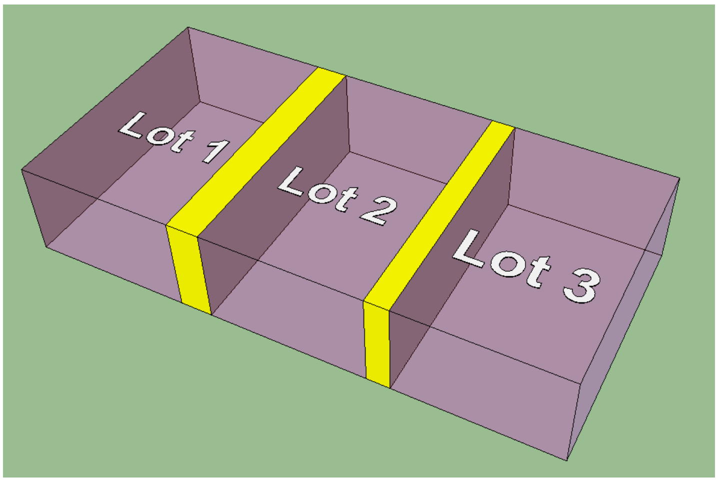
5.2.1.3 Common Property

In strata, common property refers to the spaces of land and buildings which are not included in any lot. These spaces are owned by all unit owners in each strata.

Name
Common property
Description
Common property includes areas such as driveways, staircases, corridors, and laundries and it is usually managed by an owners' corporation.[62] It is separately identified on subdivision plans.
Possible attributes
Name, plan number, land affected by owners corporation, limitation of owners corporation, entitlement, liability, description, class, state, parcel type, use of parcel, area.
Visualisation
 The above figure presents several common property areas (in grey) located in one building. Each lot (transparent purple) is associated with some of the common property areas and the lot owner's liabilities and entitlements must be described in the owners' corporation schedule. Two types of common property areas may exist on subdivision plans: • Non-structural common property areas (e.g. corridors and staircases); and • Structural common property areas (e.g. walls and slabs). Non-structural common property areas are represented as 3D volume objects (e.g. the grey colour in the above

[62] http://www.dtpli.vic.gov.au/property-and-land-titles/land-titles/about-land-titles/common-terms-land-titles#parcel

figure). Structural common property areas are not represented above to avoid complexity in visualisation. Representing the spaces among lots in an apartment, located in the structure, brings more complexity to the visualisation (see figure below).



In this figure, the yellow volumes are spaces between lots which are considered as common property areas in this case. In a big development, visualising all these spaces may cause complexity in understanding the other RRRs. Therefore, structural common property areas should not be represented on the visualisation application.

Different types of ownership boundary location (interior face, exterior face, and median) are possible in defining common property areas. For example, in the above figure, the ownership rights among these three lots are interior face and the walls are considered as common property.

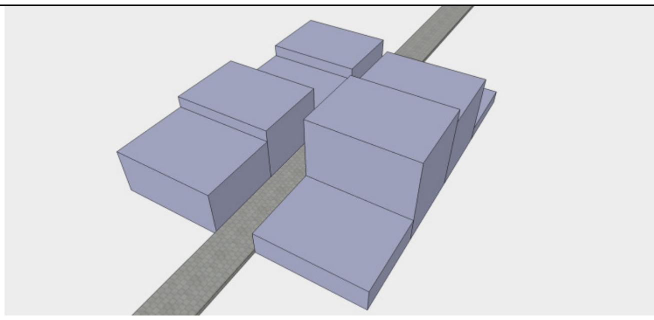
The visualisation application must be able to showcase the link between lots and common property areas. It means that, users must know which lots have access to which common property areas. This link is very important for various types of cadastral users.

5.2.1.4 Roads

Roads are another class of parcels and can be private or public. Currently, roads are represented as 2D polygons in existing 2D cadastral visualisation applications.

Name
Roads
Description
Public roads provide access to freehold and leasehold land.[63]
Possible attributes
Name, area, suffix
Visualisation

[63] http://www.lpma.nsw.gov.au/crown_lands/roads



Roads are represented in visualisation applications to show the access to land parcels. For cadastral purposes, roads are considered as spaces similar to land parcels and they may have bounded or unbounded volumes. However, for simplicity in 3D cadastral visualisation applications, they should be visualised as a closed boundary. In addition, roads are considered both as physical and legal entities. This classification is required as roads have different meanings and usages as legal or physical entities.

Roads also may be defined as easements. For example, rights-of-way may exist for different uses such as construction and access to utility lines. There may also be traditional public rights-of-way over certain parcels to provide access to rivers, the coast, roads, etc.[64]

5.2.1.5 Easements

Easements are rights for someone to use land belonging to someone else for a specific purpose. For example, drainage, sewerage and carriageway are common easements.[65]

Name
Easements
Description
Easements are one of the secondary interests in survey plans which provide benefits and/or poses restrictions on cadastral parcels.[66] Various types of easements exist, such as: • Air supply (flow of air, passage of air, air exhaust and ventilation); • Carriageway; • Drainage (floodway, sewerage, and waterway); • Erosion; • Fire (access, escape, and egress); • Floodway; • Flooding; and • Flow of light and air. [67]
Possible attributes
Name, class, state, parcel type, use of parcel, purpose, origin, beneficiary

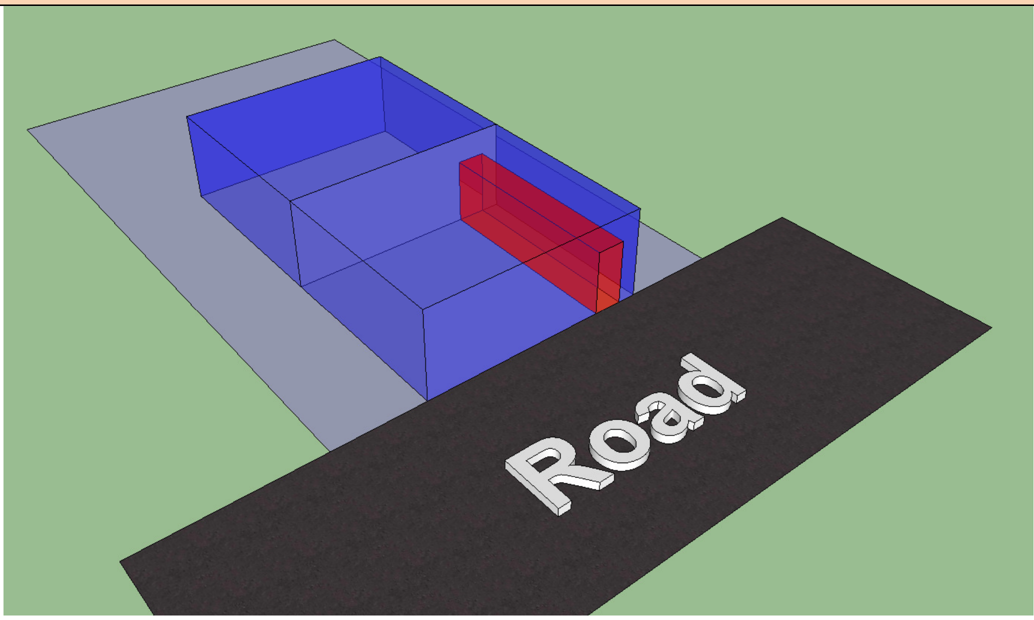
[64] https://www.fig.net/commission7/reports/cadastre/statement_on_cadastre.html

[65] http://www.dtpli.vic.gov.au/property-and-land-titles/land-titles/about-land-titles/common-terms-land-titles#easement

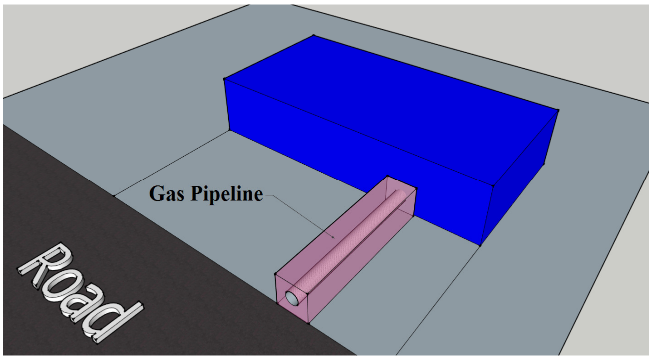
[66] http://www.spear.land.vic.gov.au/spear/documents/eplan/ePlan%20Handbook%20Section%208%20-%20Secondary%20Interest%201.3.pdf

[67] http://www.sssi.org.au/userfiles/docs/VIC%20Region/documents_1317724209l604959742.pdf

Visualisation



Representing easements depends on the type of easement. In some cases, the ownership boundary of an easement is equal to the easement object (e.g. fire access corridor in red colour – figure above). However, in some cases, the boundary of an easement is defined as bigger than the associated object (e.g. gas pipeline in the figure below). In this case, a buffer zone is created around the pipeline for further protection and therefore, an appropriate visualisation including the buffer zone is required.

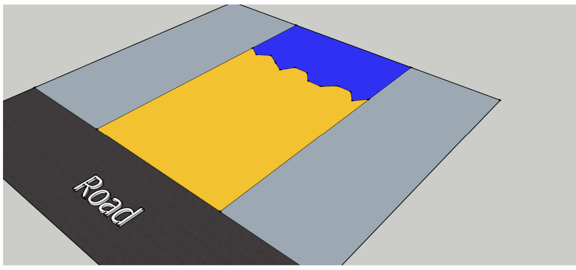


In Victoria, easements are categorised as encumbrances (or appurtenances) and they must be clearly visualised in the visualisation application.

5.2.1.6 Restrictions

Restrictions are formal or informal requirements to refrain from doing something (modified from ISO 19152: 2012 (LADM)). There are a number of restrictions recognised in Victoria, such as those included in restrictive covenants and planning and building restrictions.[68]

[68] Victorian Cadastre Terminologies, 2013, unpublished report, Land Victoria.

Name
Restrictions
Description
Restrictions are secondary interests in survey plans and are a type of covenant which defines limitations on the use of land.[69]
Possible attributes
Name, description, class, state, parcel type, land to benefit, land to be burden, expiry date.
Visualisation
Restrictions are as part of parcel elements and their spatial extent can be defined spatially or non-spatially using textual descriptions, according to the type of restriction. For example, in the following figure, the blue section of this parcel has a restriction based on the survey plan. *"Construct any building requiring sewerage services within the [blue area]"*[70].  Visualising restrictions depends on the type of restriction and can be defined differently. One solution is using transparency similar to easement representations to show the boundary and extent of restrictions.

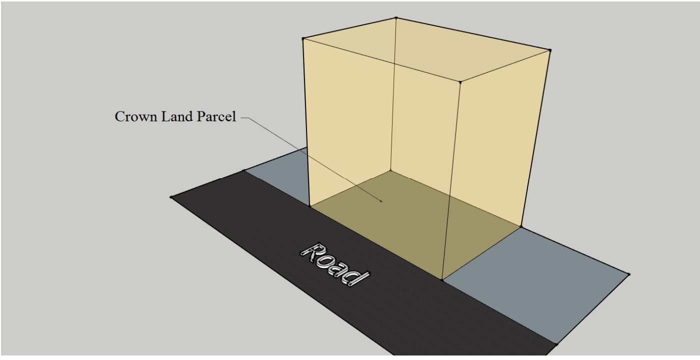
In some cases, restrictions might be temporal and the expiry date is provided.

5.2.1.7 Crown Land

Crown lands are similar to freehold lands, but are owned by governments.

Name
Crown land
Description
Crown land is a piece of land which is owned by the government, such as local parks and reserves for future projects, e.g. highways.[71]
Possible attributes
Name, class, state, parcel type, area.

[69] http://www.spear.land.vic.gov.au/spear/documents/eplan/ePlan%20Handbook%20Section%208%20-%20Secondary%20Interest%201.3.pdf
[70] http://www.spear.land.vic.gov.au/spear/documents/eplan/ePlan%20Handbook%20Section%208%20-%20Secondary%20Interest%201.3.pdf
[71] http://www.dse.vic.gov.au/property-titles-and-maps?a=94931

Visualisation
Representing crown lands is similar to visualising land parcels by considering height or depth limitations if they exist. 

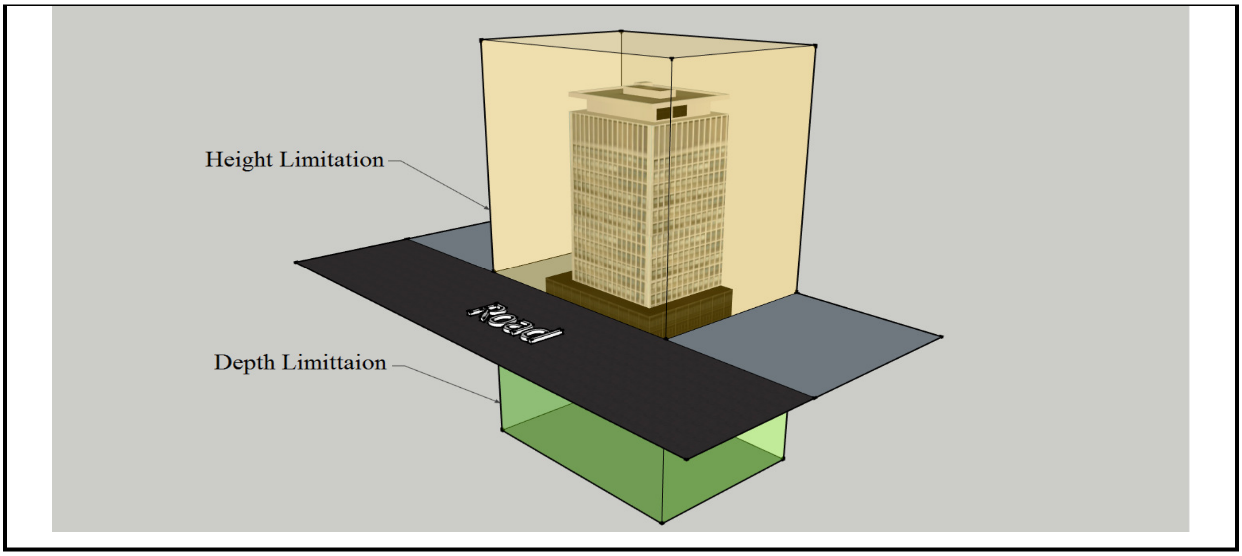
In Victoria, LASSI is able to visualise the extent of crown land parcels which is the same as visualisation of a free-hold land parcel.

5.2.1.8 Depth and Height Limitations

Depth and height limitations are spaces above and below an area which define the extent of rights.

Name
Depth and height limitations
Description
These are a type of restriction and are one of the secondary interests in cadastral survey plans. They define depth and height limitations attached to each lot and originate from the original crown grant.[72] In subdivision plans, they are recorded as notations. However, if the spatial extent of the limitation has been defined, it can be visualised graphically. Height limitation is also called air space and refers to the ownership rights above the ground surface.
Possible attributes
Name, description, class, state, parcel type, depth.
Visualisation
Depth and height limitations are visualised according to the geometry of the limitations. In the following figure, height and depth limitations are visualised by two cubes in two colours.

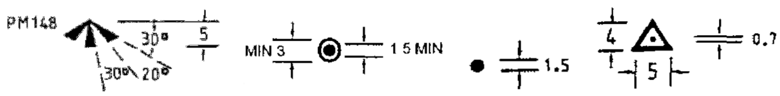
[72]http://www.spear.land.vic.gov.au/spear/documents/eplan/ePlan%20Handbook%20Section%208%20-%20Secondary%20Interest%201.3.pdf



If there is no limitation above or below an area, the volume must be unbounded. In this case, due to difficulty of visualising unbounded volumes, a 2D parcel is visualised and the extent of right is described as an attribute attached to the polygon.

5.2.1.9 Survey Marks

Survey marks define location for surveying projects. These marks are used for housing developments, new road and bridge construction, and improving railways.[73]

Name
Survey marks
Description
Various types of survey marks exist in subdivision plans and they are required for future reference.
Possible attributes
Name, survey mark type, condition, state, ID, description, setup ID, date, horizontal datum, vertical datum, latitude, longitude, zone, horizontal fix, vertical fix, currency date, positional uncertainty, order, source, point scale factor, type, status (condition).
Visualisation
In current subdivision plans, different types of survey marks are represented by the following symbols.  In 3D visualisation applications survey marks can be represented using the above symbols.

Some specific users must be able to update the information for each survey mark, create a new survey mark, or remove a survey mark from the database.

[73] http://www.lpi.nsw.gov.au/__data/assets/pdf_file/0007/169522/19608_Mark_Preservation_Flyer_web.pdf

5.2.1.10 Administrative Boundary

Administrative boundaries are represented as 2D polygons and define areas managed by authorities.

Name

Administrative boundary

Description

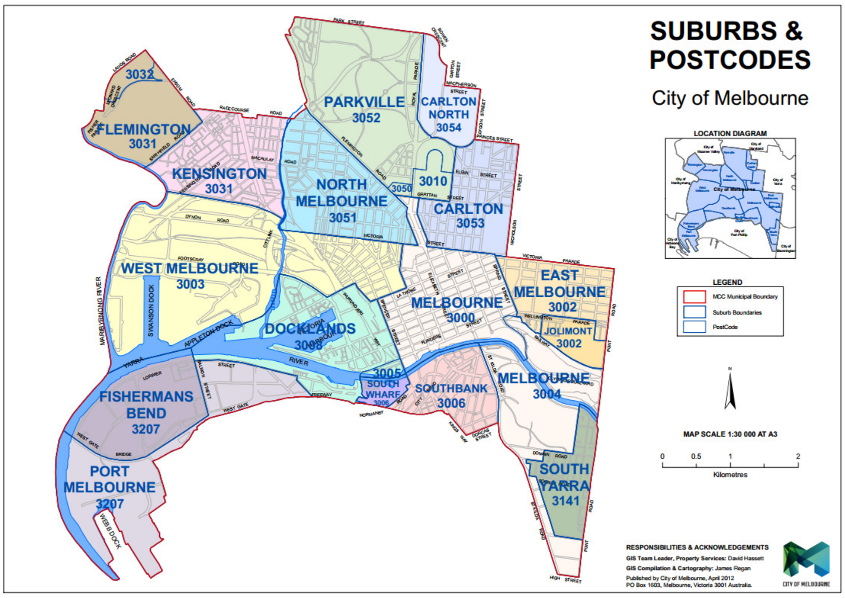
An administrative boundary is a border of an area which is managed by local governments for providing services.

Possible attributes

Name, area, code, parish, township

Visualisation

The following figure represents the administrative boundary of the city of Melbourne.[74] In cadastral applications, each administrative boundary must be specified in survey plans to specify the location.



A 2D layer representation of administrative boundaries is enough for current needs and expectations of users.

In this section, legal data was introduced and the method of visualisation for each type of data was explained. The next section, discusses the physical data required for cadastral applications.

---

74 https://www.melbourne.vic.gov.au/AboutMelbourne/CityMaps/Documents/CityofMelbourne_boundarymap.pdf

5.2.2 Physical Data

Physical data refers to visible and tangible objects that exist in the real world. Physical data in cadastral applications helps to understand the extent of RRRs as it brings context to the application. This section describes the physical data required for cadastral purposes.

5.2.2.1 3D Building Models

3D building models define the structure of a building and associated components. 3D building models are stored in 3D formats such as Collada, IFC, KML, and CityGML.

Name
3D building models
Description
A 3D building model is a computer representation of a building in 3D using various types of geometry, including building parts (e.g. walls (interior and exterior), doors, slabs, windows, roofs, and columns).
Possible attributes
Many attributes are possible.
Visualisation
For representing 3D building models for cadastral purposes, not only the external geometry, but also the internal geometry of strata buildings is required to represent the location of ownership boundaries. The figure below represents the external geometry of a 3D building model.  User need to see buildings in various resolutions. Therefore, considering Levels of Detail (LoD) is important in visualisation. For example, representing buildings with different details in various zoom levels helps 3D visualisation applications to render massive data efficiently.

Integrating 3D building models with other city structures such as bridges, roads, and rivers create a 3D city model.

5.2.2.2 Digital Terrain Model

Digital Terrain Model (DTM) represents the elevation variation of the ground surface.

Name
Digital Terrain Model
Description
Digital Terrain Model represents the topography of an area with elevation variations.
Possible attributes
Elevation
Visualisation
In 3D cadastres, the elevation of terrain is required to define and visualise parcels. The location of parcels can be above, on, or below the ground surface. Satellite and aerial images can be projected over the DTM to represent the ground surface in more details. In addition to DTM, representing contour lines and Digital Surface Model (DSM) gives clearer and more accurate information about the terrain (Dimovski *et al.*, 2011).
 Source: http://www.landinfo.com/GalDTM1mMecca.htm

The accuracy of the DTM and height value of parcel corners must be checked to avoid models flying above or sinking in the DTM.

5.2.2.3 Car Park

Car parks can be considered as both physical and legal entities. In their legal aspect, car parks are defined as simple cubes and in the physical aspect they may have defined structures such as walls to define their extent.

Name

Car park

Description

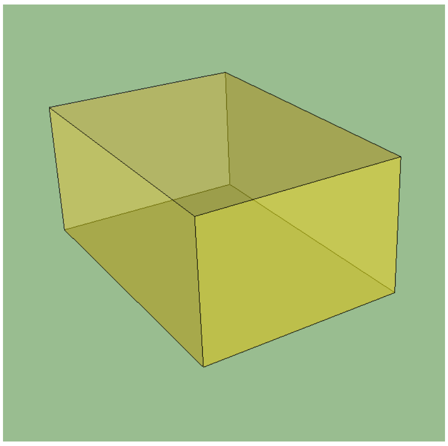
Car parks are part of lots and they are visualised by a volumetric object. In case of car stackers, two or more cars are parked in overlapped spaces and these spaces are separately owned.

Possible attributes

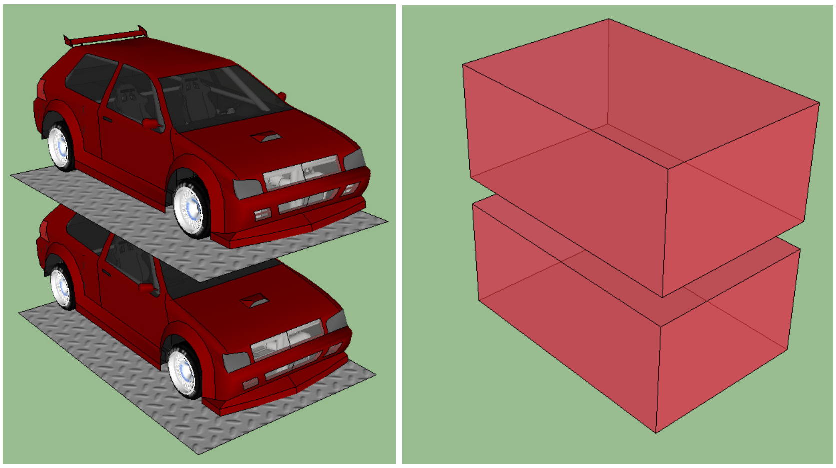
Car park number, related lot number, related apartment number.

Visualisation

For visualisation of car parks, for regular car parks, one volumetric object represents the boundary of the car park.



For representing car stackers, two or more volumetric objects are visualised, one for each parking lot (see figure below). In this figure, these two parking lots are located one on top of the other. Car stacker technology is similar to elevator technology.

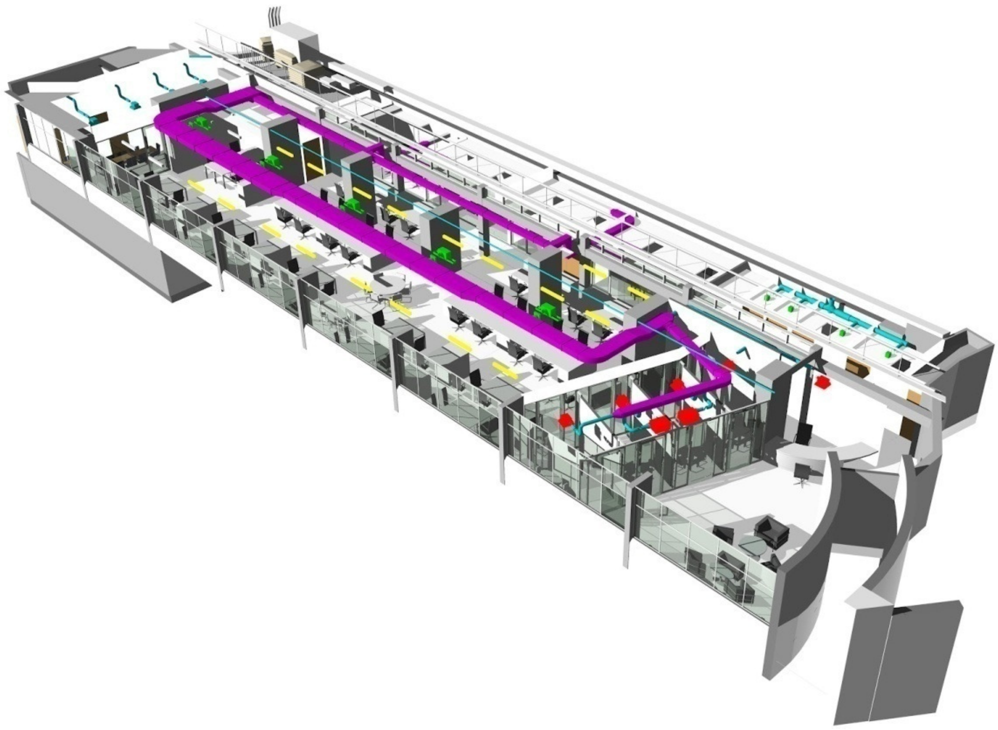


The spaces between car parks are usually defined as common property. In some cases, car stackers move horizontally. In Victoria, the moving car park is registered in a fixed location. However, in reality, the car park might be occupied by others and not specifically the lot owner.

5.2.2.4 Building Utilities

As part of physical data in buildings, building utilities are important components which need to be considered.

Name
Building utilities
Description
Building utilities include internal infrastructure which provides services to a building (such as pipes, cables, stormwater drainage).
Possible attributes
-
Visualisation
Building utilities are important from physical and legal aspects. Visualising building utilities helps in locating the easement and/or common property locations in apartments and any existing boundary around the utility networks (see figure below). In addition, it facilitates managing and maintaining of utilities for building managers and in case of any disputes, the 3D model of utility networks may help.

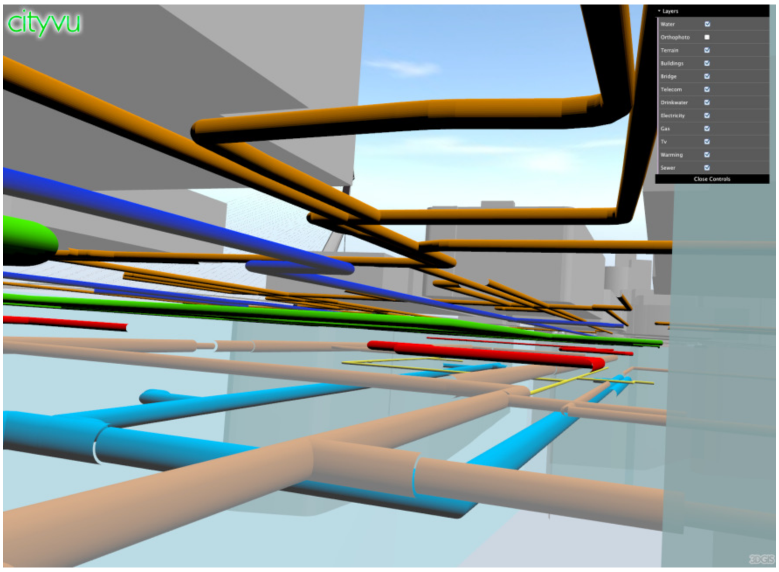


Source: http://mikewatkinsweb.blogspot.com.au/2012/09/david-miller-architects-combines-bim.html

IFC format supports various types of building utilities which can be considered for 3D cadastres.

5.2.2.5 Urban Utility Networks

Similar to building utilities, urban utility networks are important from physical and legal standpoints. From the physical aspect, visualising urban utility networks helps maintain infrastructures and from the legal aspect, visualising easements facilitates understanding of ownership boundaries.

Name
Urban utility networks
Description
Urban utility networks include various networks such as pipes, cables, stormwater drainage. Visualising them is necessary to identify and locate easements.
Possible attributes
Many attributes are possible.
Visualisation
Visualising utilities requires representing them in an accurate position to avoid damages during development and maintenance of utilities. The visualisation must specify the location and existing boundary around the utility networks (see figure below).  Source: http://blog.3dgis.it/307-asita-2012-vicenza

CityGML has UtilityNetworkADE to model utility network in 3D city models to support various analyses and simulations on utility networks.

5.2.2.6 Building Facades

Building facades refer to the exterior side of a building.

Name
Building facades
Description
Building facade is an image which represents one or more parts of a building (Wammes, 2011)
Possible attributes
-
Visualisation
Texture of buildings brings a more realistic visualisation to 3D building models. For representing building facades, the exterior surface of building models is covered by texture (figure below). Textured 3D building models help people to quickly understand the situation and orient themselves to the location of legal objects (e.g. buildings). In addition, detailed 3D objects can be represented by textured 3D models which are very useful for visualisation on mobile devices without rendering acceleration (Coors, 2003). 

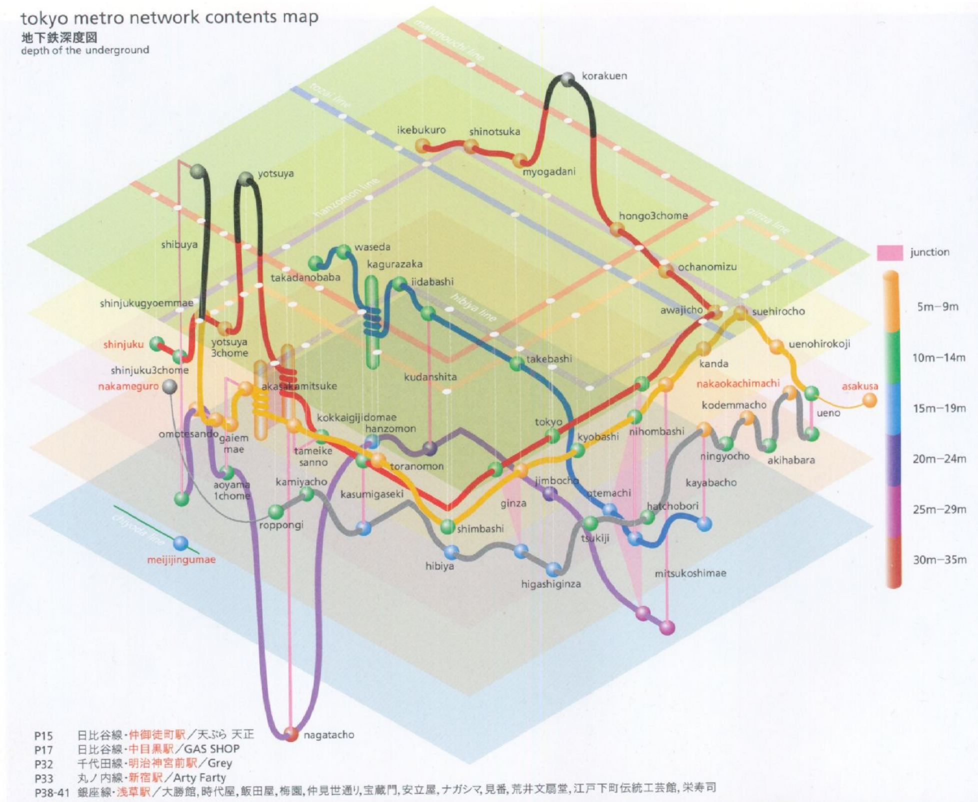
The oblique imagery technique and Mobile Laser Scanning (MLS) can be used for recording building facades.

5.2.2.7 Underground Transport Routes

Transport routes are important infrastructures in cities. Due to lack of available land in densely populated areas, these routes such as metro and highways are being built underground. Therefore, visualising the extent of underground routes helps to understand their interaction with other RRRs.

Name
Underground transport routes
Description
Underground transport routes are travelling paths in cities and representing their locations and distributions are important as they are considered legal and physical entities.
Possible attributes
-

Visualisation
Representing underground transport routes can be in 2D to show the routes. However, for underground routes, 3D representation visualises the interaction of these routes with other infrastructures and RRRs. For the design of new routes and maintenance of existing ones, the interaction of public transport routes with ownership spaces must be carefully considered. The figure below represents a 3D model of the Tokyo metro.



Source: http://www.spoon-tamago.com/2013/04/07/tokyo-arteria-3d-model-of-tokyo-metro/

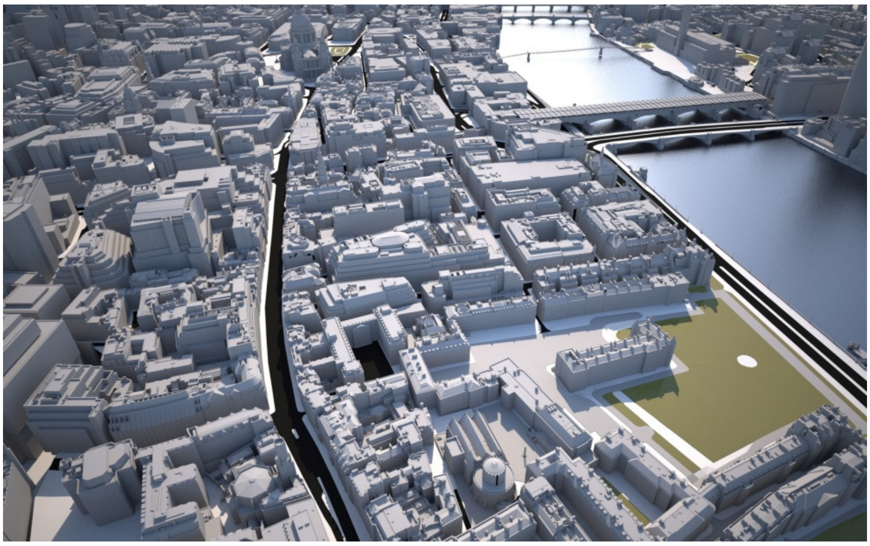
Underground routes might have different geometry as physical and legal entities.

5.2.2.8 City Structures

City structures give context to a city and must be considered from both legal and physical aspects.

Name
City structures
Description
City structures include all city elements (such as roads, railways, bridges, water bodies, and tunnels) other than buildings in urban areas.
Possible attributes
-
Visualisation
City structures are visualised to help users understand the real city components. City structures have ownership

boundaries and must be visualised accurately with their associated physical structures. The following figure represents a 3D city model including water bodies, and bridges.



Source: http://www.vertexmodelling.co.uk/site/portfolio/3d-london-model-lod3/#!prettyPhoto

5.2.3 Administrative Information

A 3D cadastral visualisation application is not only about visualising 3D physical and legal objects. Other types of information, such as attributes, legal documents, and scanned maps exist which need to be displayed for cadastral users (Prooijen *et al.*, 2011), here called administrative information. This may be important for users to complete their tasks.

5.2.3.1 Aerial and Satellite Images

Aerial and satellite images bring more context to 3D models and help to understand the locations.

Name
Aerial and satellite images
Description
Aerial and satellite images are digital media which are acquired by photographic sensors by a distance from the ground surface.
Possible attributes
Many attributes are possible.
Visualisation
Aerial and satellite images are widely used for various applications. For cadastral purposes, aerial imagery provides high resolution images to show city details. Aerial and satellite images from different years may show changes in ownership boundaries.

Aerial and satellite images can be integrated with DTM to simulate the ground surface.

5.2.3.2 Attributes

Attributes are important for cadastral purposes as they describe physical and legal objects.

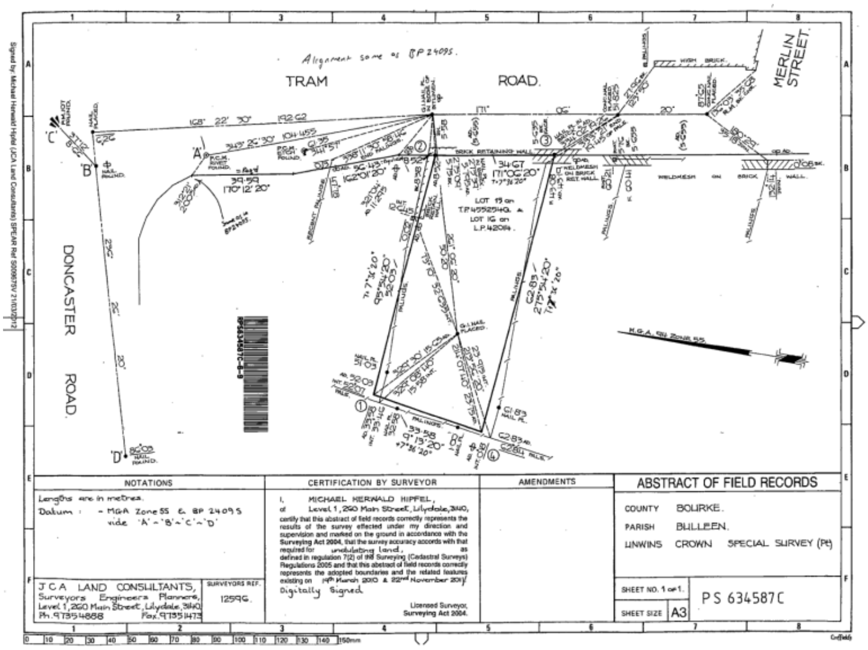
Name
Attributes
Description
Attributes provide more contextual information and are used to capture various pieces of textual information. These are important for cadastral users (e.g. surveyors, land registry) where additional textual information about the plan may be required for specific situations.
Visualisation
Attributes may include the following items: • Local government name; • Purpose of plan; • Owners corporation schedule; • Expiry of permit; • Authority notes; • Title information; • Owners consent; • Covenant document; • Engineering plan; • Photos; • Surveyors report; • Building information; • Planning permit number; • Certified plan; • Certified plan staged; • Statement of compliance; and • Council property number. These attributes are required by some users and must be accessible on the visualisation application.

Visualising attributes is not as difficult as visualising geometries and they can be presented in the visualisation application.

5.2.3.3 Surveying Report

Surveying reports are produced by land surveyors and give information about surveying operations.

Name
Surveying report
Description
A surveying report includes information about the surveying process such as "Abstract of Field Records" which contains surveying observations (e.g. distance, bearing, traversing, radiation to the corners of parcel, and survey marks).
Visualisation
The surveying report is important for controlling the accuracy of the surveying process and must be presented in visualisation applications. The figure below represents a sample of "Abstract of Field Records" which shows surveying information such as bearing and distances. A surveying report should be presented in PDF format.



Surveying reports can be used to re-establish parcel corners based on surveying observations.

5.2.3.4 Street Addressing

Street addressing helps to find properties and describes a unique address of properties.

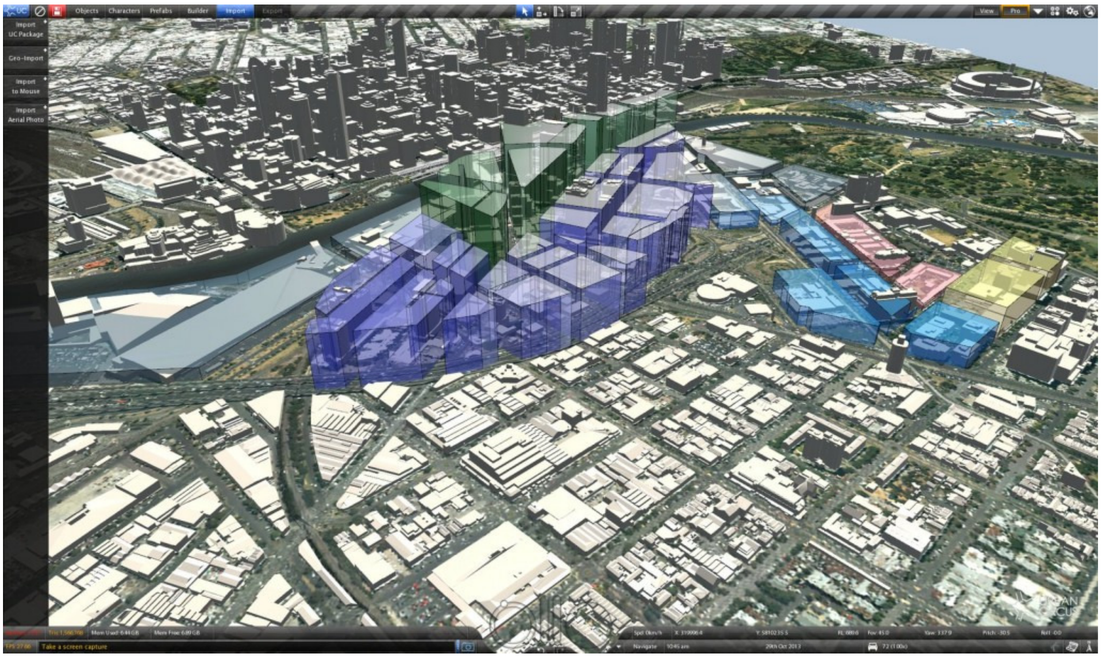
Name
Street addressing
Description
Australia has implemented the Geocoded National Address File (GNAF) for locating each property. GNAF is a unique address of each property, described by unit number, house number, road name, suburb, and post code.
Visualisation
The GNAF address of each property must be accessible in visualisation applications.

Street addressing differs in different countries, however, each property's address must be unique.

5.2.4 Recommendations

In addition to the above requirements, the following items are recommended for developing 3D cadastral visualisation applications as they are important for some specific users.

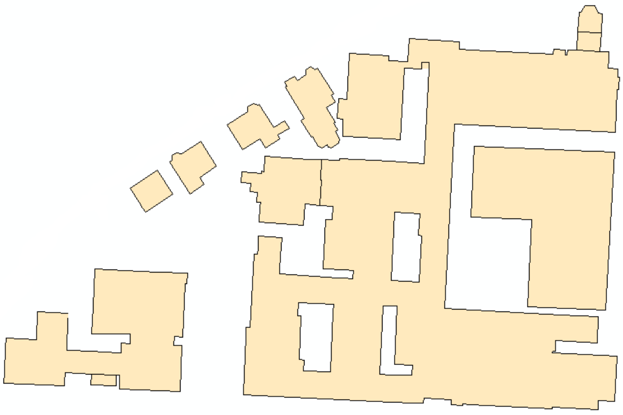
- **Planning Schemes**

Name
Planning schemes
Description
Planning schemes control land use and development within a city. They include all state and local planning policies, zones and overlays and other regulations or the use, development and protection of land[75].
Possible attributes
Many attributes are possible.
Visualisation
In representing planning schemes in 3D, like 2D, each scheme is presented to show the area of effect (under control). The following figure represents a sample of strategic development overlays in 3D in Melbourne which clearly defines the future development in this city.  Source: http://www.urbancircus.com.au/projects/melbourne-urban-planning/

[75]http://www.melbourne.vic.gov.au/buildingandplanning/planning/melbourneplanningscheme/Pages/MelbournePlanningScheme.aspx

- **Building Footprints**

Building footprints can have applications in disaster management, urban planning, 3D city modelling, site selections and land development.[76]

Name
Building footprints
Description
2D polygons showing the building outlines
Possible attributes
Land parcel ID, area
Visualisation
The following figure represents a (2D) layer of building footprints. 

Building footprints can be integrated with aerial and satellite images, street address information, and DTM to bring more context to a 3D city model.

The next section looks at user interface and system requirements and describes them in detail.

5.3 User Interface and System Requirements

These requirements define features in the graphic user interface of a visualisation application to support users. They also specify some requirements for the system, such as supporting databases and web services that help users to work with the application and complete their involved tasks.

[76] https://www.landgate.wa.gov.au/corporate.nsf/web/Building+Footprint

5.3.1 Navigation Tools

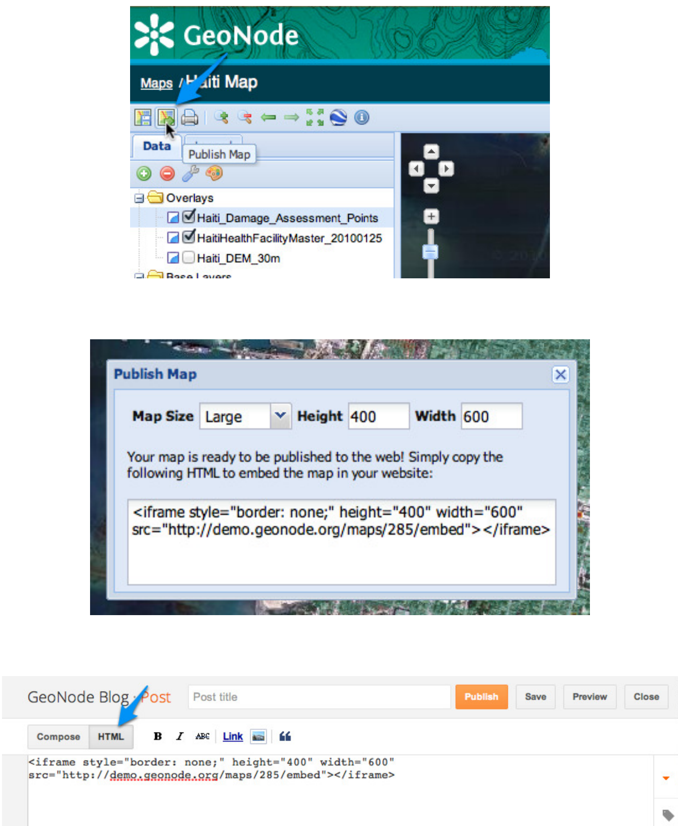
These are important features for interactive visualisation applications which allow users to view objects from different angles, heights, and distances.

Name
Navigation tools
Description
Navigation tools are used to navigate through the scene in 3D.
Features/Components
Navigation tools include the following components: • Pan; • Compass; • Tilt; • Revolve around a location; • Revolve from a location; • Zoom in/out: scrolling forward or backward to zoom in or zoom out; • Zoom to location; • Zoom to previous view; • Zoom to next view; • Zoom to max extent: Zooms out to a maximal zoom level needed for all features of a map to fit in to view; • Navigation history backward: This is used to go back to previous navigation history; and • Navigation history forward: This is used to go forward from past to more recent navigation history. Users must be able to control the views including zoom in/out, pan, and 3D fly-through. Users need to interactively see 3D models in various views. Various views are produced by moving a camera (or target objects) in a scene. By changing the camera location, users can zoom in/out, pan, and fly through. The following properties of cameras are important for controlling the view: • Pan speed sets the speed of movement of camera in the scene at the time of panning. This parameter must be interactive and change quickly according to the camera's distance from objects. The speed of panning must be different in various zoom levels. When the camera is close to the objects, the panning speed must be very low to avoid a lot of movement, and the inverse. This helps users to easily control the view whether they are close or far from the objects; • Normal field of view is 39.39 degrees which is based on the human eye; • Minimum and maximum height specifies the camera movement along the height dimension. It allows having an underground view by locating the camera below the ground surface; • The camera must not be upside down as it causes confusion for users. In this case, camera rotations are limited in some directions; and • Users must also be able to save specific views as bookmarks from the scene and then return to them.

Each navigation tool may have some rules that limit how the camera and target objects can move. For example, Zoom In/Out tool locks the target object in place and it only allows the user to move along the 3D line between its current location and the target location.[77]

5.3.2 3D Model Publishing

Users may need to publish 3D models and share it with other users.

Name
3D model publishing
Description
A publishing tool is used to generate prepared models for sharing and exchanging with other parties.
Features/Components
For example, online 3D models can be embedded in other web pages by publishing the prepared models. This feature also enables real-time collaboration with other users over the internet. The following figure represents a 2D map publishing process. 

[77] http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/3D_navigation_tools/00q8000000wp000000/

Source: http://docs.geonode.org/en/latest/users/share.html

3D model publishing is not limited to web-based applications; desktop applications also publish the prepared models to be used in other applications such as 3D PDF files. Similar to 2D map publishing, 3D map publishing requires some parameters which are provided by users.

5.3.3 Representing PDF Files

PDF files are a common data format for storing various documents.

Name
Representing PDF files
Description
3D visualisation applications must be able to display PDF files such as subdivision plans, architectural and engineering plans.
Features/Components
Representing PDF files in visualisation applications provides various sources of information to users. In addition to the usual PDF files, a 3D PDF format is becoming widespread and a number of 3D applications are able to generate 3D PDF files. 3D PDF files are suitable for visualising 3D models and can be viewed in free applications such as Adobe Acrobat Reader.

3D PDF files are created by many 3D applications such as SketchUp, CAD packages, and SolidWorks.

5.3.4 Import/Export 3D Models

Users may need to share 3D models with various users.

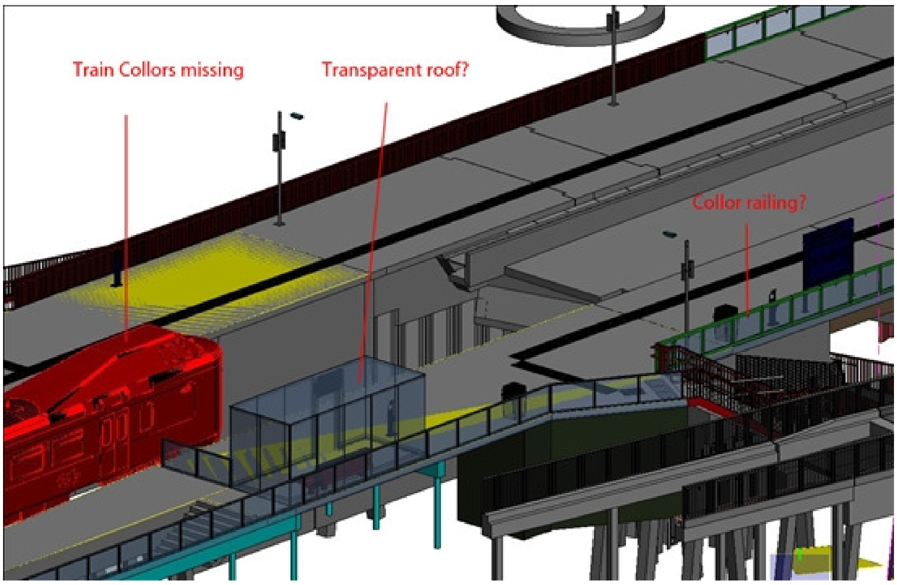
Name
Import/export 3D models
Description
The visualisation application must be able to import and export 3D models in popular formats for exchanging among various applications.
Features/Components
Users must be able to use 3D models in other applications. Also users must be able to import 3D models from other applications and databases. Some of the popular 3D formats among users are 3D PDF, CAD, KML/KMZ, Collada, CityGML, and IFC (BIM). The application must be able to export various views of 3D models in image formats (e.g. JPG, PNG) or 3D PDF to be viewed without the visualisation application (City of Melbourne, 2012).

During the import export process, some data elements may not be able to map to the new formats. Therefore, this process requires further checking for missing information.

5.3.5 Mark-up Tools

Reviewing 3D models in collaboration environments requires mark-up tools.

Name
Mark-up tools
Description
A set of tools for adding mark-ups to the images from 3D models.
Features/Components
Users need to review the 3D models and add comments, highlight objects, and draw e.g. lines or circles on a scene. The following figure represents an example of marking on a scene.



Source: http://communities.bentley.com/

Users must be able to save, print and distribute the mark-up with other users for future discussions or references.

5.3.6 Cartography Tools

Computer assisted cartography is at an advanced level which creates sophisticated maps using cartography tools.

Name
Cartography tools
Description
Some users may need to create maps for their needs.
Features/Components
Several tools are required to support design and production of 2D and 3D maps. These include annotation, north sign, legend, grid, design templates, and scale.

Cartography tools can be used for producing various plans (e.g. subdivision plans) by defining templates.

5.3.7 Support Databases

Databases are widely used for storage and managing various types of data. In current cadastral systems, 2D land parcels are stored in databases, called Digital Cadastral DataBases (DCDBs).

Name
Support databases
Description
Visualisation applications must be able to support databases.
Features/Components
Visualisation applications must be able to connect to various databases to retrieve cadastral data and also submit changes to databases for maintaining the data.

3D cadastral data must be stored in DCDBs and visualisation applications must be able to connect to them.

5.3.8 Support Data Services

Spatial data services are useful for sharing cadastral data on the web.

Name
Support data services
Description
Visualisation application must be able to support data services.
Features/Components
Cadastral data might be accessible through data services (e.g. WFS, WMS, W3DS[78]) and the visualisation application must be able to support these services.

Web 3D Service is a portrayal service for 3D spatial data which enable users to interactively explore the scene in 3D (OGC, 2005).

5.3.9 Print

Print is a common tool in many applications.

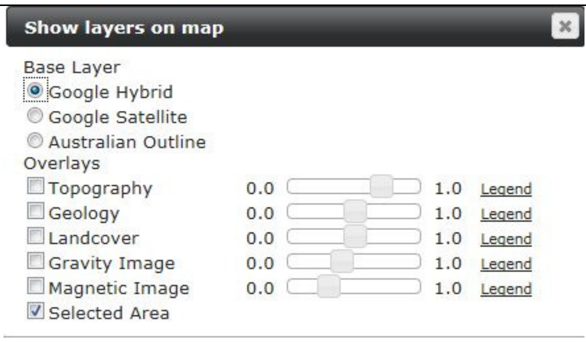
Name
Print
Description
Visualisation application must provide print facility for users.
Features/Components
Users must be able to print information displayed on the screen. Choosing paper size, format, description, legend, scale, and printing to PDF formats (2D and 3D) are important features.

5.3.10 Layer Control

Cadastral layers contain 2D cadastral information which can be used in 3D visualisation applications.

Name
Layer control
Description
Users must be able to control layers (2D) in visualisation applications.
Features/Components
Users must be able to add and remove layers, change colour, and control the visibility of layers in order to customise the view to distinguish all required visual elements.

[78] Web 3D Service



Source: http://www.ga.gov.au/search/help/help.html

The source of cadastral layers might be from flat files, web services, or databases. Therefore, the visualisation application must be able to support various data sources.

5.3.11 Object Control

Cadastral objects contain 3D cadastral information which can be used in 3D visualisation applications.

Name
Object control
Description
Visualisation applications must be able to control objects.
Features/Components
Object control refers to controlling the visibility of 3D objects. Users must be able to add and remove objects, change colour, and control the visibility of them in order to customise the view to distinguish all required visual elements. 

5.3.12 Identify Tool

Identify is a common tool in GIS applications which represents the attribute data attached to an object.

Name

Identify tool

Description

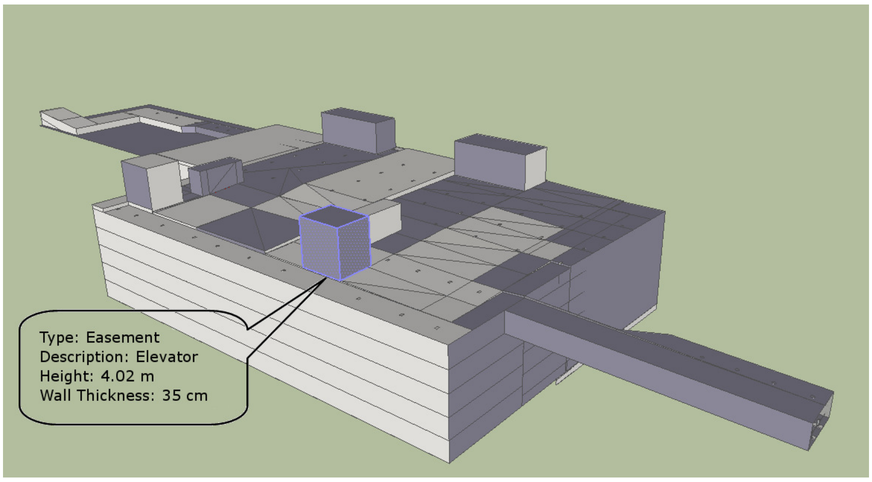
The identify tool is important for cadastral applications to retrieve information from both physical and legal objects and visualise it on the screen.

Features/Components

Users must be able to select any object on the screen and view the attribute information of each object (see figure below). The detailed information about objects can be displayed as a pop-up window on the screen. Users must be able to choose the type of information for each object. For some specific users, they should be able to update the attributes of 3D objects.

For example, the following attributes can be displayed by selecting one building:

- Building type (residential, retail, office);
- Related permits;
- Number of units and floors;
- Sustainability ratings; and
- Value.



Source: (Shojaei *et al.*, 2013)

The identify tool should include the ability to choose which aggregation level (which part of an object) should be selected. For example, when clicking on a wall of a building, the attributes of the wall may be required or the attributes of the building.

5.3.13 Manipulation Tools

Manipulation tools are a set of tools for creating and editing objects or layers.

Name
Manipulation tools
Description
Cadastral users may need to edit 3D physical or legal objects (layers) in the scene.
Features/Components
By activating the manipulation mode, users must be able to select an object and start editing the geometry using the available tools. Users also must able to delete the geometry of objects or update the attributes of objects. These tools include: • Move, rotate, and resize objects; • Trim and extend objects; • Copy objects; • Modify geometry of objects including dissolve, clip, append; • Resize objects, add or change texture, and extrude 2D objects to 3D objects; • Delete objects; and • Undo, redo, and cancel an action. Object snapping is required to have accurate manipulation (Frédéricque *et al.*, 2011). For example, in modifying objects, snapping helps to avoid topological errors (overshoot, undershoot, and sliver).

Manipulations tools must be available for those users who need to create or edit data. For example, land surveyors need to create and edit legal objects.

5.3.14 Support Various Coordinate systems and Datums

Name
Support various coordinate systems and datums
Description
Visualisation applications must support common coordinate systems and datums for importing layers and 3D models.
Features/Components
3D models and layers might be produced in various coordinate systems and datums. Therefore, visualisation applications must be able to support current coordinate systems and datums. For example, users must be able to visualise data from the Australian Height Datum (AHD) and Geocentric Datum of Australia (GDA).

5.3.15 User Profiling

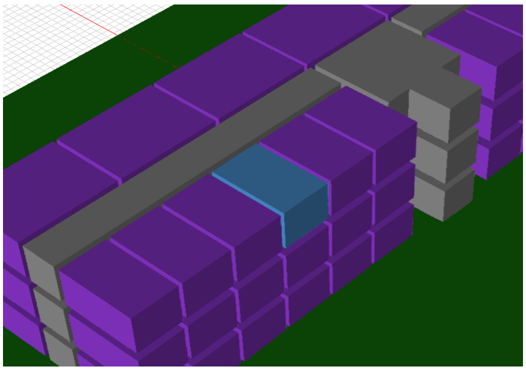
Name
User profiling
Description
User profiling helps users to customise the required layers, objects and preferred views and tools according to the type of users.

Features/Components
Users must be able to log in to the visualisation application and configure their views to specific layers and objects. In this way, users can configure their views according to their tasks and save their views for future work with the visualisation application. Users also must be able to edit their profiles to add or remove layers and objects to have their required information for their tasks. For example, users may need to see specific layers and objects in the application. In addition, users also must be able to add or remove required tools and save the preferred configuration.

User profiling can help semantic visualisation as the type of users, available resources, and their needs can be specified in each user profile.

5.3.16 Select Objects

The select object tool is a common feature in visualisation applications.

Name
Select objects
Description
Users must be able to select objects by mouse click (or touch in mobile devices).
Features/Components
The objects are highlighted when they are selected by mouse click (see figure below) for some specific functions or analyses such as manipulation of 3D objects in the scene. 

Object selection in 3D is more difficult compared with 2D. Ray tracing is an approach for finding positions in 3D. This technique was used in the second prototype, discussed in chapter 6.

5.3.17 Keyboard Shortcuts

Keyboard shortcuts are a series of keys which invoke an operation in the visualisation application when they are triggered.

Name
Keyboard shortcuts
Description
Users must be able to use various keyboard shortcuts for some functions in the application.
Features/Components
Shortcuts facilitate working with the application and they save time particularly for routine activities. Shortcuts must be defined in the application by specifying keys.

For example, F1 can bring up help pages for the visualisation application.

In this section, various user-interface and system requirements were presented which are important for cadastral purposes. The next section, describes technical requirements.

5.4 Technical Requirements (non-functional requirements)

A non-functional requirement is *"…a requirement that specifies system properties, such as environmental and implementation constraints, performance, platform dependencies, maintainability, extensibility, and reliability"* (Jacobson *et al*., 1999, Page 120).

Technical requirements (also known as non-functional requirements) are not directly related to the functionality of an application, and may not be clear to users, but these requirements define the overall quality of an application (Kotonya and Sommerville, 1998). They explain the characteristics of an application and define how it must operate. Accordingly, ignoring these requirements may cause inefficiency in the developed application. Required performance characteristics depend on users' applications and expectations and therefore cannot be defined precisely. This section describes non-functional requirements in detail.

5.4.1 Performance

Performance is a scale for the amount of useful work in a unit of time and is related to the operation speed of an application (Kotonya and Sommerville, 1998). Various types of performance requirements were specified by Cremers and Alda (2011):

- Response requirements: an acceptable response rate to end-users is that 80% of analyses return results in less than 5 seconds; and
- Throughput requirement: an interactive rate of frames per second is required to give a smooth visualisation experience (Funkhouser and Sequin, 1993). In an interactive rate of frame, the rate of frames is changed frequently to provide better performance.

5.4.2 Reliability

Reliability is defined as the ability of an application to deliver services as specified in an acceptable manner (Kotonya and Sommerville, 1998). Reliability can be defined in terms of an availability percentage. As cadastral applications are business critical systems, an application must have an availability of 99%. It means that the application does what users need in 99 out of 100 requests (e.g. run a query). In addition, all functions in the application must be performed reliably.

5.4.3 Security

Security settings are required to control access to the application, viewing, changing data or using functions on the application. These settings must protect the application to ensure unauthorised access to the application and data is not possible:

- Data and the application must be secured from accidental or malicious damage;
- Different levels of access to view, maintain data and perform analysis are required for the application and they are managed by system administrators;
- Data (discussed in section 5.2) must be backed up every day in a secured location; and
- All communication among users and servers must be encrypted.

5.4.4 Usability

Usability is defined as "*Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*" (ISO 9241-11, 1998). It is concerned with designing the user-interface and interaction of users with the application (Kotonya and Sommerville, 1998).

In the application:

- The application must have a detailed user manual and help facilities;
- The error and warning messages must be informative;
- To facilitate communication among the wide variety of cadastral users, the interface of the application must be simple; and
- The likeability of the application is important (Kotonya and Sommerville, 1998).

5.4.5 System Interoperability

Interoperability is "*the ability to exchange data between applications, which smoothes workflows and sometimes facilitates their automation*" (Eastman *et al.*, 2011, Page 99).

Interoperability facilitates the integration of an application in different levels by applying standards (Hildebrandt and Döllner, 2010). In cadastral applications, data comes from various sources (e.g. web services) and many applications are involved in the processes which need to communicate with each other. Therefore, the architecture ensures reliable and efficient systems integration with other business technologies, application data sources, and services (Dimovski *et al.*, 2011).

5.4.6 Platform Independence

Some applications work only on a specific operating system or hardware, which limits the use of these applications by other users in different operating systems and hardware specifications. As a result, it affects popularity and dissemination of the applications. Due to the wide variety of cadastral users, the end-user products must be independent from a specific platform or hardware (Prooijen *et al.*, 2011). This provides users with the flexibility to use cadastral applications without concern about the underlying technology (Shojaei *et al.*, 2013).

5.4.7 Cost

The cost of buying, developing and maintaining a computer system is a critical issue for decision makers. However, for big organisations (e.g. land registry systems) the cost of a product may have a lower impact and high governmental expenditure can be justified (Shojaei *et al.*, 2013). In these organisations, the quality of the service from the product commands has a higher level of attention. The cost-benefit principles for estimating the net social benefits for land information systems are addressed by Poe *et al.* (1992).

5.4.8 Capacity

Capacity requirements must be considered carefully in designing a cadastral application. Important aspects are:

- The application must be able to handle many concurrent users while maintaining performance objectives;
- The application needs to be able to visualise big data. 3D cadastral data including physical and legal objects for a big city can be massive and visualising this data requires appropriate visualisation techniques. As an example, the DCDB in Victoria required more than 13.5 gigabytes of storage for managing cadastral data as of April 2012 (Cadastral-Template, 2013).

5.4.9 Scalability and Flexibility

Scalability is the ability of a system, network or process to be extended to accommodate a growing amount of work (Bondi, 2000). The application must be able to grow and be flexible to accommodate cadastral users' future needs and requirements.

5.4.10 Recommendations

In addition to the above requirements, the following items are recommended for developing 3D cadastral visualisation applications.

- **Support Semantic Meanings**

Attributes and information from data, users and resources can enrich visualisation applications to decide how to represent data effectively according to defined rules. Smart applications are able to think and choose appropriate methods of visualisation for a specific user for specific tasks. For example, if the user profile specifies the type of user and tasks (semantic information), needs and resources (e.g. device, internet bandwidth, and processor speed) might be specified for the application. Ideally, the application can automatically provide a customised visualisation for the specified user according to semantic information acquired from users. In User Profiling (5.3.15) the configuration of the application is defined manually, however, semantic meanings can configure the application automatically based on user attributes. This method of visualisation is called semantic visualisation and various research activities have been conducted for developing and implementing smart visualisation applications (Klima *et al.*, 2004, Posada-Velásquez, 2006, Mitrovic *et al.*, 2005). This concept utilises semantic meanings (knowledge) in three domains: data, users and resources.

The visualisation application should be smart using knowledge to support representing 3D cadastral data for various users, based on their expectations. Semantic meanings can support 3D cadastres as they provide as much automation as possible (van Oosterom, 2013, Soon, 2012).

- **Web-enabled**

Web-based visualisation applications have been widely developed for representing ownership information in two dimensions. These applications can characteristically support a wide variety of users utilising the power of web technology to facilitate accessibility for the users.

For some cadastral users, web-based applications can support their needs to visualise RRR in 3D.

- **Mobile Capability**

Mobile applications are becoming widespread. Developing applications for visualising cadastral data on mobile devices is an important task to provide more services to users, and many potential users expressed interest in having cadastral applications on their mobile devices. Visualising 3D objects on mobile applications needs to consider appropriate techniques and technologies. For instance, augmented reality can be utilised for developing helpful applications for visualising various types of data.

- **Open-Source**

Currently, open-source technologies are used widely in many applications. In 3D cadastre, some prototypes were developed using these technologies (Dimovski *et al*., 2011, Vandysheva *et al*., 2011, Shojaei *et al*., 2014). Open-source technologies encourage the community to participate and contribute to the development of various applications and extend their capability to meet future needs. Although open-source technologies provide the source code which allows flexibility and extendibility of the application (Panchaud, 2012), developing applications using only open-source technology has its drawbacks and designers should consider all available options among open-source and proprietary products.

- **Support for Open Standards**

An open standard is defined as a standard that is publicly available. There are many organisations which develop standards in different domains. Standards play a significant role in reducing interoperability problems in computer systems. Developing applications by considering appropriate standards facilitates future extension of the application. Therefore, the system architecture should support open standards to facilitate future integration (Dimovski *et al*., 2011).

In this section non-functional requirements were presented and their importance for cadastral applications was explained. The next section looks at the visualisation requirements.

5.5 Visualisation Requirements

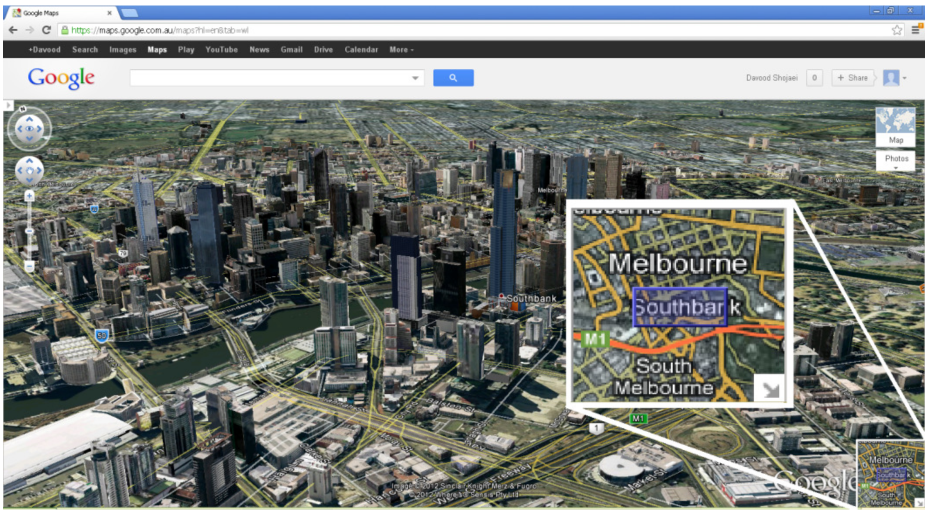
The third category of requirements applies to most 3D visualisation applications. These features enhance visual effects and improve visual perception, and are essential for cadastral visualisation. In this section, visualisation requirements are explained in detail to showcase their importance for cadastral purposes.

5.5.1 Various Views

Various views enable users to see the required information on the visualisation application. There are various view styles such as plan view, model view, and indoor view, which enable users to effectively use the 3D visualisation application to explore 3D models.

5.5.1.1 Plan View

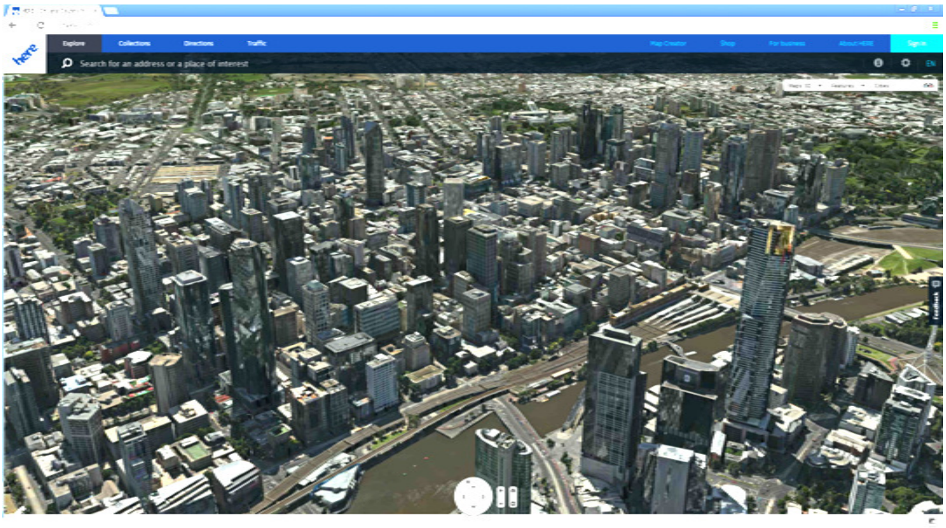
Name
Plan view
Description
Plan view gives a vertical view of the current view in the scene.
Features/Components
The plan view is a small view located at a corner of the user interface. It shows a generalised vertical view of the current view, from which users would be able to control the main view. The following figure represents an enlarged plan view from Google Map.



Source: Google Map

5.5.1.2 City View

Name
City view
Description
City view gives a view of the current camera location from a city on the scene.
Features/Components

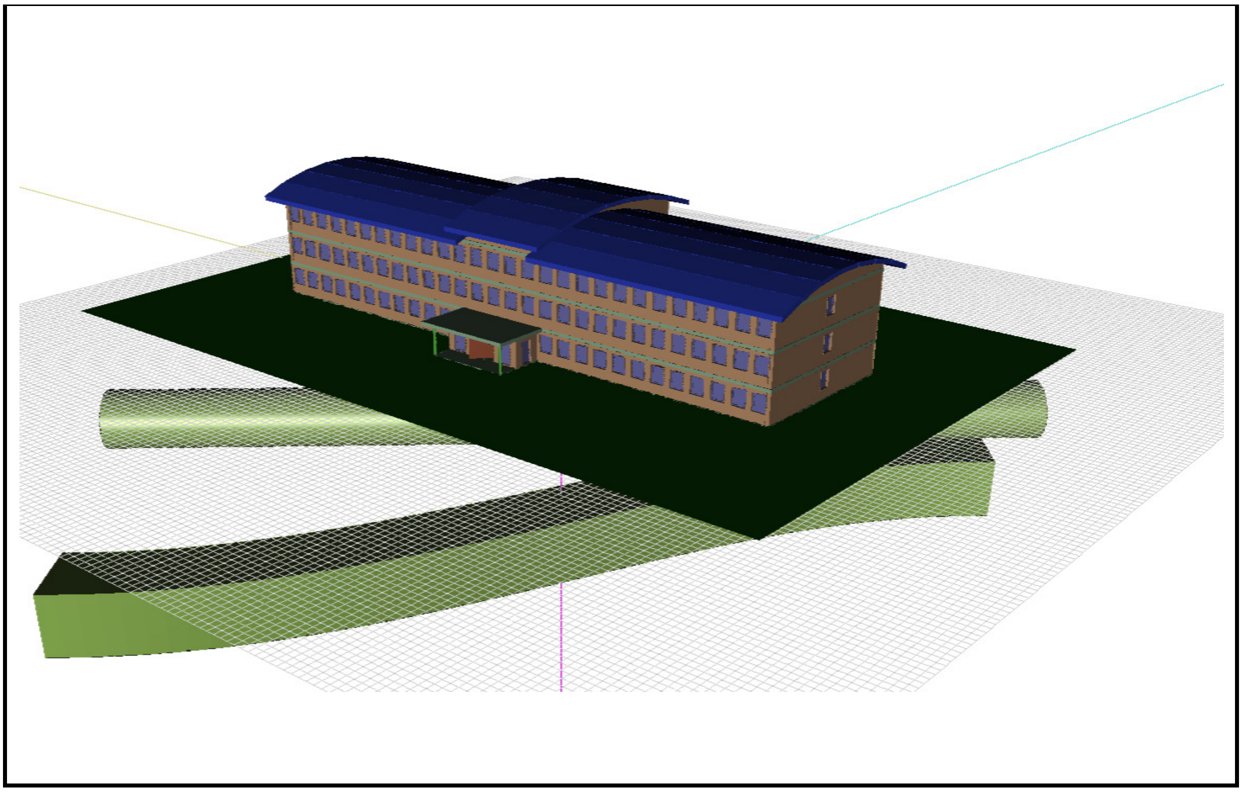
The city view is the main view on the interface of the visualisation application which shows 3D models. Users would be able to control the city view using navigation tools. The following figure represents a city view from Here Map.  Source: (Here, 2014)

The city view is the initial view in the visualisation application. Users are able to navigate through the scene and explore the data.

5.5.1.3 *Model View*

This view provides a closer view to 3D models to allow users explore the data in more details.

Name
Model view
Description
Model view allows users to see the models individually and not with neighbouring developments.
Features/Components
The model view is suitable to see just one model at a time. It helps users to interactively explore one model without the effects of other models. The following figure represents a model view.

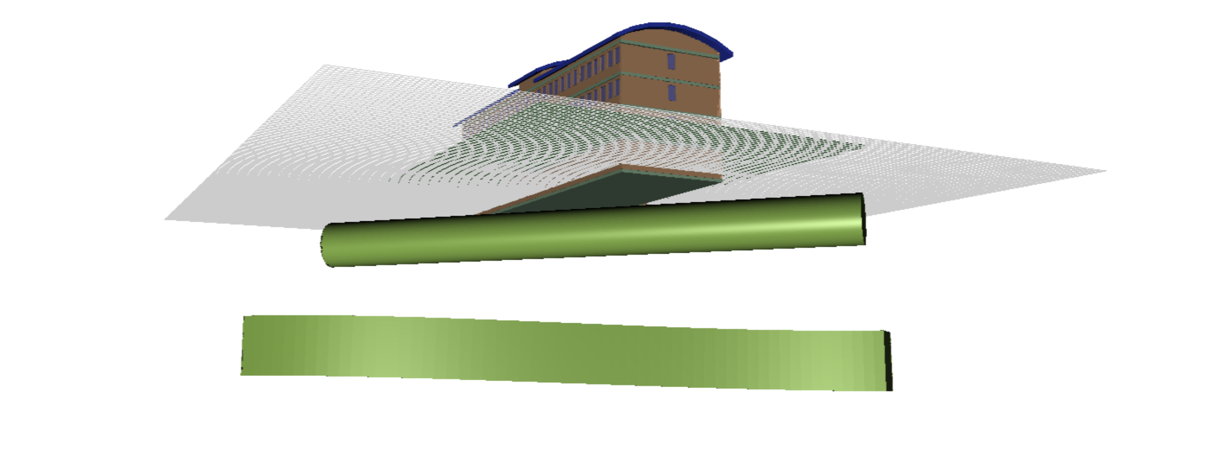


In the model view, all physical and legal data and administrative information are accessible in the visualisation application.

5.5.1.4 Underground View

Many underground developments such as shops, car parks, and tunnels are built under the ground surface, particularly in urban areas. Managing these RRRs requires the possibility of visualising underground legal and physical objects. Therefore, visualisation applications must be able to visualise underground objects.

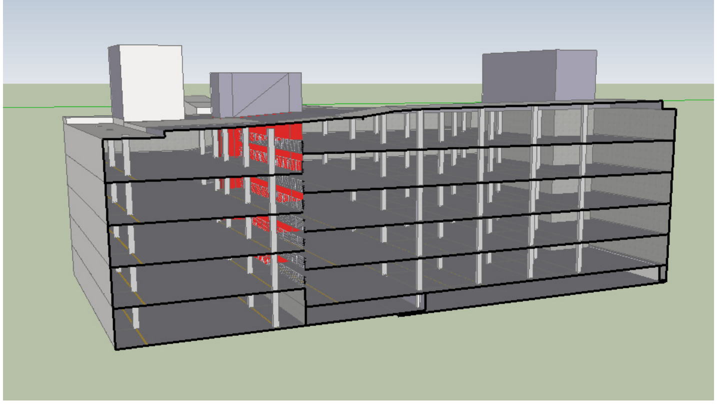
Name
Underground view
Description
The underground view allows users to see objects under the ground surface.
Features/Components
To have an underground view, camera must be able to move under the ground surface. The following figure shows a sample of an underground view from a 3D model.



Some 3D visualisation applications (e.g. Google Earth) have limitations for representing underground structures. Hence, they do not meet cadastral needs to visualise underground RRRs.

5.5.1.5 Cross-section View

The cross-section view is a useful tool in 3D visualisation applications as it shows the internal geometry of objects.

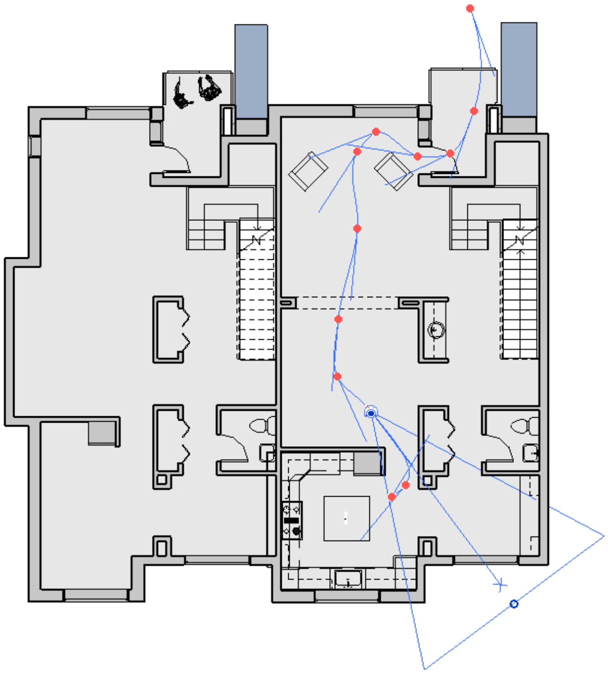
Name
Cross-section view
Description
Cross-sections are views produced by slicing a 3D model at a plane.
Features/Components
The cross-section view facilitates understanding of the interior complexity of buildings. Cross-sections provide more details for users from the interior geometry of models. The cross-section view in a cadastral visualisation application facilitates understanding of ownership information particularly in complex scenarios (Shojaei *et al.*, 2013). The following figure shows a sample of a cross-section view.  Source: (Shojaei *et al.*, 2013)

A cross-section is produced by various techniques, including using camera properties. Camera objects usually have near and far clipping planes. Only the objects located between these two planes are visualised. If an object is too close to the near clipping plane, it is cut by the plane and the camera shows the rest of the object. Therefore, by controlling the location of the near clipping planes, objects are clipped and cross-section views are generated. This technique was used in the second prototype to generate cross-section views.

5.5.1.6 Indoor View

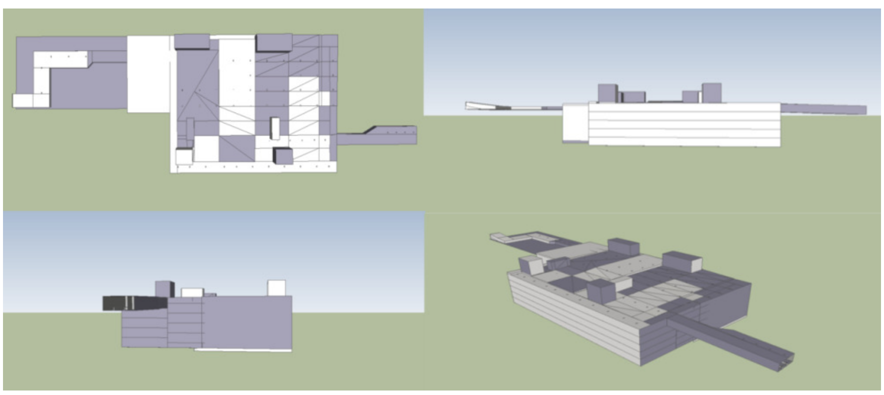
The indoor view is useful for cadastral users to understand the internal geometry of buildings and ownership boundaries.

Name
Indoor view
Description
It gives a view from the inside of a property.
Features/Components
The indoor view moves the camera to the inside of a model so that users can navigate through the 3D model. It shows the interior walls, slabs, windows, doors, and ownership boundaries. The following figure represents a snapshot of an indoor view of an apartment.  Source: http://www.bitmanagement.com/images/solutions/content6.large.png This view is defined by specifying a path for camera movements and rotations. The following figure shows a walkthrough path in a unit.



Source: http://docs.autodesk.com

5.5.1.7 *Multiple Views*

Name
Multiple views
Description
Splitting the model view into several views running side by side to show a scene.
Features/Components
Multiple views give various views simultaneously to facilitate understanding the complexity of a 3D model from different angles and allows for comparing the views. In the following figure, a building is presented from diverse views.  Source: (Shojaei *et al.*, 2013)

In multiple views, views can be produced with different information. For example, in one view, physical data is visualised and in the other, associated legal data is presented. Users should be able to control the content and decide the type of data in each view.

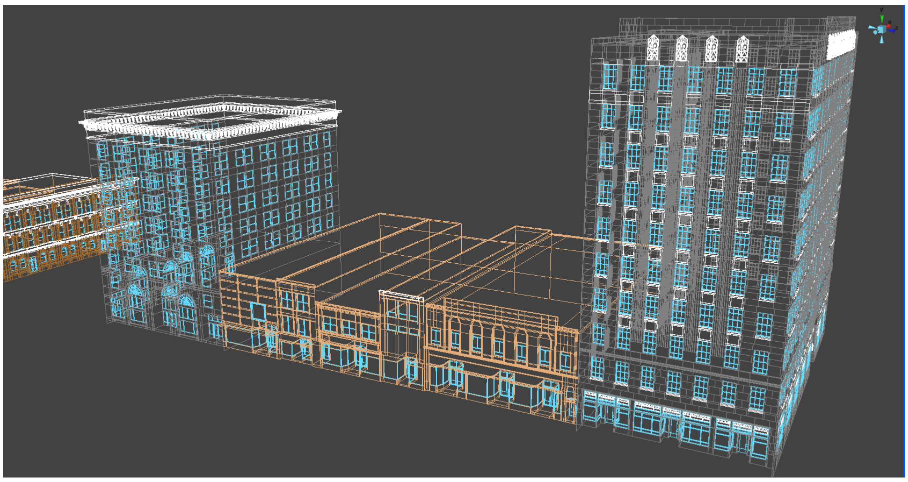
5.5.1.8 View Points

Name
View points
Description
View points locate the camera in a position on the scene.
Features/Components
Some common view points are top view, bottom view, left view, right view, front view, rear view, and isometric view. In these views, the camera is located a specific distance from a 3D model to create different viewpoints. The above figure shows four different views from a 3D model.

Users should be able to control the content and data visualised in each view.

5.5.1.9 Wireframe View

Name
Wireframe view
Description
Wireframe is a visual presentation of a 3D model that shows the edge of the geometry of objects.
Features/Components
Wireframe models help users to understand the interior design of a model. Wireframes are rendered very quickly and they are utilised when a high frame rate is required by avoiding other information such as texture. The following figure shows a sample of wireframe mode.



Source: http://bluefalconstudio.com/projCapSqMad/tenneyBldg/img_wp_sPickney_hres.html

In cadastral applications, wireframe models can be used when 3D models are very big and rendering them with a high frame rate causes long delays.

5.5.1.10 Flight View

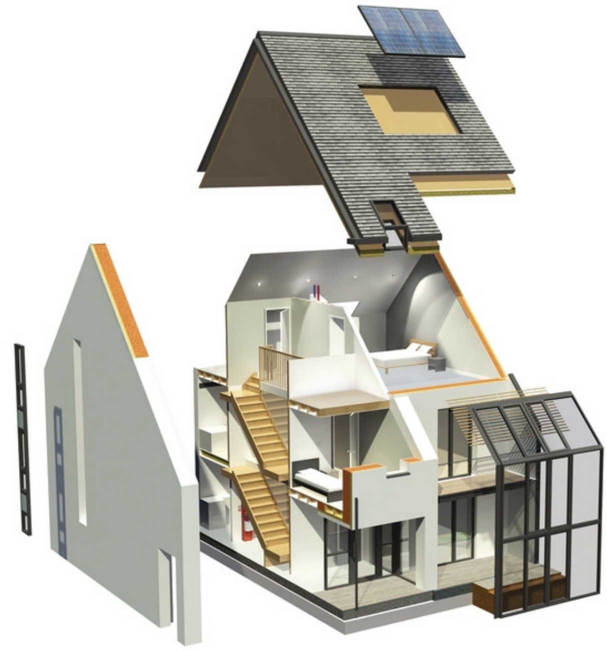
The flight view is useful for general cadastral users as it provides an exterior view from above. This feature can also be used for making videos from 3D models.

Name
Flight view
Description
Flight view is an elevated view of 3D model from above formed by defining a path over the model with a perspective of an airplane.
Features/Components
Users must be able to define a path for camera movement from a point in the scene to another point. Users must able to (City of Melbourne, 2012): • Save the flight path; • Create videos from the path; • Stop, pause, rewind and restart the flight path; and • Set the camera direction and control the view point.

5.5.1.11 Explode View

Explode view is important for cadastre as it can simply show the internal components (including legal and physical data) of a 3D model.

Name
Explode view
Description
Explode view shows the components of an object slightly separated by distance.
Features/Components
To have an exploded view, all objects of an entity (e.g. building) must move slightly to a defined distance from the original location. The following figure shows an exploded view.



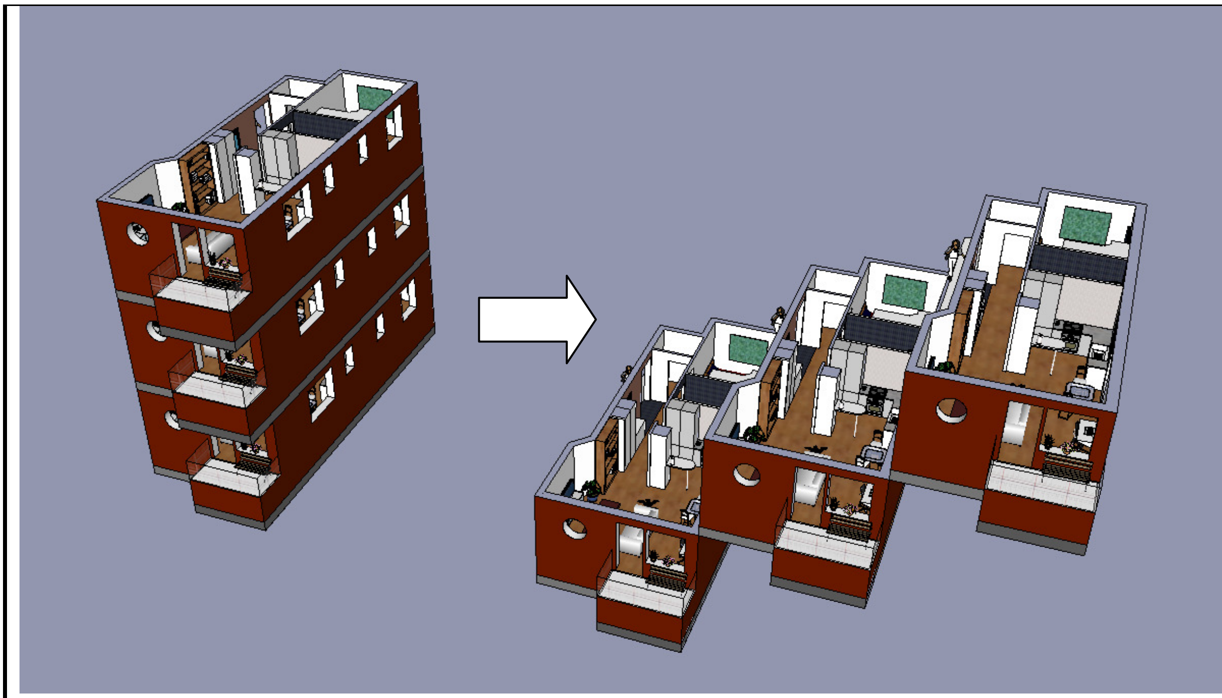
Source: http://www.insidehousing.co.uk/supersized-savings/6509674.article

Users should be able to define the content in the explode view and specify which objects are required in the view.

5.5.1.12 Sliding

Similar to the explode view, the sliding tool is useful to show the internal geometry of a 3D model as well as internal RRRs.

Name
Sliding
Description
The sliding tool shifts floors of a building horizontally on top of each other to reveal the interior geometry of a building.
Features/Components
Users need to see the interior geometry of buildings to understand the location of ownership boundaries. This tool slides floors on top of each other to show the interior geometry and help users to compare floors. The following figure represents a result of a sliding tool.

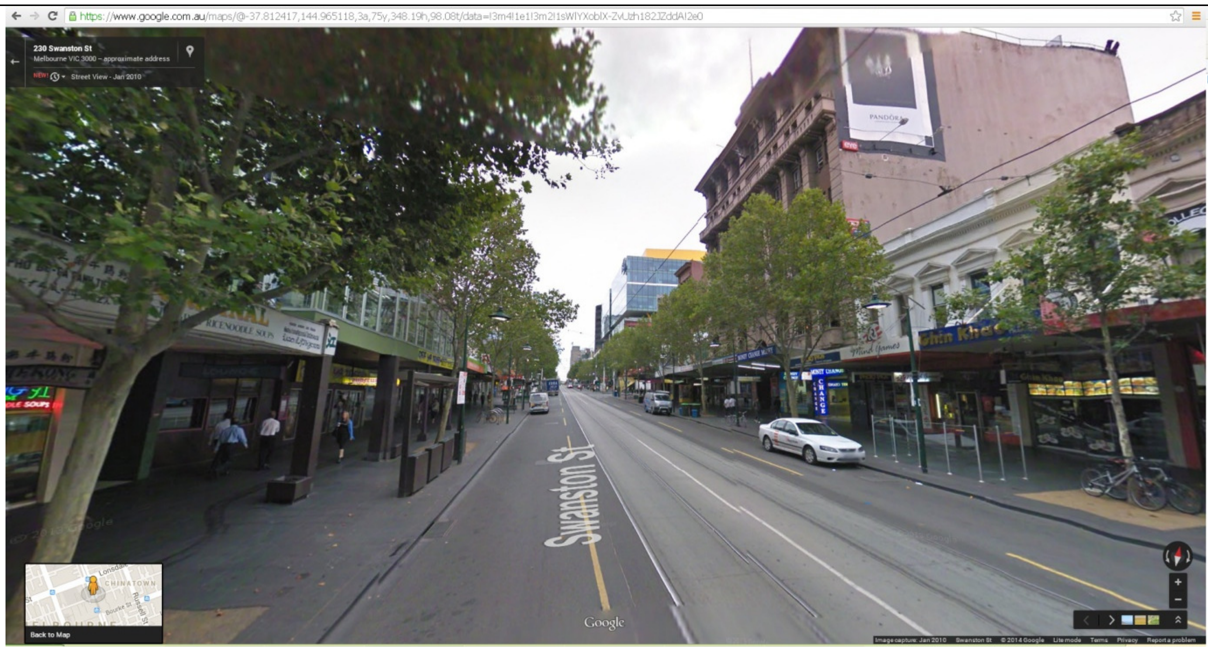


In the sliding tool, all objects in each floor must move horizontally in a specified direction.

5.5.1.13 Street View

The street view provides panoramic views along the streets.

Name
Street view
Description
The street view simulates a real movement along streets.
Features/Components
Street views give a realistic view of streets and surrounding buildings and objects to users to understand the location of a property. In some cases, it may help to reduce on site visits. The following figure shows a sample of a street view from Google.

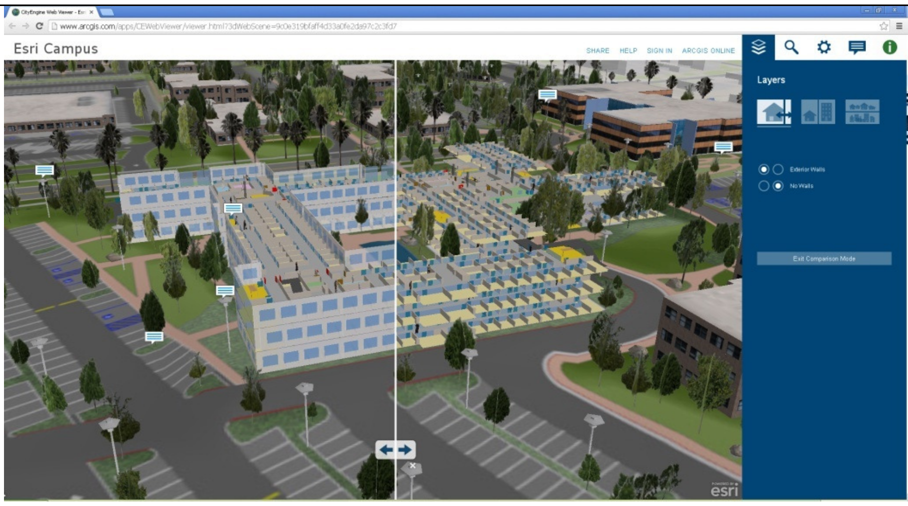


Source: (Google Maps, 2014)

5.5.1.14Swipe

The swipe tool allows users to hold and move over the scene to compare two views.

Name
Swipe
Description
The swipe tool interactively compares two views.
Features/Components
This tool makes it easy to compare a building as-built with the design of a 3D model (this would require development of an accurate as-built model). By moving the swipe tool over the scene, the top layer might be removed from the view. The following figure represents a snapshot of the swipe tool. Users are able to control the view and compare two different 3D models (e.g. as-built and as-designed) by dragging the middle line on the scene.



Source: ESRI

In this tool, legal and physical objects can be viewed separately to see the extent of objects in the scene.

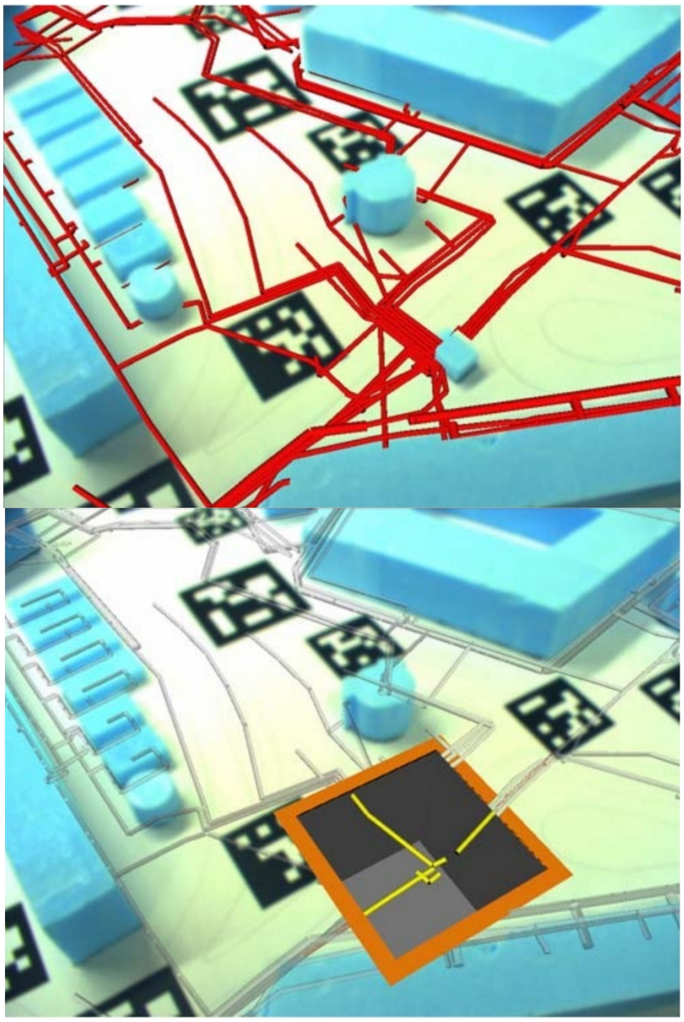
5.5.2 Labels

Name
Labels
Description
A label is a text placeholder and some text which is added to an object in the scene.
Features/Components
Labels represent information about objects in the scene. Labels can be static or dynamic (Been *et al.*, 2006). Static labels are fixed to the scene and do not move by changing the camera. Dynamic labels are appropriate for dynamic maps and by changing the camera location, labels are rotated. Users must be able to control labels in terms of colour, size, and style.

In current cadastres, many attributes such as bearing, distances, and areas are labelled in the plans. However, in a 3D cadastre, information can be retrieved by clicking on the scene using the identify tool. Therefore, there is no need to label all attributes in the scene as it adds complexity.

5.5.3 Magic Lens

Magic lens allows users to move on the 3D scene linked to a computational operator to change the view content.

Name
Magic lens
Description
"*A Magic Lens is a transparent or semi-transparent user interface element which can be placed over objects to change their appearance and/or their interactive behaviour*" (Fox, 1998).
Features/Components
Various types of magic lenses can be specified by defining different operators. For instance, in the following figures, a magic lens can show objects inside the lens with specific semantic attributes. This allows users to see an excavation hole to understand the situation and at the same time retain the context of the surrounding assets (Mendez *et al*., 2008). The first figure shows the scene before using the magic lens and the second shows the effect of the magic lens in the scene.  Source: (Mendez *et al*., 2008)

In cadastral applications, a magic lens would be used to change the view from physical to legal objects inside the lens.

5.5.4 Visual Representation

The following features are important in visual representation for cadastral applications.

5.5.4.1 Level of Detail Control

When an object on the scene is too far from the camera, there is no need to render a 3D model with full details. This is a technique for improving the efficiency of visualisation applications.

Name

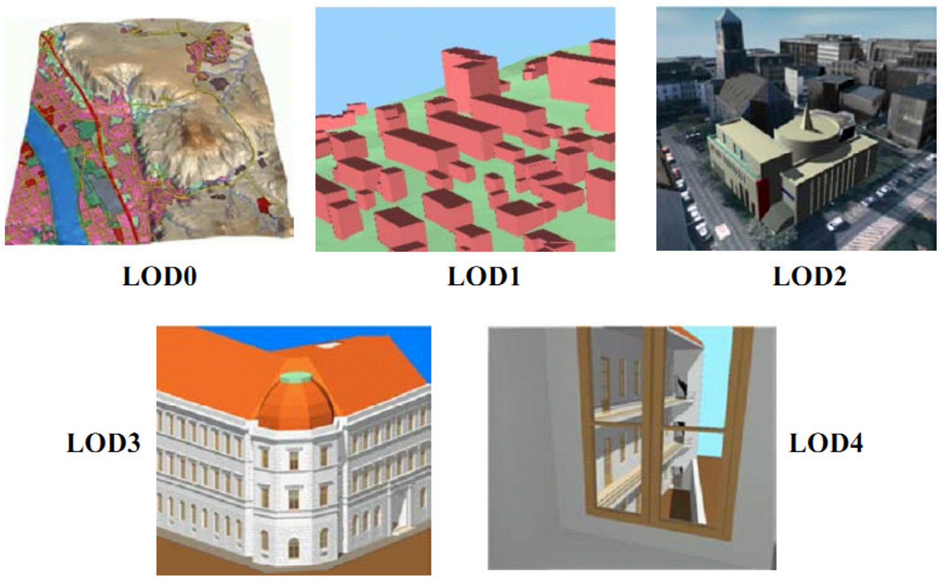
Level of detail control

Description

Level of detail (LoD) techniques decrease the polygon count to render distant objects with less details (Balzer and Deussen, 2007).

Features/Components

LoD is widely used in computer graphics to specify generalised 3D models (e.g. of a building) in various details. In CityGML, five LoDs have been implemented for visualising 3D building models (Kolbe *et al*., 2005). The levels used in a city wide model have a direct impact on time and effort for visualisation (Wergles and Muhar, 2009). Therefore, to reduce unnecessary costs and tasks, an acceptable level of abstraction is needed (Bishop, 1992). The following figure represents five levels of detail in CityGML.



Source: (Gröger *et al*., 2008)

Unlike physical objects, legal objects cannot be generalised in cadastres. For example, at a city level, it would be misleading to generalise and merge legal objects (e.g. lots in a high rise) and visualise them in a single volume. Each legal object needs to be always visualised individually and legal objects must be homogenous which means that 3D legal objects are visualised as small as necessary to represent RRRs (van Oosterom *et al.*, 2011). Therefore, the traditional concept of LoD is not applicable to legal concepts.

5.5.4.2 Symbology

Symbols play an important role in visualisation applications as they give more context to the scene.

Name
Symbology
Description
Symbols are cartographical elements for creating more informative maps (Shojaei *et al.*, 2013).
Features/Components
Symbols are used in maps to give a better interpretation. Symbols can be used for both physical and legal data to give contextual information. Survey control points and trees are examples of symbology. Users must be able to manipulate symbols in the scene, including changing the scale, angle, and type of symbols.

5.5.4.3 Colour, Thickness and Line-style

Colour, thickness and line-style can be applied to data to explain information.

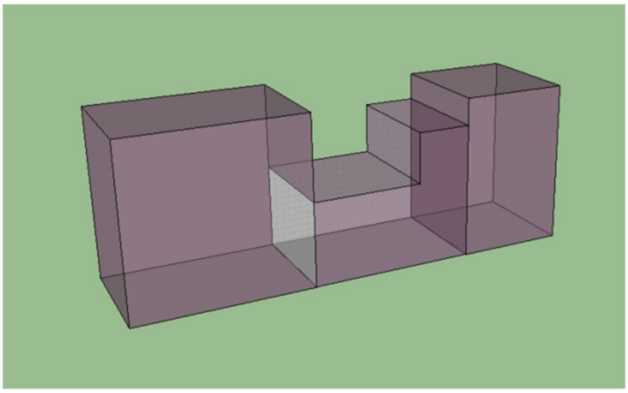
Name
Colour, thickness and line-style
Description
Colour, thickness and line-style are object properties for visually representing 3D objects. By changing these properties information can be translated.
Features/Components
These properties affect the visual representation of volume objects. These properties were discussed for visualisation of 3D legal objects in a 3D cadastral application (Wang *et al.*, 2012). Changing these variables helps to produce different views from the same data (Panchaud, 2012).

5.5.4.4 Transparency

Transparency can be specified for 3D objects to show the interior components of a 3D model.

Name
Transparency
Description
Transparency allows an object to be represented as transparent to various degrees.
Features/Components

This object property is used to change the opacity of 3D objects. Users must be able to control the transparency of objects in the scene. Transparency is very useful for visualising complex legal and physical objects (Vandysheva *et al.*, 2011). The following figure represents the effect of transparency on objects.



Source: (Shojaei *et al.*, 2013)

5.5.5 Recommendations

In addition to the above requirements, the following items are recommended for developing 3D cadastral visualisation applications.

- **Day and Night View**

Day and night view is mainly used in city planning purposes.

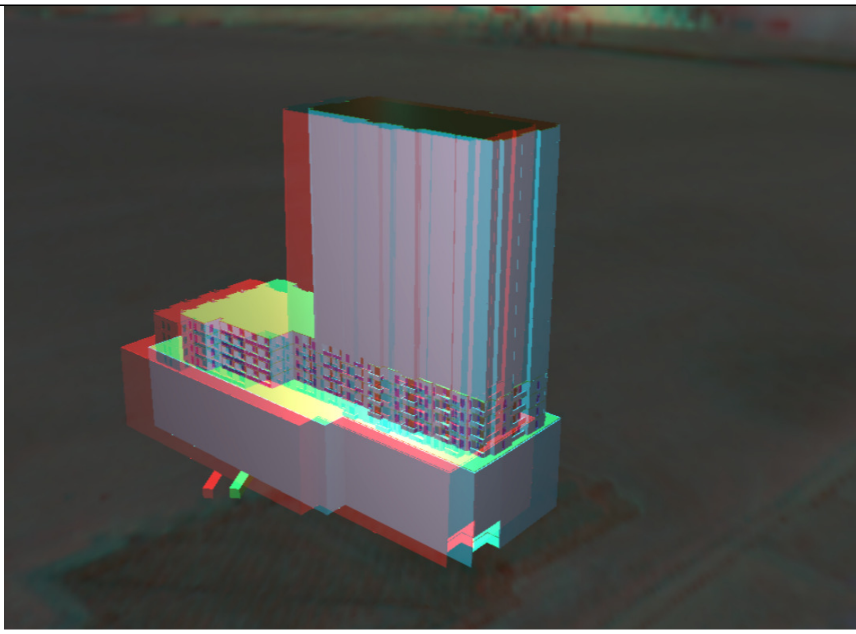
Name
Day and night view
Description
Day and night view simulates day and night on the scene.
Features/Components
Cities have a very different appearance during the day and night and it is very important to have a realistic view of cities at these times. This feature extends the capability of a visualisation application to render models based on the defined light. User should be able to control the light (natural and artificial light sources) for any time of day or night and for any time of the year. These views can include light, shade, and colour effects. It helps when comparing a building model to see the differences at night and during the day. The following figure represents a sample of day and night views.

Source: http://www.mountainsoftravelphotos.com/

- **Stereo View**

There are many techniques for stereo representation such as 3D TVs and 3D glasses. In these techniques, two different images are presented into right and left eye to give 3D perception.

Name
Stereo view
Description
Stereo view provides users with depth perception (3D perception) without the aid of parallax (i.e. while not moving).
Features/Components
Stereo view may help cadastral users to understand the ownership right in a 3D simulated environment. The following figure represents an example of a stereo view of a high rise (red/green lenses are required to see depth).



- **Special Effects**

Special effects are useful for city planners in the land development processes.

Name
Special effects
Description
Special effects are visual enhancements which add effects to the scene.
Features/Components
There are various types of special effects, including the following (City of Melbourne, 2012): • Atmospheric effects; • Sun & moon effects; • Seasonal effects (e.g. street trees with and without leaves); • Fog effects; • Cloud effects (type, thickness, density, altitude, width, and length); • Air pollution effects; • Wind effects (direction, speed); • Rain effects; and • Visibility range effects.

These effects require visualisation techniques to simulate the reality.

This section described the visualisation requirements for 3D cadastral applications. The importance of these requirements is described in chapter 7.

5.6 Analytical Requirements

The application not only provides users with a 3D visualisation of RRRs, but must also provide analytical tools which are important for cadastral users. For example, it should show which legal objects are located on top or under a certain legal object. Although these are not pure visualisation features, the analytical results must be visualised in the applications. This section explains analytical requirements in detail.

5.6.1 Ensure Spatial Validity

Cadastral data must be spatially valid to be used for cadastral applications. For example, unclosed 2D parcels are not valid objects in 2D cadastres.

Name
Ensure spatial validity
Description
Controlling spatial validity of 3D objects.
Features/Components
The application must be able to ensure the spatial validity of 3D legal objects. For example, all volumes should be closed; no overlap should exist among 3D objects; and no unwanted 3D gaps should be present. In cadastres, the main focus of spatial validity is legal objects; however, any issues with the validity of both physical and legal objects may need to be represented.

This feature is not a pure 3D visualisation requirement; however, data validity is important for visualisation applications. For example, 3D gaps may be seen in a volume object which affects the quality of visualisation.

5.6.2 Search Methods

Search tools are useful features in cadastral applications which enable users to find required information.

Name
Search methods
Description
The application must support various search methods for both spatial and non-spatial data.
Features/Components
The application must support both geo-processing and geo-coding functions. Users must be able to search and select objects using spatial functions (e.g. overlay, proximity and intersect). Users also need to search and find objects by address, name, or other attributes. In addition, the application must allow users to find a location based on coordinates.

In cadastral applications, various search methods are possible. For example, in LASSI the following searches are available to find a property:

- Address;
- Coordinates;
- Council Property Number;
- Crown Description;
- Lot on Plan;
- Lot on Street; and
- Melway/VicRoads.

5.6.3 Spatial Measurement Tools

Spatial measurement tools are common among GIS applications, and these tools allow users to interactive with the application and do measurements.

Name
Spatial measurement tools
Description
The application must allow users to do measurements based on their needs.
Features/Components
Users need to accurately measure distances between points and calculate areas defined by three or more points on a selected surface (horizontally, vertically and on an oblique surface). The measurement line would be drawn by moving and clicking the mouse and the result is updated automatically on the screen. The application must allow users to do the following: • Measure distances including cumulative, horizontal, vertical and 3D; • Calculate areas, and volumes; • Measure bearings; • View coordinates; and • Mark a location with a geospatial annotation.

Object snapping is necessary for accurate measurements, as it allows users to accurately point to objects.

5.6.4 3D Analysis Functions

The 3D analysis functions provide a set of geo-processing tools that help users to do a variety of analytical functions. Two main analyses (3D buffer and intersection in 3D) are required for cadastral applications. These are described below.

5.6.4.1 Support of Topology and Required Analyses

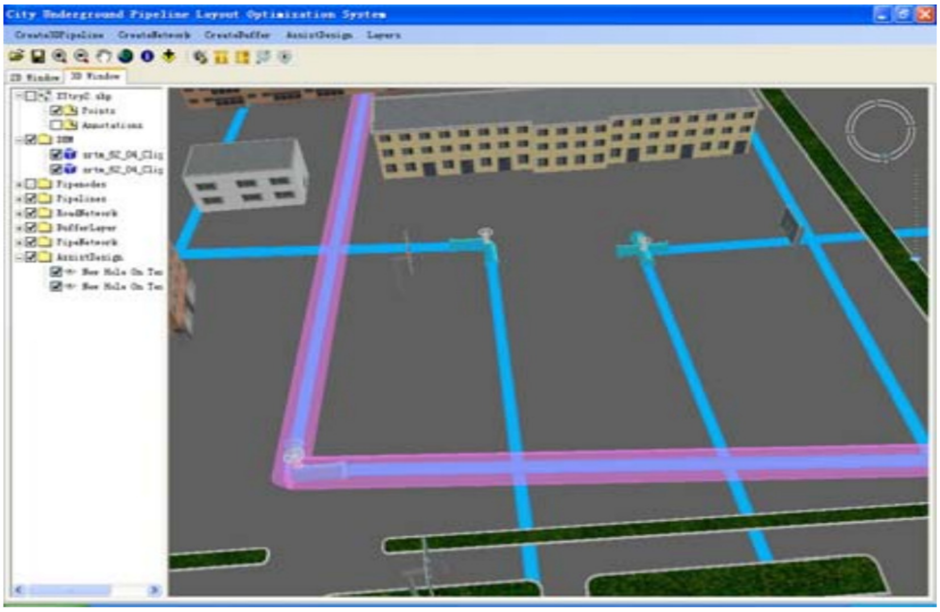
Topology structure in data allows various types of analyses which are important for cadastral applications.

Name
Support of topology and required analyses
Description
In spatial domain, topology is implemented through data structures. In these data structures, geometry is defined based on primitive objects and topological relationships. For example, in 2D data structures, geometry of objects is generated by storing the topology relationships, list of nodes, arcs, and polygons. Polygons are created from arcs and arcs are generated by connecting nodes. By maintaining topology, the geometry of objects is generated from stored topological relationships (Stoter and Salzmann, 2003). Topological primitives are required in many rendering engines to visualise 3D objects (Ellul and Haklay, 2006). Topology structure in data enables various spatial analyses which are useful for 3D cadastre.
Features/Components
The following analyses are possible in 3D using topology (Ellul and Haklay, 2006): • Identify adjacency of the different polyhedral; • Intersection between objects; • Connectivity of objects; • Containment of geometries; • Identify disconnected objects; • Directional adjacency – is object B above, to the side or below object A? What is above object A? and • Describe the topological structure of an object – how many holes, tunnels, faces, etc. does it contain? Stoter and Salzmann (2003) also listed some required queries in 3D cadastre: • Which 3D physical objects are located on top of or under a certain 3D physical object?; • Which parcels intersect with a 3D physical object?; • Which 3D object intersect with a certain parcel?; • Is the owner of the parcel the same as the owner of the 3D physical object?; and • What rights are established on surface parcels intersecting with a 3D physical object?

This feature is not strictly a 3D visualisation requirement, however, visualisation applications can benefit from topology for efficiently rendering 3D objects. For example, in data structures without topology support, data may be redundant, requiring more resources for rendering the data compared with a topological data structure.

5.6.4.2 Three Dimensional Buffer

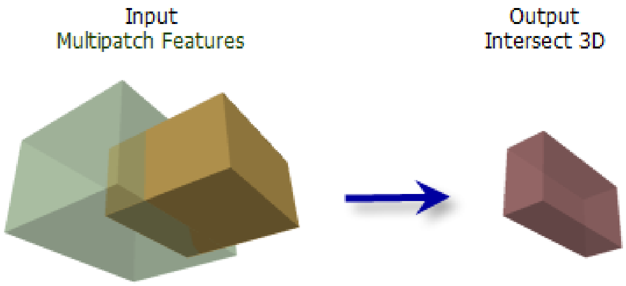
A 3D buffer is a useful feature for processing spatial data. A 3D buffer creates a buffer zone around an object.

Name
3D buffer
Description
Creates a 3D buffer around an object
Features/Components
The application must be able to create a 3D buffer to query neighbouring objects to a 3D object. For example, by using a 3D buffer, a property can be assessed to be constrained by certain regulations (e.g. historical protection) (Pouliot *et al.*, 2010). The following figure represents a sample of a 3D buffer around a pipe, which can be considered as an easement for a parcel. Any intersection with other objects can be detected for further processing using spatial analyses.  Source: (He *et al.*, 2010)

A 3D buffer must be possible for both physical and legal objects to support various analyses.

5.6.4.3 Intersect in 3D

3D intersection is a useful feature in cadastres which enables various queries. As discussed in 5.6.4.1, topology assists users to find intersections between objects.

Name
Intersect in 3D
Description
Produces the geometric intersection between two volume objects.
Features/Components
This Boolean function computes the intersection of two 3D objects – otherwise known as clash detection (Prooijen *et al.*, 2011). For example, the following figure shows the input and the result. By identifying intersections this function helps to detect overlapped spaces among 3D objects.  Source: http://resources.arcgis.com/en/help/main/10.1/index.html#//00q90000007m000000 There are other types of Boolean operations such as difference, inside, and union which in some cases they would be useful for various queries.

Legal objects such as an easement and a lot may intersect; however, some types of intersections are not valid. For example, lots cannot intersect with each other or with common property areas.

5.6.5 Visualisation of Result of Functions and Queries

Visualisation applications must be able to show the results of queries and analyses. Depending on the type of results, an appropriate method must be utilised for representation.

Name
Visualisation of results of functions and queries
Description
The results of functions and analyses can be textual or/and geometrical which need to be presented in the visualisation application.
Features/Components
A 3D cadastral application must support 3D spatial analyses, namely 3D buffering and 3D intersections, to answer queries about RRRs. The result of these queries and analyses must be presented in the application. In case of textual results, a message box or notation on the scene is possible. For geometrical results, visualisation is required. For example, a simple query like apartments of more than 200 m^2 must highlight all the apartments which meet the condition, and must automatically generate a report including the list of these apartments. The other scenarios require an appropriate method for representation.

5.6.6 Augmented Reality

Augmented reality is a technique which uses other sensors, such as cameras and GPS to provide a visualisation integrated with the real world.

Name
Augmented reality
Description
"*Augmented reality allows the user to see the real world, with virtual objects superimposed upon or composited with the real world.*" (Azuma, 1997).
Features/Components
3D visualisation applications should support "Augmented Reality" functionality for mobile devices. This functionality has the capability to visualise graphics, audio and attributes. Augmented reality helps users to understand 3D ownership rights in the real-world using computer graphics and mobile sensors such as camera, GPS, and accelerometer. In addition, both physical and legal entities can be visualised on mobile devices (e.g. iPad) by pointing at a building. This functionality is useful to view and assess proposed plans on site for city planning purposes. The following figure shows how a user is able to use augmented reality in a mobile device to select a unit in a building and receive more information about it.

Source: http://petitinvention.wordpress.com/2009/09/04/red-dot-design-concept-award-2009/

Augmented reality applications are being developed for various applications. For cadastral purposes, augmented reality can help significantly as it provides an augmented visualisation using various sensors and visualisation techniques to represent RRRs.

5.6.7 Temporal Modelling

Temporal modelling is an active topic in many applications. For cadastral purposes, visualisation of cadastral data and associated changes in time is important.

Name
Temporal modelling
Description
Visualising 3D legal objects in different time slots
Features/Components
Time can be added to 3D legal objects and make a 4D legal objects (van Oosterom *et al*., 2011). Users need to see changes in 3D legal objects over time. The application must support visualisation of spatio-temporal cadastral objects (Doner *et al*., 2008). A time slider tool is required in the application to control the visualised data based on the date.

5.6.8 Logical Consistency

Logical consistency is required in a full 3D cadastre as it controls the quality of cadastral data.

Name
Logical consistency
Description
Controlling the quality of data using logical rules.
Features/Components
The logical consistency of a data model is defined by consistency constraints (Stoter, 2004). The visualisation application must be able to test and control logical consistency among objects by defining appropriate constraints, e.g. 3D parcels (lots) are accessible through common property or roads.

5.6.9 Recommendations

In addition to the above requirements, the following items are recommended for developing 3D cadastral visualisation applications.

- **Scenario Modelling**

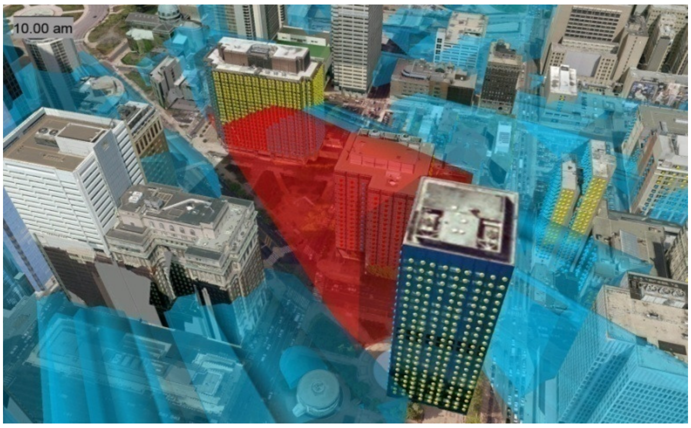
Name
Scenario modelling
Description
Users should be able to test and assess different planning scenarios in the visualisation application.
Features/Components
Utilising visualisation applications in assessment of planning proposals or scenarios can support decision making. Various analytical functions such as noise emission simulations, air pollution simulation, and shadow analysis are important to help decision makers and optimise planning proposals or analyse existing urban structures (Ross, 2010). Such analytical functions add value to a 3D cadastre as well as to the land development process. The visualisation application should have the capability to test various proposed plans and identify their effects on the city environment and infrastructure. Users should be able to add or remove 3D models in the scene to test scenarios (City of Melbourne, 2012). Some examples of scenario modelling from (City of Melbourne, 2012) are: • Analysing the effect of a proposed development on its surroundings; • Predicting pedestrian and traffic movement by changing conditions; • Disaster management and planning; • Big event planning (e.g. city celebrations); • Modelling building rooftops for various uses (e.g. gardens, water capture, solar power, wind power generation); • Tree growing models (e.g. modelling a tree species in different years and during the seasons); • Heat analysis for buildings and environment; • Applying various rules such as height limitations, setbacks, heritage and zoning and identify non-compliant buildings; • Assessing the shadow and wind effects on proposed developments; • Modelling the energy consumption of a city; and • Evacuation modelling in disasters.

- **Shadow and Shadow Analysis**

Shadow and shadow analysis are useful in cadastral applications as they are useful features for urban planning purposes.

Name
Shadow and shadow analysis
Description
Shadow analysis is a tool for modelling shadows by analysing sunlight situations.
Features/Components
Shadow analysis helps users to simulate sunlight situations at a given date and time. This tool helps users to make decisions about proposed buildings and their effects on other buildings. The following figure represents a sample of shadow analysis results. This feature is necessary for city councils when issuing plan permits for

proposed developments that affect the right to light of other properties.



Source: http://blogs.esri.com/esri/arcgis/2011/01/10/updated-shadow-analysis-template/

- **Line of Sight and Visibility Analysis**

This is another analytical feature which helps users to check line of sight and visibility.

Name

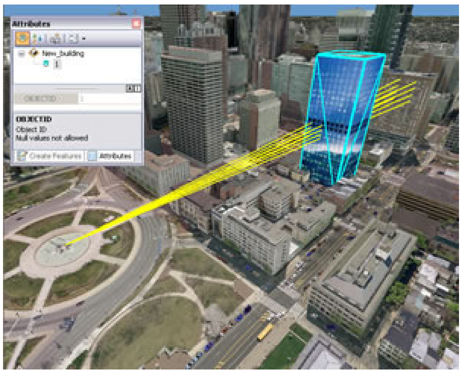
Line of sight and visibility analysis

Description

Line of sight is a line drawn between some point of interest and an observer location.

Features/Components

The application should be able to check the inter-visibility of two points in 3D. The following figure shows a line of sight study for a proposed building.



Source: http://www.esri.com/news/arcwatch/0210/feature.html

This analysis can be used for a variety of applications, such as coverage of radio frequency and installation of a terrestrial positioning system (TPS) to find the moving cars for traffic control (Moser *et al*., 2010). This tool is useful to assess a property outlook and the right of view which is important in 3D cadastres.

- **Vertical Exaggeration**

Name
Vertical exaggeration
Description
Scaling the height dimension of objects in order to highlight an aspect of data.
Features/Components
The visualisation system should be able to use vertical exaggeration tool to emphasize one aspect of data using height information. For example, the height of land parcels can be specified based on the number of owners. By exaggerating this height, land parcels which have more owners can be simply identified.

5.7 Chapter Summary

In this chapter, 3D cadastral visualisation requirements were classified into five groups dealing with data, the system and user-interface, technical performance, visualisation, and analysis. Each group was explained and discussed in detail. These requirements were identified from various methods, described in chapter 3.

These requirements have been investigated mainly in Victoria for 3D cadastral users. Due to the different cadastral laws and regulations in different jurisdictions, some changes are required to localise these requirements for other jurisdictions. 3D cadastral users may be able to use these requirements as an initial list and customise it according to their own laws and regulations. The validation of these requirements is explained in chapter 7.

The next chapter discusses the implementation of 3D cadastral visualisation prototypes to show to potential users to help them understand the concepts and therefore provide well-informed feedback.

CHAPTER 6

DEVELOPMENT OF PROTOTYPES FOR 3D CADASTRAL VISUALISATION

"Try out your ideas by visualising them in action."

– DAVID SEABURY

6 Development of Prototypes for 3D Cadastral Visualisation

6.1 Introduction

This chapter explains the implementation of two 3D cadastral visualisation prototypes to address the fourth research objective, which is "*to validate and showcase the developed 3D cadastral visualisation requirements*". Prototyping is a solution for bridging communication gaps in requirements identification and illustrates something concrete to the stakeholders (Kimmond, 1995). A prototype is not an end-product and it may lack some functionalities.

The first part of this chapter describes the architecture and capabilities of the first prototype. The second part describes the architecture and capabilities of the second prototype.

6.2 A Desktop 3D Cadastral Visualisation Prototype

As described in chapter 3, the first prototype was designed and implemented to help understand problems in representing 3D cadastral data. In fact, understanding the users' needs and associated challenges was the purpose of this prototype.

Before developing the first prototype, four candidate 3D visualisation applications were selected based on availability, cost, user-friendliness and development environment, while still providing a reasonable approximation of the desired requirements (Shojaei *et al*., 2013). These visualisation applications (Google Earth, NASA World Wind, TerraExplorer, and ArcGlobe) are introduced below.

6.2.1.1 Google Earth

Google Earth is a 3D visualisation application, popular among various types of users, for representing the earth. Although Google Earth is not an open-source application, the basic version can be downloaded for free. It is offered in desktop, web and mobile versions. This application can load 3D models in KML/KMZ formats, which allows sophisticated 3D representations. Google Earth provides visualisation of 3D city models in conjunction with high resolution satellite/aerial images, Google street views, temporal visualisation, and flight paths. However, Google Earth is not able to visualise underground objects, such as underground tunnels or structures. Some 3D cadastre prototypes have been developed using Google Earth (e.g. Aditya, *et al.* (2011)). Also, Google Earth API was utilised by Shojaei *et* *al.* (2012) for visualising LandXML/ePlan files. Figure 6.1 illustrates a 3D city model in Google Earth.

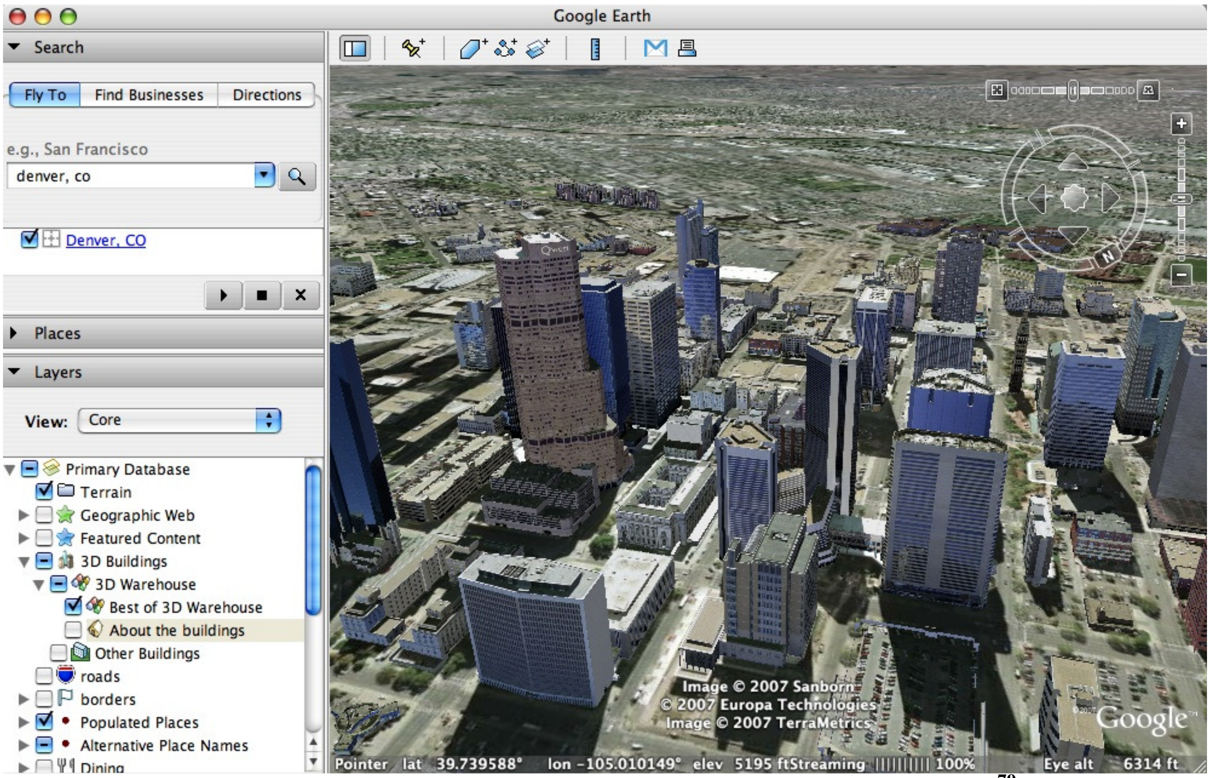


Figure 6.1: A snapshot of 3D city model representation in Google Earth[79]

6.2.1.2 NASA World Wind

NASA World Wind (NWW) is a 3D application for visualising the globe developed by NASA Ames Research Center. Unlike Google Earth, NWW is an open-source application based on Java which works on various platforms. Similar to Google Earth, it supports Digital Elevation Model (DEM), satellite images, and navigation tools (Panchaud, 2012). Dimovski, *et al.* (2011) utilised NWW to develop an operational web-based 3D cadastral visualisation application for the Real Estate Cadastre of the Republic of Macedonia (figure 6.2). Similar to Google Earth, NWW is limited to visualisation of the earth's surface and above-ground buildings.

[79] http://www.gearthblog.com/about

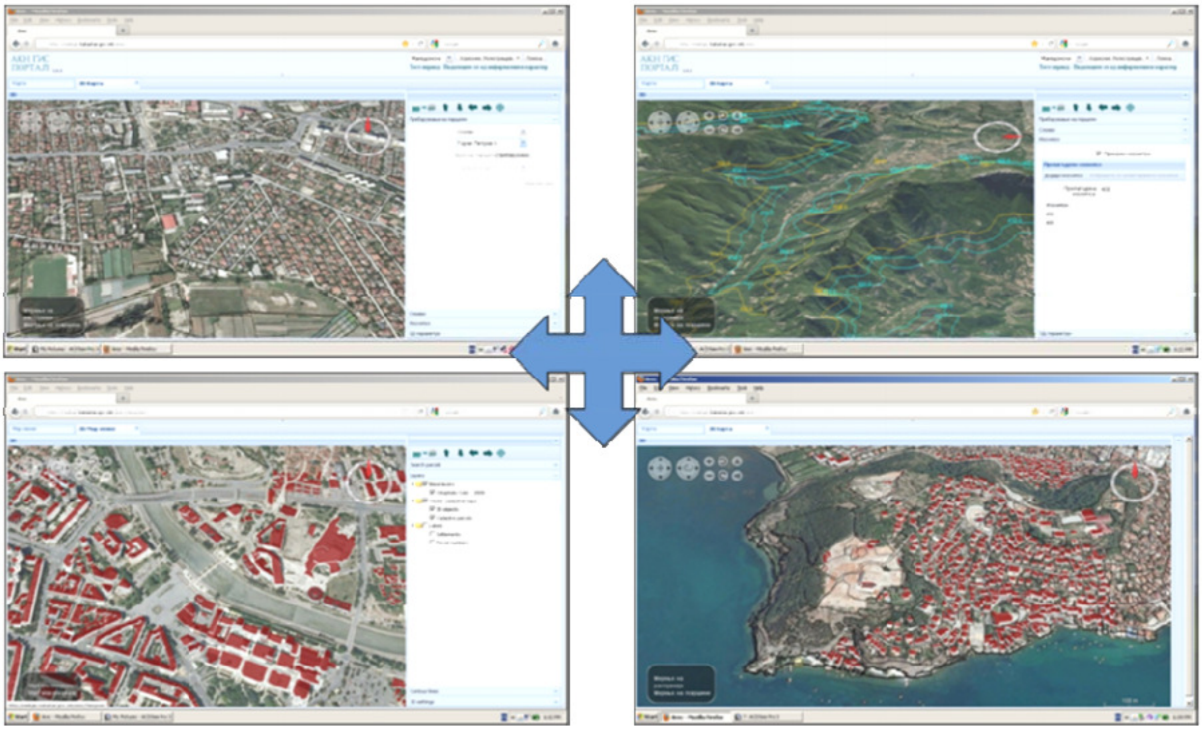


Figure 6.2: An operational web-based 3D cadastral visualisation application for Real Estate Cadastre of the Republic of Macedonia (Dimovski *et al*., 2011).

6.2.1.3 TerraExplorer

TerraExplorer is an application for exploring, editing, analysing and publishing photo-realistic 3D environments. TerraExplorer is a proprietary application and has various products for different purposes. Skyline Globe Viewer, one of the products, provides advanced API capabilities for developing 3D visualisation applications on the web. TerraExplorer Plus and Pro provide users with capabilities to edit objects, add or remove layers, and publish data to be visualised in the Skyline Globe Viewer (Shojaei *et al*., 2014). For cadastral purposes, Ying *et al.* (2012) developed a 3D cadastral visualisation prototype using TerraExplorer for representing 3D buildings and associated rights (figure 6.3). TerraExplorer is capable of visualising underground objects, supporting various data formats and 3D functions.

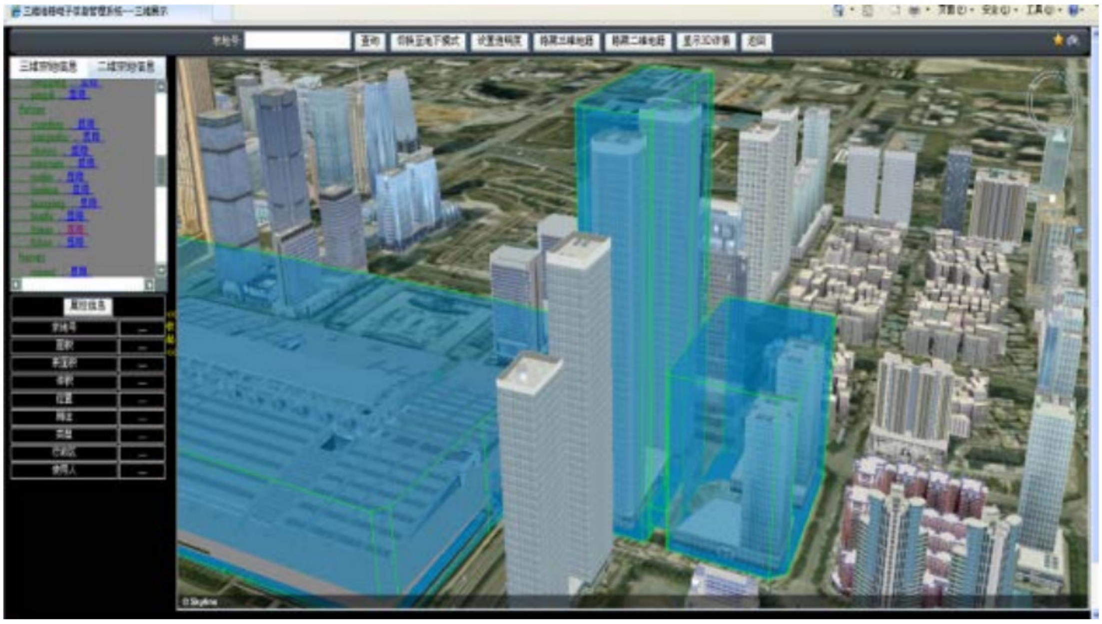


Figure 6.3: A snapshot of a 3D cadastre prototype using TerraExplorer (Ying *et al.*, 2012).

6.2.1.4 ArcGlobe

ArcGlobe is one of the ESRI products in ArcGIS. This virtual globe application was developed to visualise raster and vector data in 2/3D. It supports terrain data, satellite and aerial images, navigation tools, 3D functions and GIS capabilities. It is a proprietary product which provides a development environment for further analysis. ArcGlobe is able to represent underground objects, which is an advantage in this application. Ekberg (2007) utilised ArcGlobe to represent properties in 3D. A snapshot from ArcGlobe is presented in figure 6.4.

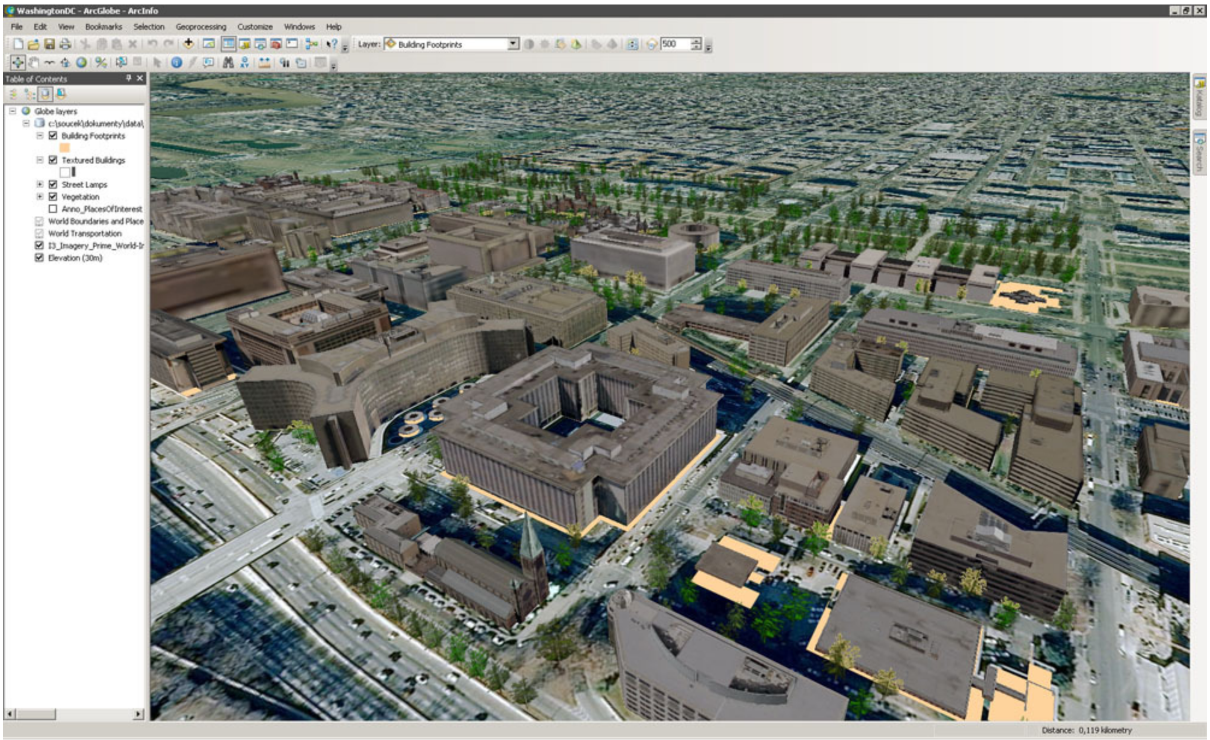


Figure 6.4: A snapshot of ArcGlobe representing a 3D city model.[80]

In order to choose the most suitable visualisation application, these candidates were evaluated against the initial 3D cadastral visualisation requirements which were identified in Shojaei *et al.* (2013). Table 6.1 represents the result of this evaluation.

[80] http://www.arcdata.cz/produkty-a-sluzby/software/arcgis/arcgis-for-desktop/nadstavby-pro-arcgis-for-desktop/arcgis-3d-analyst/

Table 6.1: Evaluation of the visualisation applications (Shojaei *et al*., 2013).

Features	Visualisation Applications			
	Google Earth	**ArcGlobe**	**NASA World Wind**	**TerraExplorer Viewer**
Handling Massive Data	Yes (network links)	Yes (caching)	Yes	Yes
Result of Functions and Queries	Yes (only search)	Yes	Yes (only search)	Yes
Underground View	No	Yes	No	Yes
Cross-section View	No	No	No	No
Measurements (3D)	No	Yes	No	Yes
Non-Spatial Data Visualisation	Yes	Yes	Yes	Yes
Interactivity	Yes	Yes	Yes	Yes
Levels of Detail	Yes	Yes	Yes	Yes
Symbols	Yes	Yes	Yes	Yes
Colour, Thickness, Line-Style	Yes	Yes	Yes	Yes
Labelling	Yes	Yes	Yes	Yes
Transparency	Yes	Yes	Yes	Yes
Identify	Yes	Yes	Yes	Yes
Profiling	No	Yes	Yes	Yes
Shadow Analysis	No	Yes	No	Yes
Animation Creation	Yes	Yes	Yes	Yes
Line of Sight and Visibility Analysis	No	Yes	Yes	Yes
Skyline Creation	No	Yes	No	No
Texture Mapping	Yes	Yes	Yes	Yes
Aerial and Satellite Images	Yes	Yes	Yes	Yes
3D Updating and Manipulating	No	Yes (rotate, scale, shift)	Yes	Yes

Based on this table, all aspects of each application were carefully reviewed. Google Earth and NWW do not meet some of the requirements and are not able to visualise underground objects. Therefore, they are not qualified for cadastral applications. Both the other candidates meet most of the defined criteria and have almost the same capabilities. However, because of the experience of the author in developing ArcGlobe applications and the availability of ArcGlobe, it was selected as a core engine for developing a 3D cadastral visualisation prototype.

6.2.2 Implementation Architecture

The architecture for implementing the 3D cadastral visualisation prototype is illustrated in figure 6.5. This architecture contains three main layers (Shojaei *et al*., 2013):

- Data access layer;
- Process layer; and
- Presentation layer.

The data access layer is able to import data from different data formats, e.g. ESRI Shapefile, Personal Geodatabase, KML, DWG, 3D PDF, and 3DD. In addition, spatial databases such as Oracle, SQLServer, and PostgreSQL/PostGIS are able to communicate with this prototype. The data access layer can also access OGC web services such as Web Map Service (WMS) and Web Coverage Service (WCS) (Shojaei *et al.*, 2013).

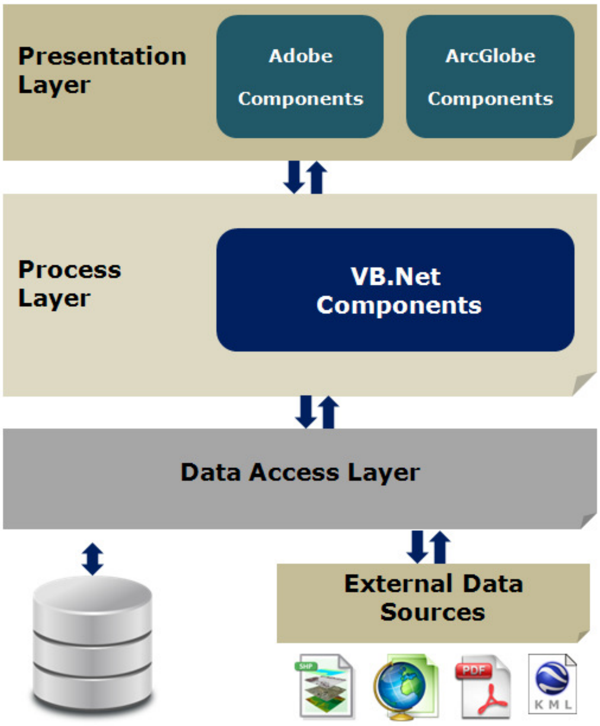


Figure 6.5: Architectural framework (Shojaei *et al.*, 2013).

The second layer is the process layer and VB.Net was chosen as a core engine to provide the required functionalities and analyses for 3D cadastral visualisation. In the presentation layer, ArcGlobe components play an important role for visualising the 3D cadastral data. These components are capable of visualising satellite images from the ArcGIS online resource centre, terrain data, and 3D objects. The prototype is able to visualise underground objects, and support 3D measurement functions.

The 3D PDF data format is also supported using Adobe components. 3D PDF is widely used for presenting 3D objects on a wide range of devices. Many 3D visualisation applications are able to generate these files and several free viewers exist for visualising them. Also, Adobe components are able to provide cross-section views for visualising the inner complexity of buildings.

In order to test the capability of the prototype, an underground car park at the University of Melbourne was chosen, as discussed in chapter 4 (figure 6.6).

Figure 6.6: Mini case study (1) location; (a) Australia, Victoria, Melbourne; (b) The University of Melbourne Campus; (c) University Square Underground Car Park, (Google Maps, 2012).

The survey plans of the car park were received from the land registry of Victoria and carefully studied. Then the legal objects (including lots and easements) of the car park were produced in Shapefile format using these plans. Later official measurements (bearings and distances) were attached to them as attribute data. Data was visualised in the prototype using different colours and transparencies (figure 6.7 (a)). By clicking on the edges of each object, additional information such as bearing and distance were displayed. In addition, the survey plans were attached to the 3D model for users (figure 6.7 (c)). For visualising physical data, the 3D PDF file of the car park was prepared and users could explore the car park and generate user-defined cross-sections (figure 6.7 (b)) (Shojaei *et al.*, 2013). In this prototype, Google SketchUp and the Simlab Soft plug-in were used for creating the 3D PDF files.

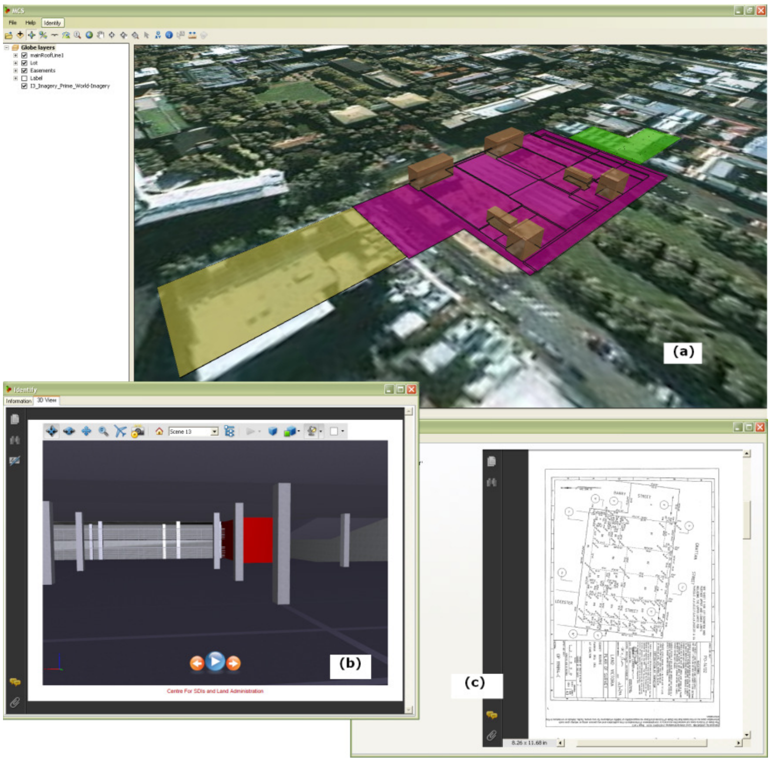


Figure 6.7: (a) A snapshot of the prototype; (b) 3D PDF of the car park; and (c) the survey plan of the car park (Shojaei *et al.*, 2013).

6.2.3 Summary of the Prototype Development

In this section, the first prototype was introduced and its architecture was explained. There were some technical challenges in developing the first prototype. Among the available 3D visualisation solutions, none of them fully met the defined requirements. Therefore, a new approach and innovation was required to address the limitations. However, the closed-source products still had limitations in terms of further development. For instance, due to the limitations of ArcGlobe for developing a cross-section tool, Adobe components were used.

Other technical challenges were:

- The identify tool in ArcGlobe was not very accurate for pointing to 3D objects. In other words, selecting 3D objects on the scene was a big challenge. The identify tool has a sphere with a fixed radius to search objects. Therefore, a new identify tool was developed to be more accurate for selecting objects;
- Physical and legal objects were presented separately. The integration of these objects together would help understanding of ownership boundary locations;
- The prototype was slow for rendering a big 3D model;
- Desktop-based applications are not easily available to users compared with web-based applications; and
- Regular updating and maintenance of desktop-based applications are very challenging.

Based on these challenges and also the received comments from users, no further work was done on this prototype and a new prototype was designed and developed, as discussed in the next section.

6.3 A Web-based 3D Cadastral Visualisation Prototype

This section explores the implementation of the second prototype based on the requirements of 3D visualisation of cadastral data, discussed in chapter 5. Comments on and experience from the first prototype were considered in the design and development of this prototype. The primary purpose of developing this prototype was to evaluate some of the identified requirements and their contributions to understanding of RRRs. The secondary purpose was to explore the challenges of developing a 3D cadastral visualisation application.

A web-based approach for the second visualisation prototype was chosen based on users' feedback and comments from on the first prototype. Six 3D web-based visualisation candidates were compared with the identified requirements. Selection of these six candidates was based on availability, cost, user-friendliness and development environment. Some of these visualisation solutions are introduced below (three having been analysed in the previous section).

6.3.1.1 WebGL Technology

Web Graphics Library (WebGL) developed as a plug-in-free 3D viewer for web browsers by the Khronos Group (Panchaud, 2012). WebGL is a royalty-free web standard that can visualise 3D models using canvas elements, that is, containers for graphics, in HTML 5.

WebGL is discussed further in section 6.4. Figure 6.8 presents a snapshot of a WebGL application representing a 3D city model.

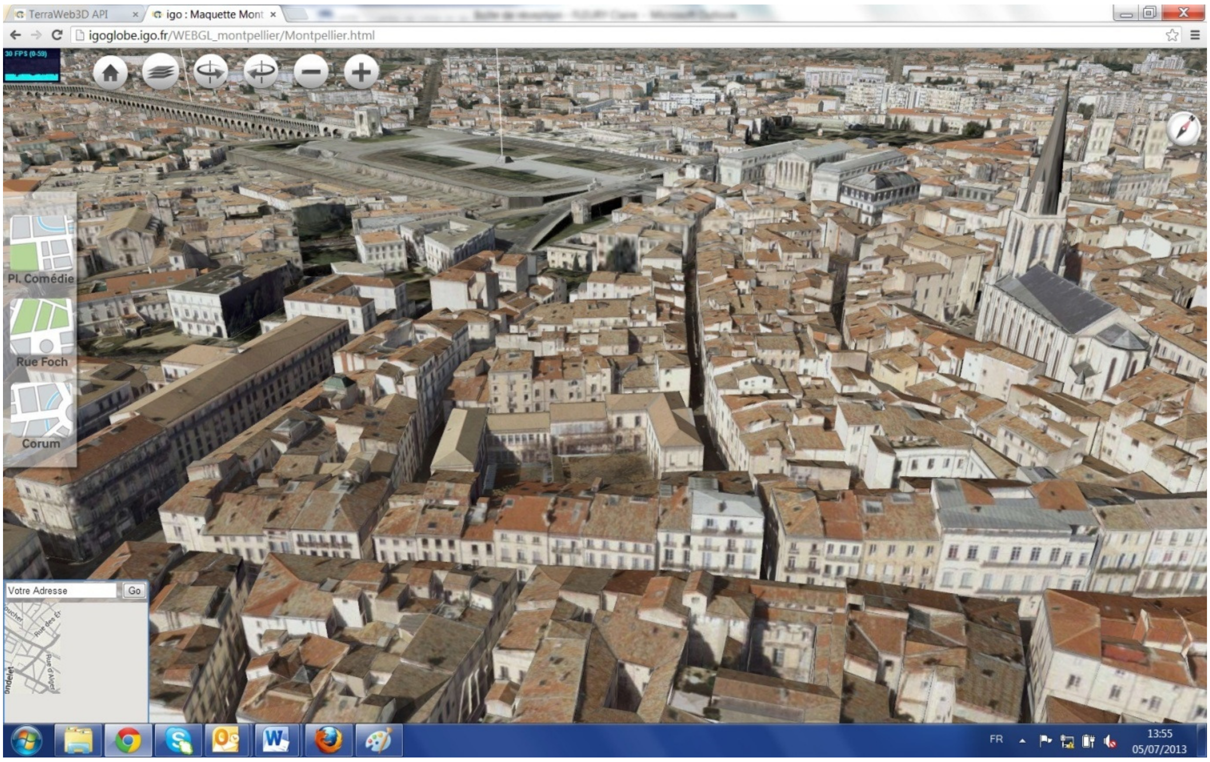


Figure 6.8: A snapshot of a WebGL application.[81]

6.3.1.2 BS Contact

BS Contact is a web-based 3D visualisation application which provides full interactivity with a plug-in. It is a proprietary product; however it can be easily integrated with other applications. BS Contact is a cross-platform application which works on Windows, Linux, Mac, and mobile platforms (Bitmanagement, 2014). It can visualise various 3D formats such as VRML (Virtual Reality Modelling Language), X3D (Extensible 3D), Collada, and KMZ formats. In cadastral applications, BS Contact was used by Vandysheva *et al.* (2012) to develop a web-based 3D visualisation prototype in the Russian Federation to represent 3D volume objects and associated administrative data.

6.3.1.3 XNavigator

XNavigator is an interactive 3D visualisation application for exploring 3D environments and is an online viewer for OpenStreetMap Globe.[82] The software is built on Java technology and

[81] http://www.terraweb3d.com/gallery/
[82] http://www.osm-3d.org

runs on a wide range of platforms including Windows, Linux, and Solaris. The 3D graphics use OpenGL hardware acceleration and the Java technology allows integration into web pages. XNavigator relies on a client-server architecture and supports Open Geospatial Consortium (OGC) standards (XNavigator, 2014). XNavigator supports various OGC services such as Web 3D Service (W3DS), Web Map Service (WMS) and Web Feature Service (WFS). For cadastral applications, Vandysheva *et al.* (2011) developed a prototype using XNavigator to visualise 3D legal objects. Figure 6.9 presents a snapshot of XNavigator representing a 3D city model.

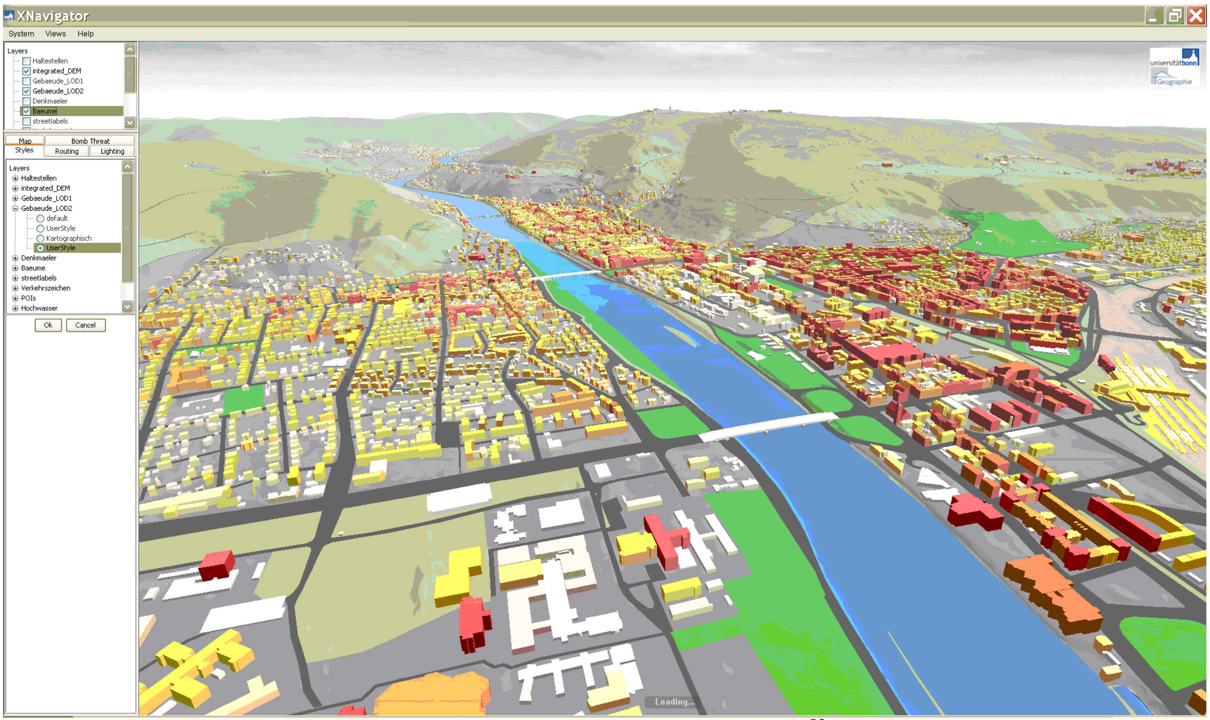


Figure 6.9: A snapshot of XNavigator.[83]

In order to choose an appropriate solution for developing a 3D cadastral visualisation prototype, these candidates were carefully reviewed and assessed against the requirements. A summary of this comparison is presented in table 6.2.

[83] http://www.gislounge.com/heidelberg-3d-interactive-3d-city-mapping-based-on-ogc-standards/

Table 6.2: Comparison table (Shojaei *et al.*, 2014).

Visualisation Features	Visualisation Solutions					
	WebGL	**Google Earth**	**NASA WW**	**BS Contact**	**TerraExplorer**	**XNavigator**
Handling Massive Data	No	Yes (Network links)	Yes	No	Yes	No
Result of Functions and Queries	Yes	Yes (only search)	Yes	Yes	Yes	Yes
Underground View	Yes	No	No	Yes	Yes	No
Cross-section View	No	No	No	No	No	No
Measurements (3D)	No	No	No	No	Yes	No
Non-Spatial Data Visualisation	Yes	Yes	Yes	Yes	Yes	Yes
Interactivity	Yes	Yes	Yes	Yes	Yes	Yes
Levels of Detail	Yes	Yes	Yes	Yes	Yes	Yes
Symbols	Yes	Yes	Yes	Yes	Yes	Yes
Colour, Thickness, Line-Style	Yes	Yes	Yes	Yes	Yes	Yes
Labelling	Yes	Yes	Yes	Yes	Yes	Yes
Transparency	Yes	Yes	Yes	Yes	Yes	Yes
Identify	No	Yes	Yes	No	Yes	Yes
Technical Diversity	Weak	Yes	Yes	Yes	Yes	Yes
System Integration and Interoperability	Yes	Yes	Yes	Yes	Yes	Yes
Usability	Low	High	Medium	Medium	Medium	Low
Platform Independence	PC, Mac, Linux, Android	PC, Mac, Linux	Platform Independent (java based)	PC, Mac, Linux, Mobile	Windows	Platform Independent (java based)
Cost	Open-source	Freeware	Open-source	Proprietary	Proprietary	Open-source
Web-based 3D Visualisation	Yes	Yes	Yes	Yes	Yes	Yes
Plug-in Free	Yes	No	No (Java is required)	No	No	No (Java is required)

According to table 6.2, TerraExplorer only supports Windows and cannot be used in other operating systems. Except WebGL, all solutions are not plug-in free and users need to install the plug-ins or Java for using these solutions.

Due to the limitation of Google Earth and NWW in representing underground objects, both were rejected. None of the candidates were able to directly produce cross-section views.

However, open-source candidates, WebGL and XNavigator, allow extendibility of the product. TerraExplorer and BS Contact are proprietary products, and the ability to develop other functions may be limited. Therefore, open-source candidates, WebGL and XNavigator, were the remaining options. WebGL was chosen due to its rapid on-going development and better support through its community of users. WebGL meets most users' expectations for providing better graphics on the web and many web browsers support this technology (Shojaei *et al.*, 2014).

Although it has some benefits, the following limitations are seen in WebGL:

- Visualising massive datasets is not easy in WebGL. The supported browsers have a limited amount of cache memory which cannot be exceeded. Also, loading massive data into RAM can crash the application (Pereira, 2013); and
- Old generations of computers may not support WebGL, as it has been designed for today's typical graphic cards.

6.3.2 Implementation Architecture

WebGL is a low level API and visualising a simple 3D object such as a cube needs a lot of programming. To facilitate development of applications using WebGL, various open-source JavaScript libraries are available to simplify the programming of 3D capabilities using WebGL. These libraries provide high level access to the API, which makes it easier for software developers to build applications.

Currently, some popular WebGL libraries are three.js[84], Cesium[85], SpiderGL[86], Kuda[87], and SceneJS[88]. These libraries are widely utilised for developing 3D web-based visualisation applications. Three.js has the most users, who also help extend its capabilities. Consequently, three.js was used for developing the prototype.

For developing this prototype, two aspects were considered, discussed below.

- **Data**

In developing 3D visualisation applications, understanding the type of data is very important. In cadastral applications, representing both legal and physical objects is important (Shojaei *et al.*, 2013) and special functionality is required for representing these two types of data. As

[84] http://threejs.org/
[85] http://cesiumjs.org/
[86] http://spidergl.org/
[87] https://code.google.com/p/kuda/
[88] http://scenejs.org/

discussed in chapter 2, physical data includes walls, roofs, ceilings, doors, windows, etc: physical objects that exist in reality. However, legal objects such as lots are conceptual and abstract.

For cadastral purposes, both physical and legal data need to be visualised to leave no room for ambiguity about the boundary of RRRs (Aien *et al.*, 2013). It is important to consider that legal objects can be both bounded or unbounded volumes (Lemmen *et al.*, 2010).

Various data formats such as Collada, CityGML, and IFC are widely used to store 3D objects. Importing the data into three.js involves finding a match between the formats it supports and the formats in which physical and legal objects can be stored.

The two main approaches in three.js for loading data are hard coding and direct import. Hard coding means the codes of 3D models are written using three.js components. However, this method is not feasible for big models. The second approach is reading 3D objects from a file. Currently, JSON and Collada parsers have been developed for three.js.

JSON format does not support all types of primitive objects (e.g. line) and it is very limited in its ability to support complex 3D models. Consequently, the Collada parser was chosen for direct import of 3D objects. Collada is a popular 3D file format which is based on an XML schema. It is also suitable for exchanging 3D models among 3D applications, while there are a number of applications for conversion of other formats into Collada.

In the literature, several data formats have been suggested for cadastral purposes including LandXML and KML (Shojaei *et al.*, 2012), CityGML (Dsilva, 2009) and IFC (El-Mekawy and Östman, 2012, Shojaei *et al.*, 2014). However, IFC was chosen as a starting point for conceptual thinking and modeling in this development because:

- IFC is a popular format among architects because of its central role in Building Information Modelling (BIM);
- Hence 3D building models generated by architects in Victoria are often in IFC format; and
- It is a powerful format which is flexible enough to geometrically represent complex objects.

Other 3D formats have limitations such as:

- LandXML cannot easily support objects with very complex geometry; and
- CityGML receives a lot of attention in the academic environment, but it is not widely used in industry.

In this research, there was no insistence on only using IFC format, as the main focus was on 3D visualisation. Therefore, other data formats can potentially be utilised in 3D cadastres.

Architectural companies may create IFC files using various 3D software products such as Autodesk Revit and ArchiCAD in the 3D design process of developments. Then, the proposed designs are presented to the clients and, after the design is approved, they are converted into 2D plans and delivered to other users such as developers, land surveyors, and local governments.

IFC is a strong candidate for long-term use in development of a 3D cadastre. However, IFC is not supported in three.js. Therefore, for this prototype, IFC needs to be converted to Collada format to be imported in three.js. IFC files may not include visual variables (e.g. colour, texture and transparency) and after converting them to other formats such as Collada, all objects will be white and have no transparency. Therefore, a styling process is required to assign styles including colour or transparency to the objects for better visualisation.

El-Mekawy and Östman (2012) have described the deficiencies of IFC for 3D cadastre and suggested extensions to meet cadastral needs. IFC files only include physical objects such as walls, windows, slabs and doors and do not support legal objects such as lots, easements, and common property, which are important objects in a 3D cadastre.

These 3D legal objects are not supported by 3D software products. For instance, Autodesk Revit is only able to create physical objects and does not support legal objects. Therefore, having legal objects in IFC files require extending the IFC schema to support them.

As a test case for this prototype, subdivision plans of a newly built high-rise were employed to create the ownership boundaries of the legal objects using Autodesk Revit. This test case was fully described in chapter 4. However, as a reminder, a summary of it is provided here.

This high rise has 26 levels and three basements. It has 401 lots and six common property areas. The location of the high rise is shown in figure 6.10.

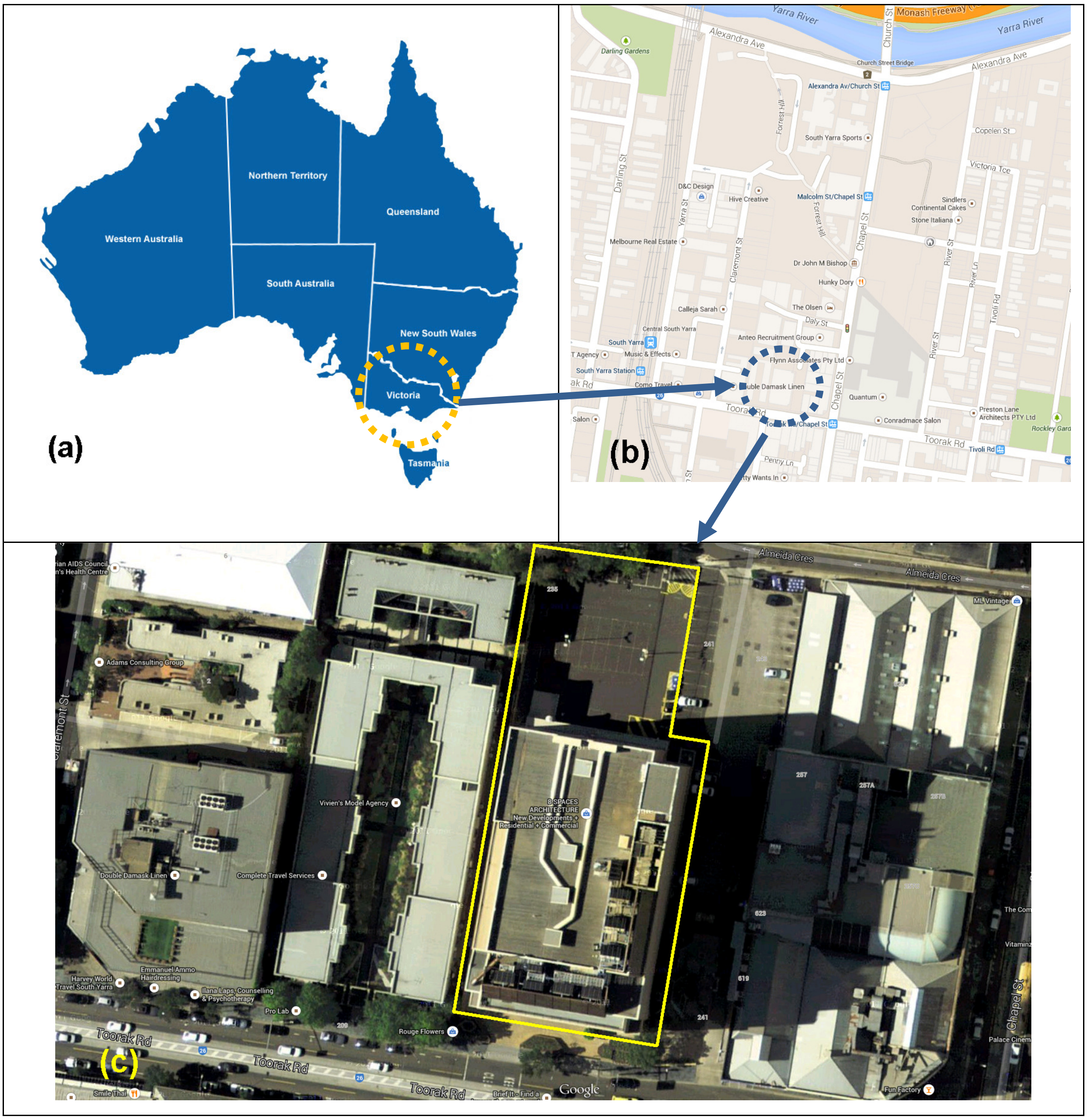


Figure 6.10: Mini case study (2) location; (a) Australia, Victoria, Melbourne; (b) The location of the building on Google Maps; (c) An aerial image of the building with the parcel boundary (Google Maps, 2014).

This high-rise was a good test case for the prototype because of the complexity of the building and the availability of required data. The architectural plans and subdivision plans of this development were provided by the associated surveying company to allow for the creation of legal and physical objects.

Autodesk Revit was utilised to prepare the IFC file, including physical and legal objects. The physical objects were drawn based on the architectural plans. In addition, utility networks were added to the 3D model based on engineering plans. In this research, the IFC schema was carefully analysed and the "Space" component in IFC schema was chosen as a substitute for 3D legal objects. Space is defined in Autodesk Revit using walls (or user defined boundaries), ceiling and roof. This component was utilised to define the boundaries of lots, easements and common property areas (Shojaei *et al.*, 2014).

Then, Blender software[89] was used to convert the IFC file into Collada format. Blender itself does not support importing and exporting IFC files, however, IfcBlender[90] (a plug-in) was used to provide this functionality.

In the next step, the 3D model was exported to Collada format. The Collada file was edited in a text editor to link the legal information to the 3D IfcSpaces. As figure 6.11 shows, (#mesh3827-mesh) is assigned to an IfcSpace and was defined as an IfcLot.

```
...
<node id="_12" name="_12" type="NODE">
        <translate sid="location">0 0 27.51</translate>
        <rotate sid="rotationZ">0 0 1 0</rotate>
        <rotate sid="rotationY">0 1 0 0</rotate>
        <rotate sid="rotationX">1 0 0 0</rotate>
        <scale sid="scale">1 1 1</scale>
        <instance_geometry url="#mesh3827-mesh">
                <bind_material>
                        <technique_common>
                                <instance_material symbol="IfcSpace-material"
                        target="#IfcLot-material"/>
                        </technique_common>
                </bind_material>
        </instance_geometry>
</node>
...
```

Figure 6.11: The XML codes of the Collada file

The 3D model was then copied to a server to be retrieved by the prototype (Shojaei *et al.*, 2014).

- **Users**

This prototype can be used by anyone who wishes to understand RRRs. This may include the public, property managers, referral authorities, developers, architects, real estate agents, lawyers, land surveyors and the land registry.

This prototype is useful for viewing cadastral data, while creating and editing 3D objects on-line is not recommended as it is too slow and too complicated to develop required functions

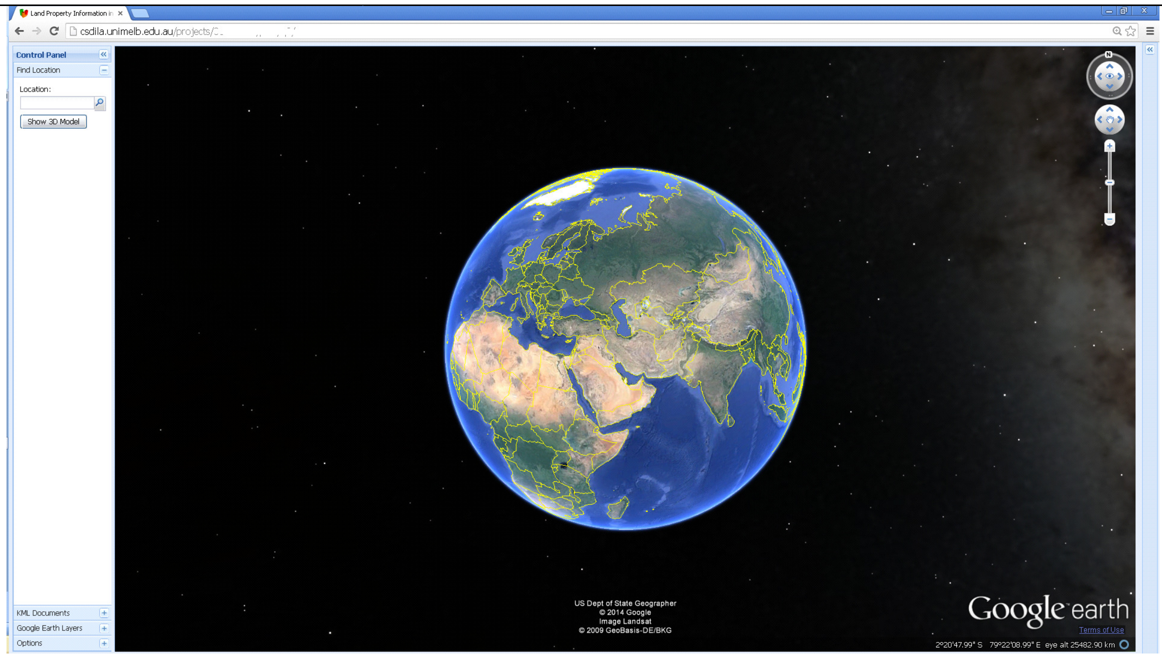
[89] http://www.blender.org/
[90] http://ifcopenshell.org/ifcblender.html

on the web (Shojaei *et al*., 2013). Therefore, the prototype is designed to provide only a viewing environment.

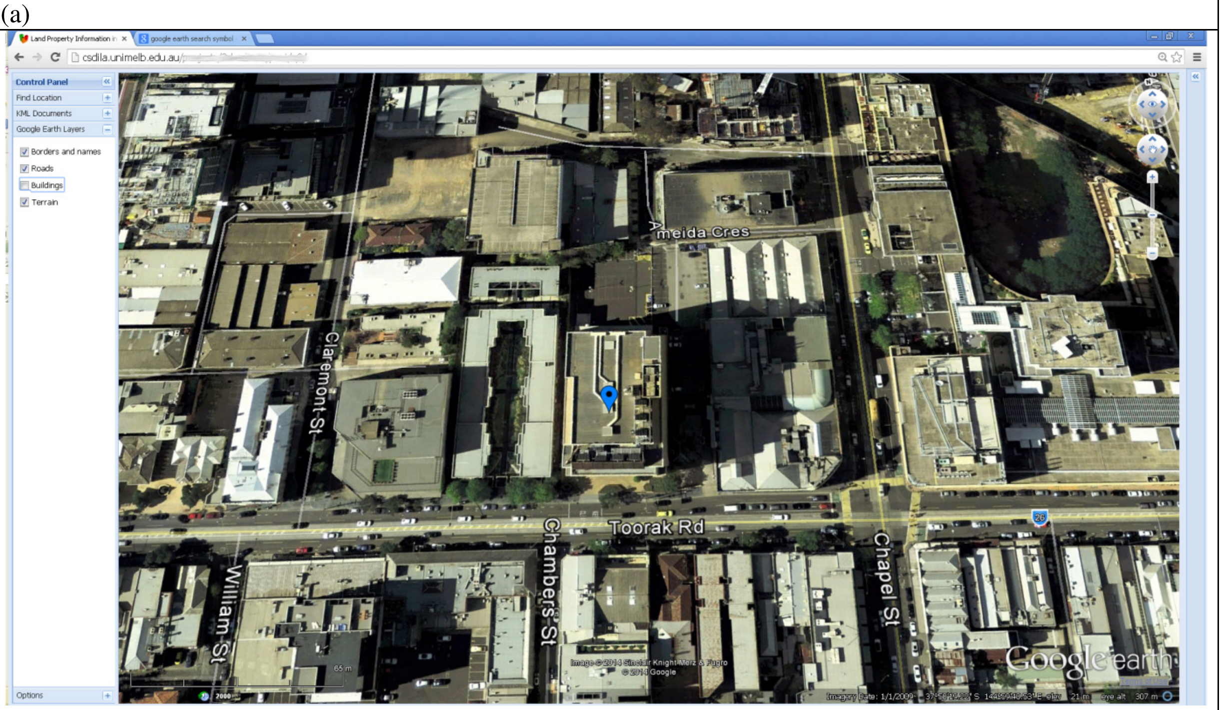
The following section provides an overview, describes the architecture and functional features, and reviews development issues in the prototype design and development phase.

6.3.2.1 Functional Overview

Users are able to search and find properties based on any address. This would be the usual way to start an exploration and occurs in a browser window. This follows a pattern used in current web-based services from many land registry organisations. Once the property has been found, users are able to navigate around and see its location and other adjacent developments (figure 6.12 (a) and 6.12 (b)). Although Google Earth has limitation in representing underground objects, it was only utilised in the prototype to give a property overview and provide the address of each property.



(a)



(b)

Figure 6.12: (a) The GUI developed using Google Earth API WebGL; (b) Search and find buildings based on the 2D cadastral parcel address (Shojaei *et al.*, 2014).

After finding a property, the user clicks a button, "Show 3D Model", and a new tab opens containing the WebGL canvas. This provides a view of the individual building on the parcel and associated legal objects (figure 6.13).

At this stage, the prototype visualises just a single parcel at a time because of the data load and processing limitations in WebGL. All the normal navigational functions are available for exploration, and a variety of additional functions have been included. For example, users are able to turn various physical and legal objects on and off to see the building parts and property rights attached to each. Also, users are able to measure a distance in 3D or create a cross-section view. Moreover, all existing legal documents such as subdivision plans are accessible as PDF documents in the prototype.

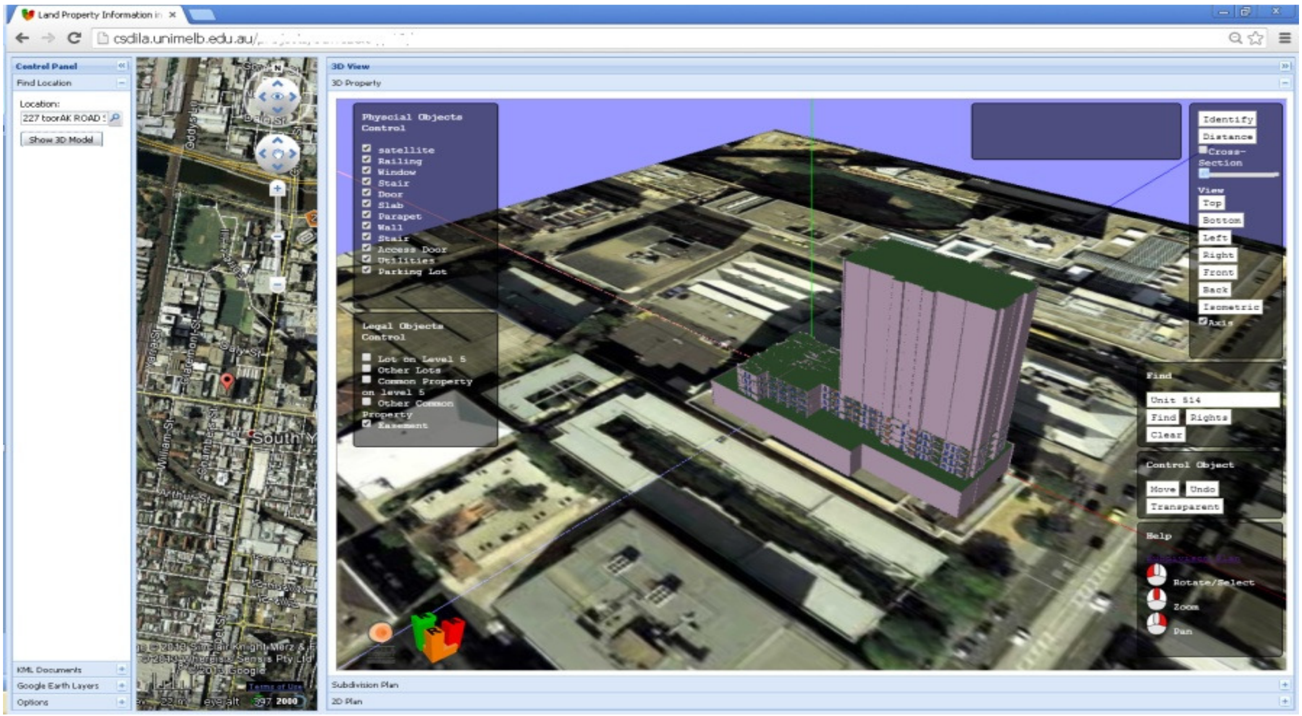


Figure 6.13: A snapshot of the GUI and the WebGL tab (Shojaei *et al.*, 2014).

6.3.2.2 The Prototype Architecture

The architecture of the prototype is illustrated in figure 6.14. This architecture contains two main functional parts, a data repository and the GUI (Graphic User Interface), which are here explained in detail.

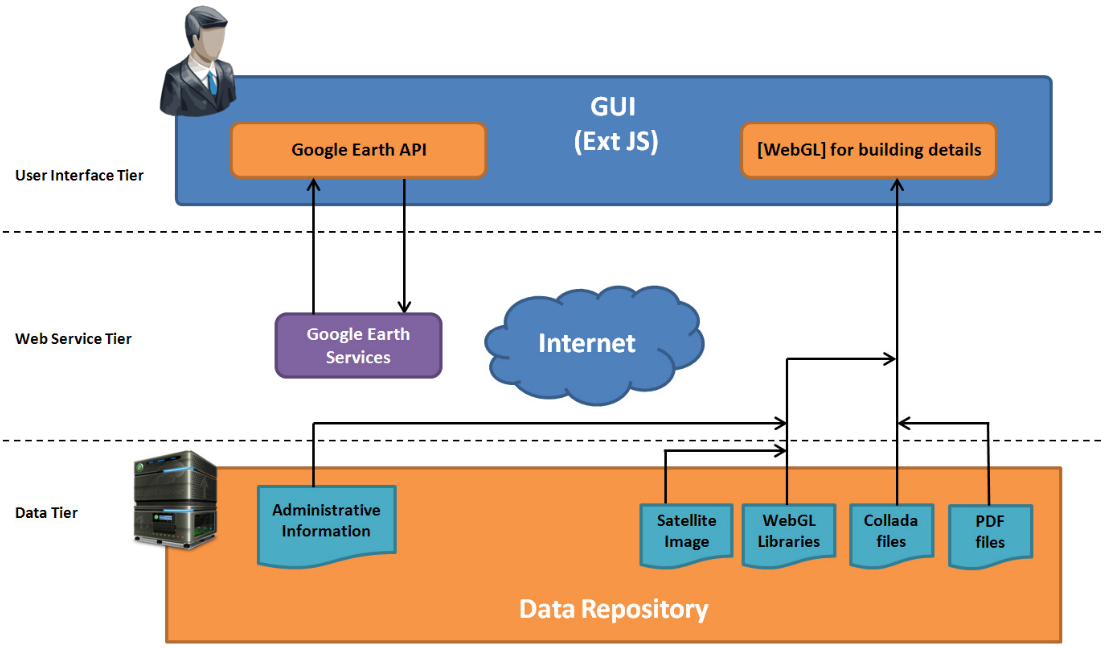


Figure 6.14: The proposed architecture for design and development of the prototype (Shojaei *et al.*, 2014).

- **Data Repository**

The data repository which is located in the data tier includes 3D models (Collada files), subdivision plans (PDF files), WebGL libraries, satellite images and administrative information attached to 3D models in the server. Administrative information includes ownerships, plan numbers and plan permit numbers. In order to connect administrative information to 3D models, unique IDs were attached to each object in the Collada files (Shojaei *et al.*, 2014).

- **User Interface**

The GUI, located in the user interface tier, draws 3D models derived from the server. Various technologies were utilised to produce the GUI namely Google Earth API, WebGL technology, HTML 5, JavaScript and Ext JS. The Google Earth API provides users with some initial capabilities such as searching an address and also seeing a parcel in the context of the city. This could be extended to include the DCDB (Shojaei *et al.*, 2014).

Google Earth was embedded in a page using JavaScript. Google Earth API is not open-source, however, some small changes are allowed to customise applications for various needs. For example, layers and objects can be switched on or off. These functions are controlled using the API. In addition, Ext JS was utilised, which provides the GUI programmer with customisable frames, buttons, and tabs to build a robust application interface (figure 6.15).

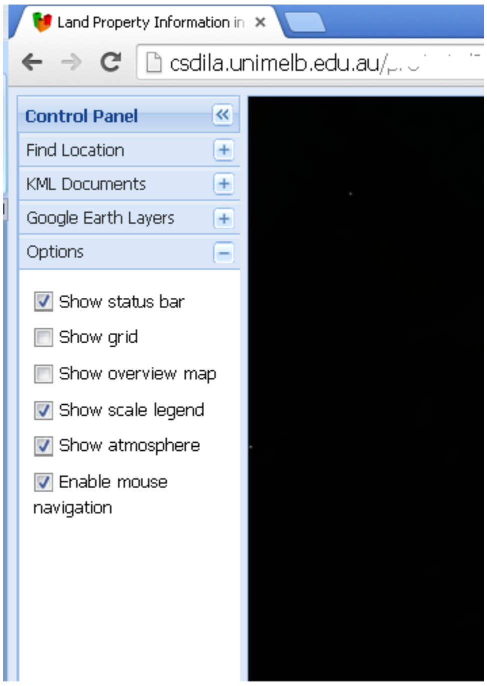


Figure 6.15: Controlling the Google Earth layers and options.

In figure 6.15, the Find Location helps users to find a property based on an address. KML Documents allow users to upload a 3D KML or KMZ file in the prototype. Google Earth Layers are controlled by users to activate various layers. Lastly, users are able to control the features of Google Earth such as status bar, grid, and scale.

Because of limitations in the Google Earth API for representing underground objects, WebGL was required to provide a 3D canvas into the browser. Figure 6.13 shows snapshots of the GUI including both Google Earth and WebGL. The features of the GUI are described in detail below.

6.3.2.3 Functional Features

The following functions were developed using three.js libraries in the JavaScript development environment.

- **Identify Tool**

In order to retrieve information attached to each legal and physical object in the scene, an ‘identify tool’ was developed using a ray tracing approach. By a mouse click on the scene, the 2D position of the cursor is converted into 3D and a hidden line is drawn from the 3D cursor position to the camera location. This line may intersect with many objects on the scene. The closest intersection to the camera is detected and highlighted. In addition, information about that object is retrieved for displaying in the GUI (figure 6.16).

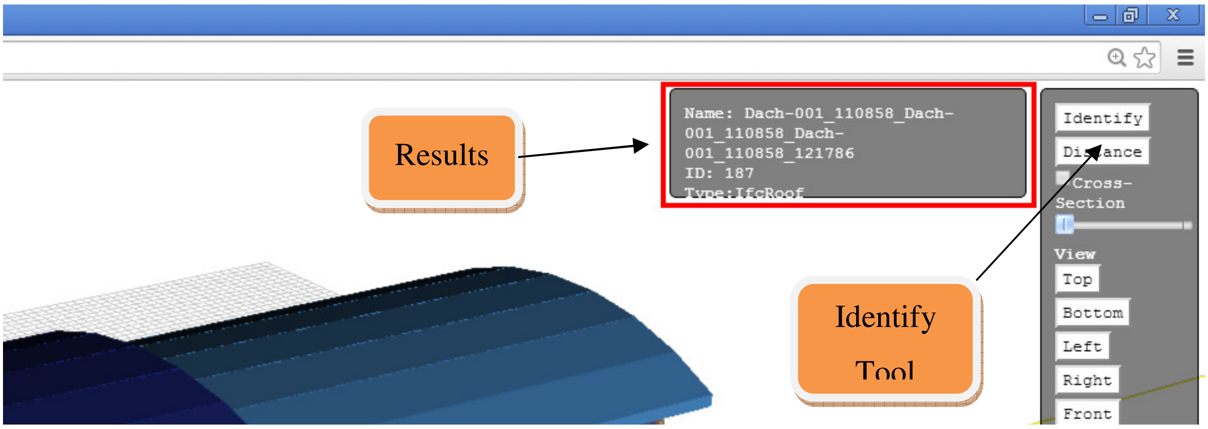


Figure 6.16: The identify tool retrieves the information of each object after click.

- **3D Measurement Tool**

This tool was developed to measure 3D distances between two points on the scene. After each click, 2D cursor position is converted to 3D position using the ray tracing technique from the camera location to the nearest surface close to the cursor. By using two consecutive 3D positions of mouse clicks, a 3D distance is computed and a line is visualised to show the location of the measured distance (figure 6.17).

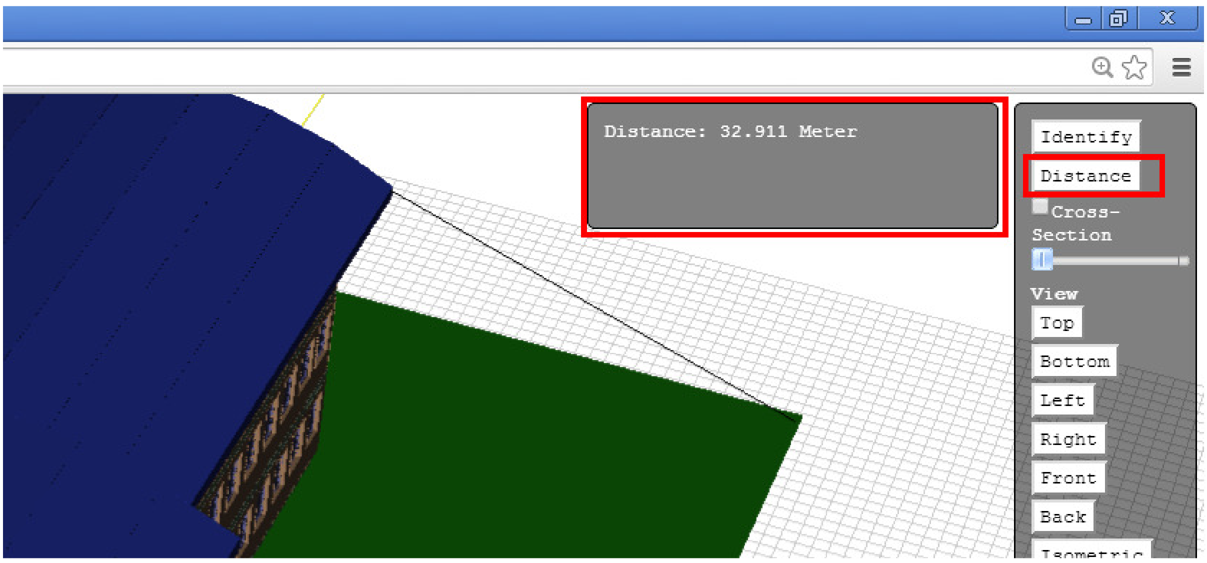


Figure 6.17: The measurement tool.

- **Cross-section Tool**

The cross-section tool shows the internal complexity of buildings. The camera component of three.js has two clipping planes, namely the near and far clipping planes. The 3D objects which are located in between these two planes are rendered in the scene. By changing the distance of the near clipping plane from the camera, different cuts through the objects can be seen (figure 6.18).

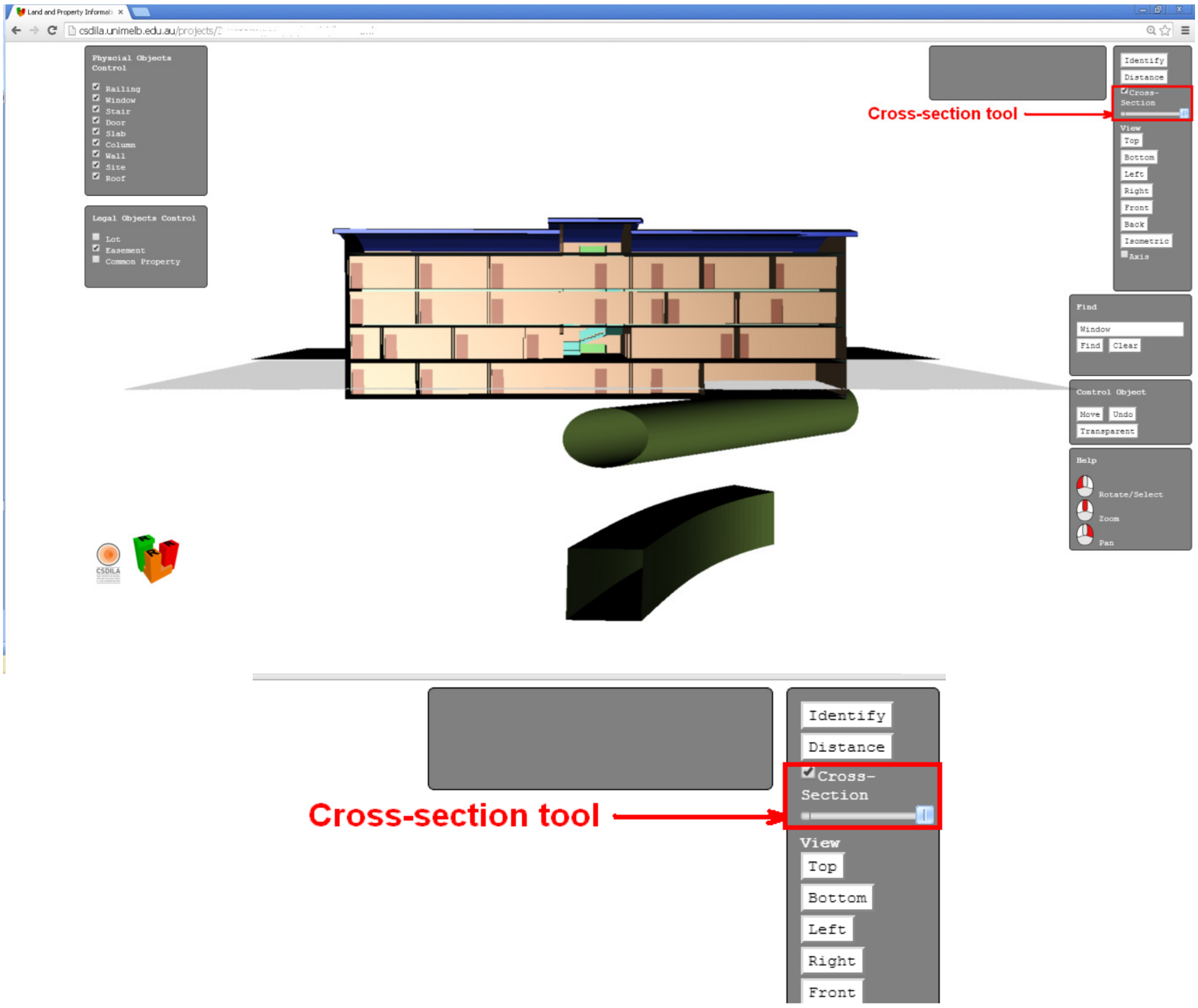


Figure 6.18: The cross-section tool.

- **Various Views**

The prototype is able to control views based on camera positions and angles. In addition to free movement, the camera can be quickly located at specific angles such as front, back, isometric, top, right, left, top and bottom, relative to the building (figure 6.19).

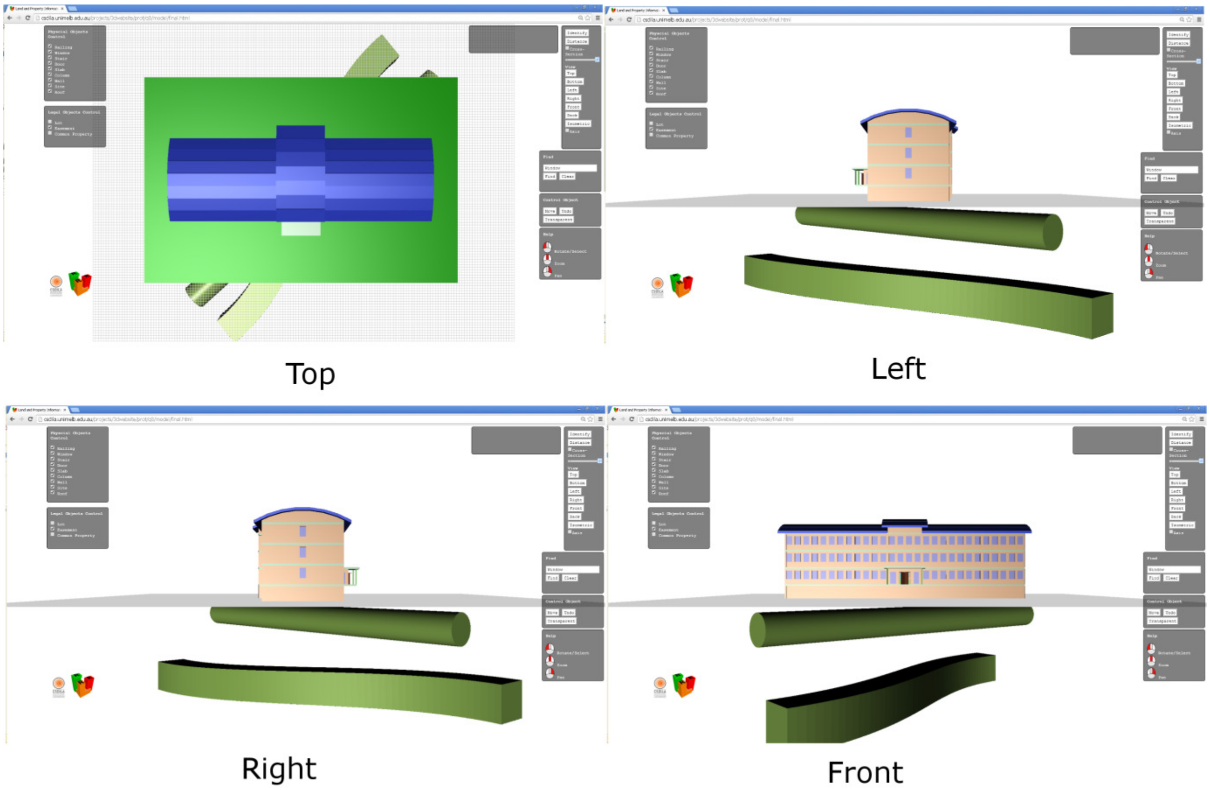


Figure 6.19: Control views.

- **Search and Find Tool**

A search functionality was also implemented in the prototype as part of the defined requirements. After entering an attribute of the objects in the search box, objects with similar attributes are highlighted. For example, owners can find lots which they own by entering their names. These lots are not necessarily adjacent. For example, the user's apartment, their allocated car park and their common property areas can be highlighted. Once the query is completed, the original colour is restored (figure 6.20).

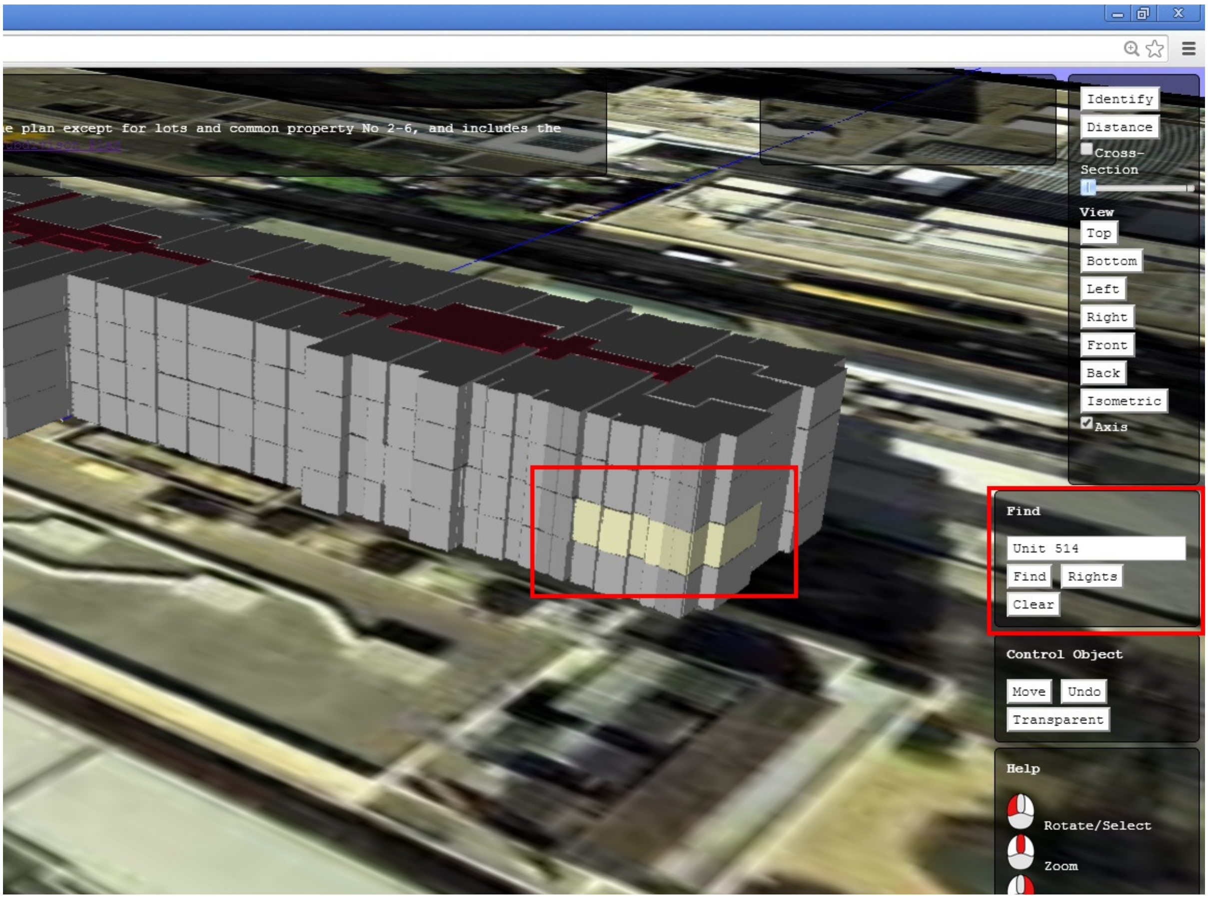


Figure 6.20: Search and find tool.

In figure 6.20, "Unit 514" is entered in the Find tool. After clicking the "Find" button, Unit 514 is highlighted. By clicking on the "Right" button, the associated rights attached to the Unit 514 are highlighted. If there is any restriction and responsibility, the associated information can be presented. In this case, the common property and the car park of this unit are highlighted (figure 6.21).

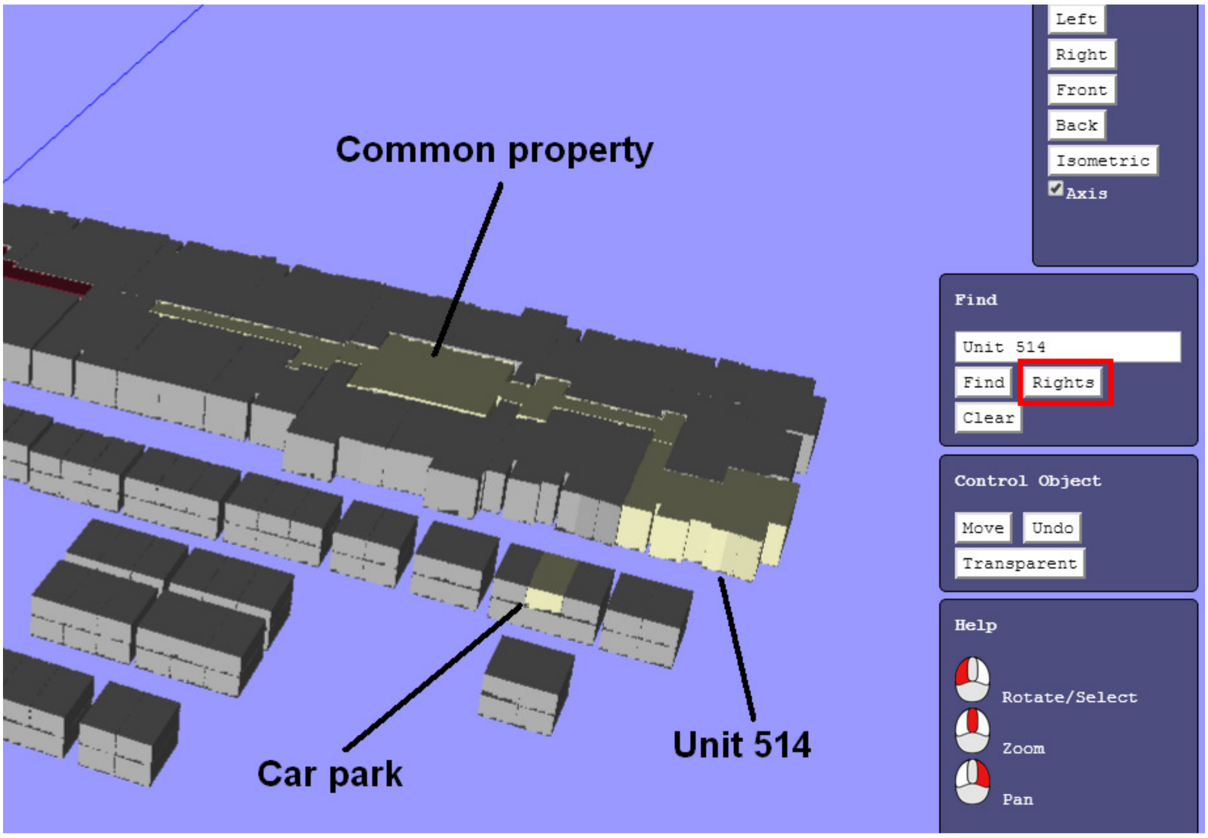


Figure 6.21: Finding associated rights attached to a lot.

- **Move, Undo, Transparent**

In some cases, it is important to slide out an object (e.g. a lot) from its original location and view it in more detail individually and then bring the object back. Thus, a tool was developed that allows any highlighted object to be moved in the scene. The object can return to the previous position by a simple Undo option. Figure 6.22 shows move, undo and transparency tools.

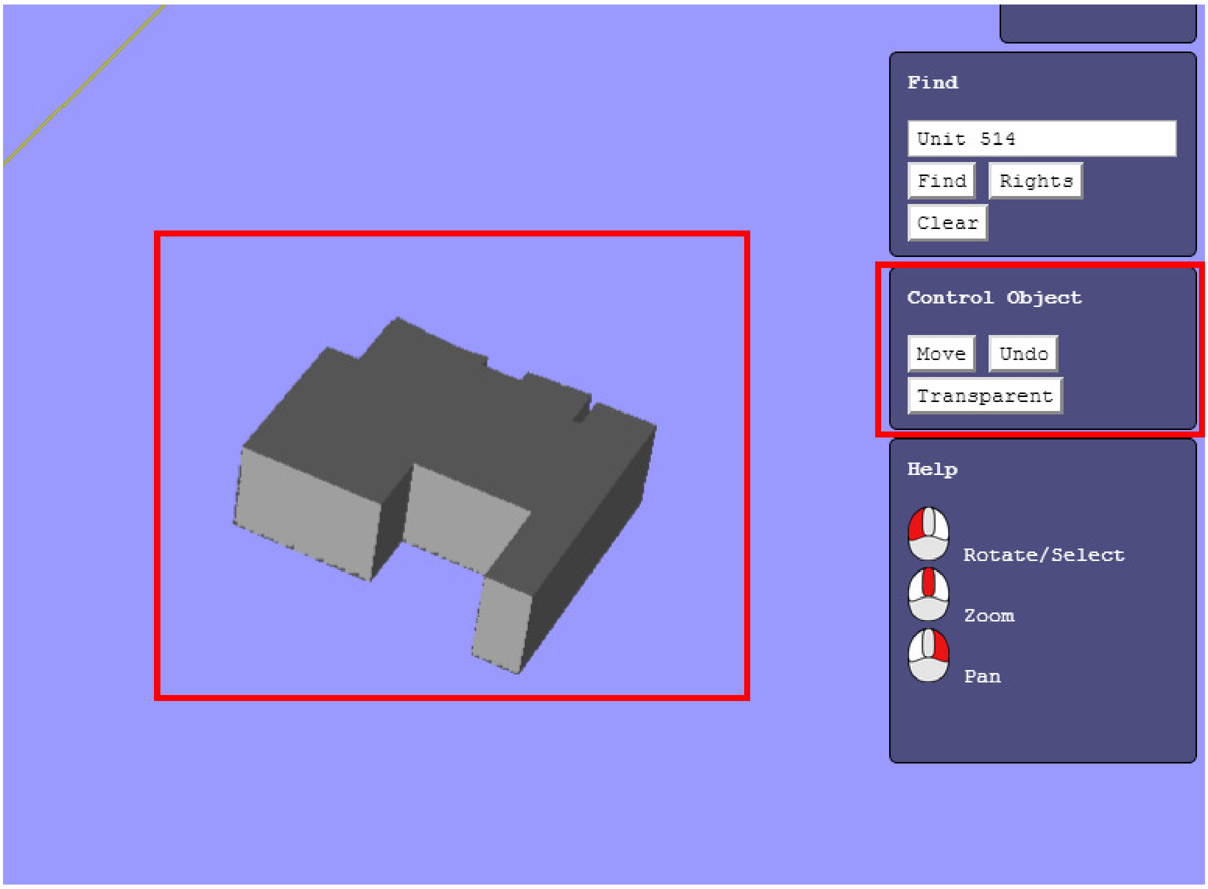


Figure 6.22: Sliding out an object from its original location to view it in more detail and then bring it back using Undo function.

- **Object Control**

There are two sets of lists at the left side of the scene which provides users with check-box control over object visibility of physical and legal objects. This allows any combination of physical and legal objects to be viewed in the scene (figure 6.23).

Figure 6.23: Controlling object's visibilities.

- **Representing Administrative Information**

There are two other tabs on the bottom of the page which provide the option to view administrative information, such as subdivision plans and associated documents. Users can refer to these for more detail and in order to see legal documents (figure 6.24).

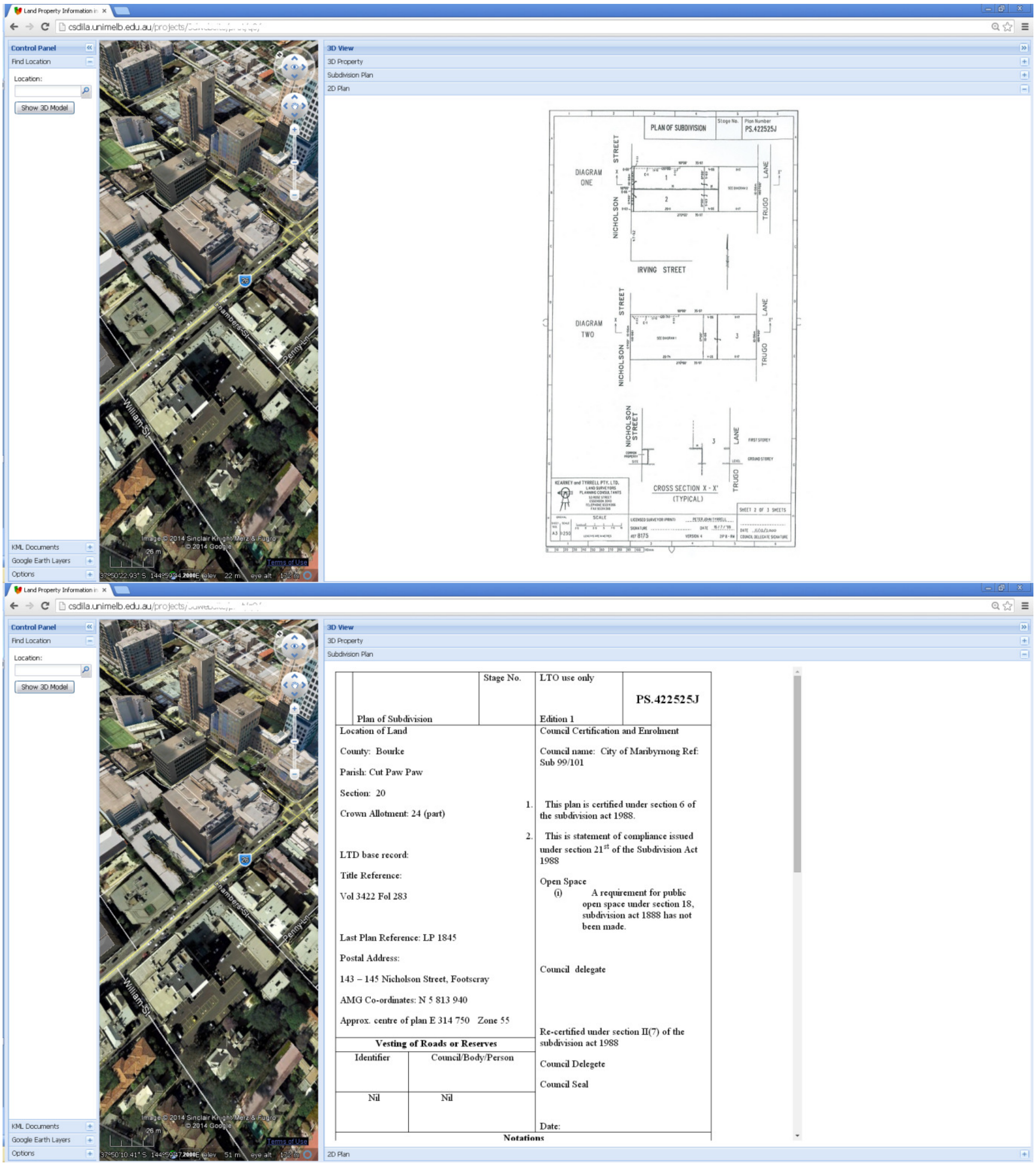


Figure 6.24: Representing administrative information.

6.3.2.4 Additional Development Issues

Other issues had to be resolved in this prototype to increase the usability.

- **Camera**

There are various types of camera components in the three.js libraries. In order to give users the most natural form of control over the objects, the upside of the camera should be always towards the top of the screen: buildings do not normally turn upside-down.

- **Zoom and Pan**

The interactivity in visualisation applications is reduced if zoom and pan are poorly designed. For example, the amount of movement should be based on the distance of the camera from the object of interest. Typically finer movements are required when camera is close to the objects. For example, if a camera is 100 metres from objects, the zoom speed should be different than with a closer distance. This distance should be reduced more slowly when the objects are very close to the camera.

Similar to zoom, when objects are far from the camera, pan speed should be high and the inverse. This provides smoothness in visualisation applications. Therefore, the source code in the three.js libraries was changed to provide users with more smoothness in the prototype by changing the zoom and pan speed dynamically.

6.3.3 Summary of the Prototype Development

In this section, the second prototype was introduced and its architecture was explained. Then, various functions, features and capabilities of the prototype were discussed. During the implementation of the second prototype, various technical issues and challenges arose which are discussed below:

- Data
  - There was a big challenge in terms of intellectual property for accessing IFC files of buildings. Many architectural companies did not provide IFC files of their designs. Therefore, the only solution was redrawing the 3D model of high-rises based on architectural plans and creating an IFC file. This process was very time-consuming along with many issues in the design process;
  - The size of IFC files increased significantly for bigger models. Due to this, transferring big 3D models over the internet requires an acceptable internet speed;
- Technology
  - WebGL is a new technology and evolving quickly. However, it is still in the beginning of its development. During the development phase, many functions were written and changed to meet the users' requirements. These changes were often too difficult as three.js libraries had many issues and shortcomings;
  - The other issue in this technology was the limitation of WebGL in loading massive data on the web browsers and mobile devices. Therefore, depending on the users' resources, a smooth visualisation is not always possible.

6.4 Lessons Learned from Prototype Implementations

None of the available 3D visualisation solutions could fully meet the defined requirements. Therefore, new approaches and innovations were used to address the limitations. However, the closed-source products still had limitations in terms of further development. For instance, due to the limitations of ArcGlobe for developing a cross-section tool, Adobe components were used. Therefore, there is a lack of appropriate 3D visualisation solutions to fully support cadastral needs.

There are also limitations in some existing 3D visualisation applications and further improvements are necessary. For example, the identify tool in ArcGlobe was not very accurate for pointing to 3D objects.

Future 3D visualisation applications should be able to visualise integrated physical and legal objects. The integration of these objects would help understanding of ownership boundary locations.

Efficient 3D visualisation engines are required to render massive 3D cadastral data. Some of the solutions have limitations in terms of processing big developments.

Web-based and mobile applications are getting more popular among users. Although they have specific limitations, web-based and mobile applications must be considered for some specific users.

Various 3D data formats exist for storing 3D objects. However, there is no fully supported 3D data format for storing 3D legal objects. Although LandXML supports various specific needs of land surveying, its capabilities to support 3D are limited and cannot support modelling of complex developments.

There is a need for an efficient 3D spatial database for managing 3D cadastral data and supporting required analyses. This database should be able to store legal objects and physical counterparts. The link between them should be kept for required analyses.

Visualising all legal objects may increase the complexity of a 3D model. For example, visualising structural common property areas (e.g. slabs, walls, columns, and roofs) in a high rise brings a high level of complexity, which makes it difficult for users to understand RRRs. In the second prototype, structural common property areas were excluded in the scene and replaced by notations. The notations addressed the areas outside of lots and easements that are common property areas.

In addition, unbounded volumes (e.g. air space) were not visualised in the prototypes as visualising unbounded volumes is not simple. To simplify the visualisation of unbounded volumes, they were replaced by notations in the prototypes. The other solution is visualising a 2D ground parcel with related attributes for describing the extent of RRRs.

Cadastral data is used by various types of users for various applications. Therefore, the visualisation application is required to support various GIS functionalities including intersection, buffer, and spatial analysis (Karki *et al.*, 2013b).

Height information is not available in all plans and creating 3D legal objects using only these plans are not possible. The alternatives are new measurements in the field or using architectural plans to identify the height information.

Geometrically visualising restrictions and responsibilities is not always possible. A restriction is a formal or informal requirement to refrain from doing something (modified from ISO 19152: 2012 (LADM)). There are a number of restrictions recognised in Victoria, such as those included in restrictive covenants and planning and building restrictions. A responsibility, also known as an obligation, is a formal or informal requirement to do something (modified from ISO 19152: 2012 (LADM)). Examples include the obligation of a landowner to pay municipal rates and taxes, to comply with Section 173 agreements under the Planning and Environment Act 1987 and not to cause a nuisance to other landowners. In some cases, restrictions and responsibilities cannot be visualised and they are only presented as a notation. However, easements are visualised to define the restrictions. In addition, common properties define additional responsibilities of maintenance for owners' corporations.

Developing these two prototypes and the case study facilitated understanding and identifying requirements and challenges for representing RRRs. The feedback received from workshops, meetings, and seminars were used for improving the functionality of the prototypes and the final list of requirements.

6.5 Chapter Summary

This chapter explained the implementation of two cadastral visualisation prototypes for representing cadastral data in 3D. These prototypes were designed and developed to help understanding the issues and challenges in visualising 3D cadastral data.

The first part of this chapter looked at the first prototype and discussed the utilised technologies and architecture for implementing a 3D cadastral visualisation prototype. The first prototype helped significantly in terms of identification of the needs and expectations of users and investigation of an approach for visualising 3D cadastral data.

The second part of the chapter explored the architecture and considerations for developing a web-based 3D cadastral visualisation prototype. The second prototype was mainly based on the lessons learned from the first prototype and the experience gained from the research activities.

Some of the main challenges encountered during the implementation of these two prototypes were discussed at the end of each part of this chapter. Sharing these issues and challenges could facilitate further design and development of similar applications for cadastral purposes.

The assessment of these two prototypes is discussed and explained further in chapter 7.

CHAPTER 7

VALIDATION OF 3D CADASTRAL VISUALISATION REQUIREMENTS

"Everything that can be counted does not necessarily count; everything that counts cannot necessarily be counted."

– ALBERT EINSTEIN

7 Validation of 3D Cadastral Visualisation Requirements

7.1 Introduction

This chapter presents a validation of the identified requirements using two techniques (requirement review and prototyping) as described in chapter 3 (3.5.4). For the requirements review, two questionnaires were designed and distributed among cadastral users to receive their feedback. In addition, two prototypes were designed and implemented to validate the requirements. The prototypes and analysis of the responses to two questionnaires were used to address the research objective of validation of the developed 3D cadastral visualisation requirements.

Based on chapter 3, the multilevel model was chosen from various triangulation methods, as different types of data were collected in three levels. With the intent of forming an overall interpretation, analysis and validation in different levels are required in multilevel model. Figure 7.1 presents a diagram of requirement validation process conducted in this research.

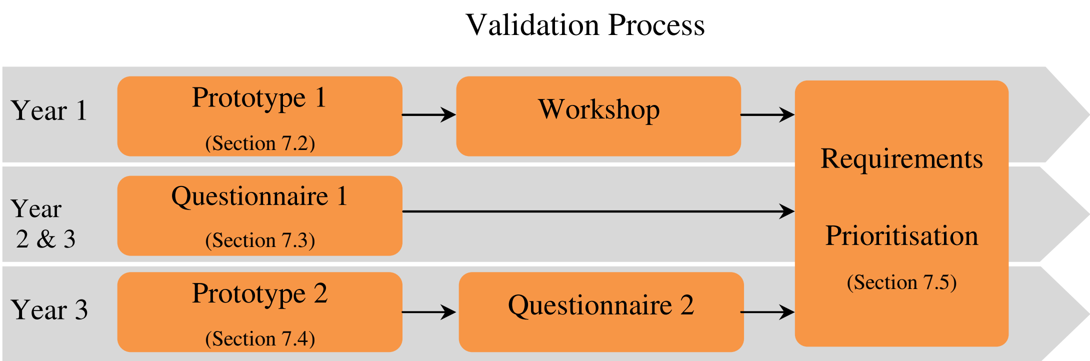


Figure 7.1: A diagram of requirement validation process to validate and prioritise the identified requirements.

Figure 7.1 shows the activities in each year during this research regards to validation requirements. In the first year, the first prototype was designed, implemented and evaluated in a workshop. In years 2 and 3, the first questionnaire was conducted. In year 3, the second prototype was designed, implemented and evaluated using the second questionnaire. The outcomes of these activates were used for validation and prioritisation of requirements. In general, the aim of requirements validation is to ensure that all requirements support the relevant business, fulfill its objectives, and meet user needs (IIBA, 2009).

7.2 Validation Requirements Using the Desktop 3D Cadastral Visualisation Prototype

The prototyping approach was used to validate the identified requirements. The first prototype (the Desktop 3D Cadastral Visualisation Prototype-section 6.2) was developed and then evaluated. In the prototyping technique, prototypes help users to validate the requirements, identify the problems, and how to enhance the efficiency of the final system. Prototypes do not need to include all requirements, however, a sufficient number of features must be implemented for users to use prototypes (Kotonya and Sommerville, 1998).

Kotonya and Sommerville (1998) developed a prototype evaluation with four phases: choosing prototype testers, developing test scenario, executing test scenario, and documenting results.

7.2.1 Choosing Prototype Testers

A workshop was held (5 October 2011)[91] at the University of Melbourne and twenty participants from industry and academia specialising in cadastre, were chosen and invited to the workshop. They came from different backgrounds such as land registry, land surveyors, owners' corporations, city councils, architects, and lawyers. Some of these participants were industry partners of the 3D Land and Property Information Project.[92]

7.2.2 Developing and Executing Test Scenario

In order to validate the requirements in a systematic way, a test scenario was designed and executed. The scenario had four sections. The first section was introducing the research project to the audience in order to clarify the aim and objectives of the research. Secondly, the survey plans were provided to users to understand the situation. The survey plans had diagrams and notations of the University Square Underground Car Park (See section 4.2.3.1) and they were asked to interpret the plans and understand the ownership rights, restrictions and responsibilities. The third section was presenting the prototype with its capabilities including search, identify, cross-section, and navigation using a 3D model of the car park and the final section was designed for collecting the comments from the testers in open discussion, to understand their needs and expectations from a visualisation application in the light of the demonstration.

[91] http://csdila.unimelb.edu.au/BeyondSpatialEnablement/programme.html
[92] http://csdila.unimelb.edu.au/projects/3dwebsite

7.2.3 Documenting Results

Testers were invited to discuss their ideas and each of them was able to raise their concerns. Their comments were documented in table 7.1.

Table 7.1: Evaluation of the first prototype based on the users and their requirements (Shojaei *et al.*, 2013).

User	User Needs	Does the prototype meet the requirement? Yes	No	Comments/ Discussions
Land Registry	Visualising ownership RRRs in 3D	√		• Parcel boundaries and building boundaries are represented to facilitate understanding RRRs in 3D. • Height and depth limitations are presented to define the extent of the rights. • Unbounded volumes should be visualised using 2D objects such as lines or parcels.
	Searching lots using plan numbers	√		• Lots are searchable on the prototype that can be used like an index in 3D. • Parcel identifiers are specified. The parcel identifier facilitates integration of land parcel information. • The address should be included to facilitate search for specific properties.
	Retrieving ownership information for each lots, easements and common properties	√		• Lots, easements, and common properties and associated information are retrieved by using the identify tool.
	Examining and validating RRRs		√	• Validation rules are not currently available on the prototype to check the geometrical errors. • Official areas are labelled and unofficial area measurements can be calculated by use of the measurement tools. • Cross-section view is possible using the Adobe Acrobat Reader component. • Surveyor's report and abstract of field record are accessible in PDF format.
Land surveyors	Understanding 3D legal boundaries	√		• The prototype facilitates understanding of RRRs in 3D.
	Generating subdivision or consolidation plans		√	• Drawing and editing 3D objects to generate subdivision or consolidation plans are not possible on the prototype. • Control points are also accessible on the prototype that can be referenced for land surveyors.
	Generating survey's reports	√		• Information available on the prototype facilitates production of survey's reports.
	Viewing abstract of field records	√		• Abstracts of field records are represented on the prototype.
Owners' Corporations	Understanding of entitlements for managing common properties in 3D	√		• Owners' corporations need a visualisation tool to understand RRRs and associated information.
City Council	Property management in 3D	√		• 3D property information is very significant for councils to facilitate decision making processes. For example, an estimate of habitable properties in an area facilitates calculation of required energy.

				• The prototype represents ownership boundaries with unit granularity in 3D and additional information from city councils can be attached to the prototype to run other queries which assists property management. For example, the number of occupied properties in an area can reveal the extent of properties available for citizens.
	Review of plans and issue planning permits	√		• The prototype facilitates issuing of planning permits by representing ownership boundaries in 3D. Currently, plans are assessed manually which is too time consuming and error-prone.
	Plan land use	√		• The prototype provides users with a realistic visualisation and land use data can be imported to facilitate land use planning processes.
	Public participation	√		• Councils are required to provide public information for new developments. A representation system facilitates communication between professional and the public. Web-based visualisation applications are recommended for public participation.
Architects	Digital representation of the physical environment	√		• Architects are more interested to see physical data, and a realistic 3D representation can give them a better view.
	Create and edit 3D models		√	• The prototype does not support tools required for creating and editing 3D models.
Lawyers and conveyancers	Understand ownership boundaries for resolving disputes and supporting their clients	√		• 3D models can improve dispute management. • In case of building subdivisions, owners, owners' corporations and lawyers need to know where the boundaries between lots and common properties and between individual lots lie (interior, exterior or median boundary).

According to table 7.1, the prototype was able to assist for different usages and in different cases. However, there were some limitations in the prototype identified through this evaluation. These limitations were mostly functional requirements (such as creating and editing 3D objects) and were not directly related to visualisation of 3D objects. On the other hand, these limitations highlights that just one application might not be able to meet the different expectations of all users. Users who need editing tools to create or manipulate data certainly require a more complex application than those who only need to view and understand the data.

A comment was received regarding system accessibility, which is very important to users. It was explained that web-based solutions are able to engage a wide variety of users. Another comment was about representation of unbounded volumes. The view was expressed that using 2D parcels is one method to represent unbounded volumes. Also, ISO 19152 (LADM) mentions that use of 2D parcels (LA_BoundaryFaceString) is the preferred approach to represent unbounded volumes. When 2D objects such as lines (LA_BoundaryFaceString) cannot describe 3D spatial units and unbounded volumes sufficiently, the ISO recommends using faces (LA_BoundaryFace) to represent them (ISO19152/TC211, 2012).

7.2.4 Summary of the Requirements Validation Using the First Prototype

In this validation technique, a prototyping approach was used to validate the identified requirements. In this approach, a case study was chosen and the required data was prepared to visualise RRRs in 3D. The prototype and the case study were presented in a workshop and feedback received from 20 specialists.

Based on the users' feedback in table 7.1, each type of user has different needs and expectations. For example, some users need to edit as well as view data, whereas some users only need to view data.

Based on the feedback and analysis of the requirements, a list of required features for different types of users was developed and summarised in table 7.2. The listed features were based on the initial requirements identification for representing RRRs in 3D as presented in chapter 5. At the bottom of table 7.2, some other features which were useful but not essential for all types of users were recommended, as they were identified in the workshop as new requirements.

For example, city councils need all these additional features according to the involved tasks which were discussed in table 7.1. Also the use of aerial and satellite images as background seems to be important for all users and should be included in the main requirements list (Shojaei *et al*., 2013).

Table 7.2: Required features based on users' feedback (Shojaei *et al.*, 2013).

Features	Users					
	Land Registry	Land surveyors	Owners' Corporations	City Council	Architects	Lawyers and conveyancers
Handling Massive Data	√	√	√	√	√	√
Result of Functions and Queries	√	√	√	√	√	√
Underground View	√	√	√	√	√	√
Cross-section View	√	√	√	√	√	√
Measurements (3D)	√	√	√	√	√	√
Non-Spatial Data Visualisation	√	√	√	√	√	√
Interactivity	√	√	√	√	√	√
Levels of Detail	√	√	√	√	√	√
Symbols	√	√	√	√	√	√
Colour, Thickness, Line-Style	√	√	√	√	√	√
Labelling	√	√	√	√	√	√
Transparency	√	√	√	√	√	√
Tooltips	√	√	√	√	√	√
Technical Diversity	√	√	√	√	√	√
System Integration and Interoperability	√	√	√	√	√	√
Usability	√	√	√	√	√	√
Platform Independence	√	√	√	√	√	√
Cost	√	√	√	√	√	√
Web-based 3D Visualisation	√	√	√	√	√	√
Shadow Analysis	-	-	-	√	√	-
Line of Sight and Visibility Analysis	-	-	-	√	√	-
Texture Mapping	-	-	-	√	√	-
Aerial and Satellite Images	√	√	√	√	√	√
3D Updating and Manipulating	-	√	-	√	√	-

7.3 Validation of the Requirements Using the First Questionnaire

The section explores the validation of the identified requirements using the requirements review technique through the first questionnaire (See 3.5.4). The questionnaire had three parts: participant's information, organisational spatial data characteristics, and visualisation requirements validation. The questionnaire is provided in Appendix 2.

Part three included five sections and collected information on required data elements, analytical requirements, user interface and system requirements, technical requirements and visualisation requirements. To keep the length manageable, more obvious needs (e.g. map navigation in 3D, support databases, support data services, and print) were not included in the questionnaire.

An online version of this questionnaire was designed using SurveyGizmo[93] and advertised among cadastral specialists using various approaches including posting on social media (e.g.

[93] www.surveygizmo.com

LinkedIn),[94] sending emails, posting on the website of the FIG Joint Commission 3 and 7 Working Group on 3D Cadastres,[95] and posting on the website of the 3D Land and Property Information Project.[96] Also, several hard copies of the questionnaire were distributed in a workshop.[97]

The online questionnaire was available from October 2013 until April 2014 and 197 responses were received from 37 countries in this period. 93 of the responses were complete and the rest were only partially complete and were deemed not usable, as participants had left the questionnaire after answering question 1. The results are discussed further in the following sections.

7.3.1 Participant Information

A wide variety of users from different disciplines around the world responded to the questionnaire. Figure 7.2 illustrates geographical distribution of the participants and table 7.3 presents the work environment of participants.

Figure 7.2: Geographical distribution of participants.

[94] au.linkedin.com
[95] www.gdmc.nl/3DCadastres
[96] csdila.unimelb.edu.au/projects/3dwebsite
[97] http://www.sssi.org.au/userfiles/event_doc1372386349.pdf, Page 4

Table 7.3: The work environment of participants.

Specialists	Number of Participants
Academia	22
Architects	5
Building developers	3
City councils	10
Land registry services	18
Land surveyors	20
Owners' corporation	5
Referral authorities	1
Software developers	4
State government	5
Total	**93**

Academia and software developers with special interest in 3D cadastre were selected as part of this study to share their knowledge and experience. Although they are not specifically cadastral users, they have valuable knowledge regarding 3D cadastre and/or visualisation concepts to support cadastral users.

People working as architects, building developers, land surveyors, professionals with city councils, land registries, and owners' corporations are direct cadastral users and they play important roles in the land development processes.

Referral authorities[98] and state government employees, involved in building and construction, participate in the land development processes. In Victoria, building permits for development over 25,000 square metres are issued by the state government.

The number of referral authorities who completed the questionnaire was very low; consequently the requirements of this specific group of users can not be validated.

Participants were requested to report their level of experience in land and property information and, as figure 7.3 illustrates, more than 58% of participants had more than 10 years experience in this field.

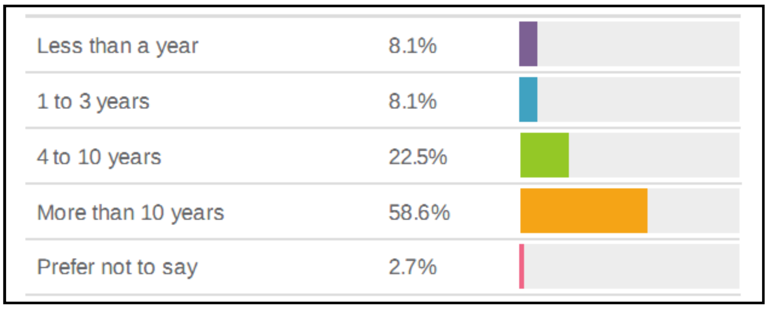


Figure 7.3: The level of experience of participants in land and property information.

[98] An authority or government department to which a planning permit must be referred for advice before it is granted. The Law Handbook, http://www.lawhandbook.org.au/handbook/go01.php

7.3.2 Organisational Spatial Data Characteristics

Participants were coming from different organisations and the activities of these organisations regarding land and property information are shown in figure 7.4. Respondent could choose multiple options.

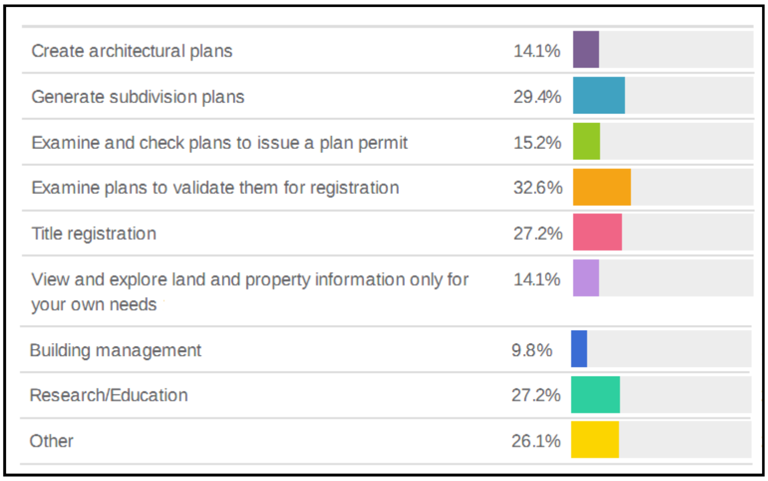


Figure 7.4: Participants' activities regarding land and property ownership information. 'Other' includes various types of activities associated with land and property information, e.g. policy and regulation, property assessment, tax, software training, and land development.

Participants were asked which media suited their tasks and more than 63% selected '3D models on computer screens with all details in 3D'. Figure 7.5 shows the other alternatives and selection percentages. Respondents could choose multiple options.

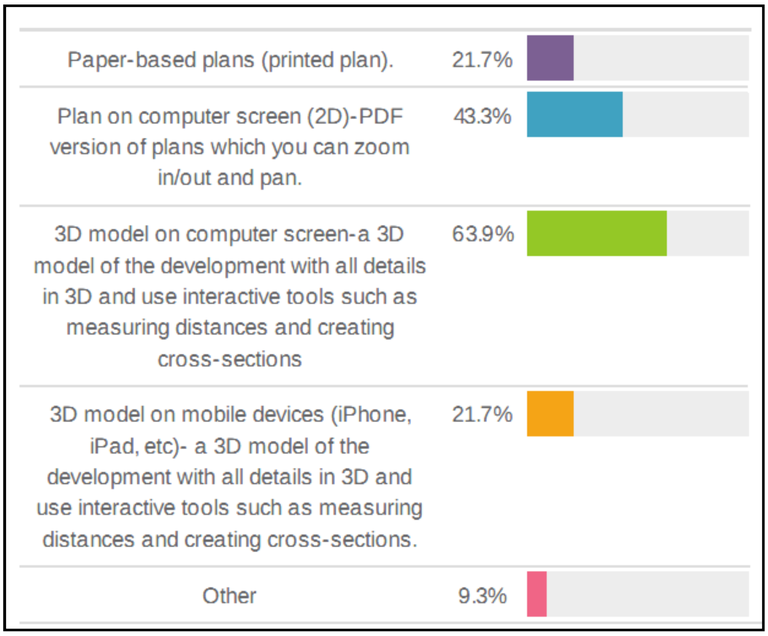


Figure 7.5: Preferred visualisation media suited for participants tasks.

Those who responded as 'Other' mentioned 2D GIS systems, 3D prints, augmented reality, and 2D CAD files. Some participants provided the following comments:

- *"We use various media tools depending on the application/purpose of the task";*
- *"A printed plan is usually most appropriate for a legal document. Computer stored versions greatly assist in the accessibility of the information. A single tier title has no need for a complex visualisation media. Conversely, a complex land holding with multiple tiers, rights of access and encumbrances can benefit from elevation plans. Introducing 3D modelling which can then be leveraged into alternative media (including mobile devices) is an asset when interacting with clients, governments and fellow professionals on the intent and purpose on modifying the land title or purpose. The 'tasks' performed vary in such a great extent of purpose that a single media type is impractical and self-limiting".*

The next question was about the challenges and issues associated with visualising 3D models for land and property ownership information (figure 7.6). Respondents could choose multiple options.

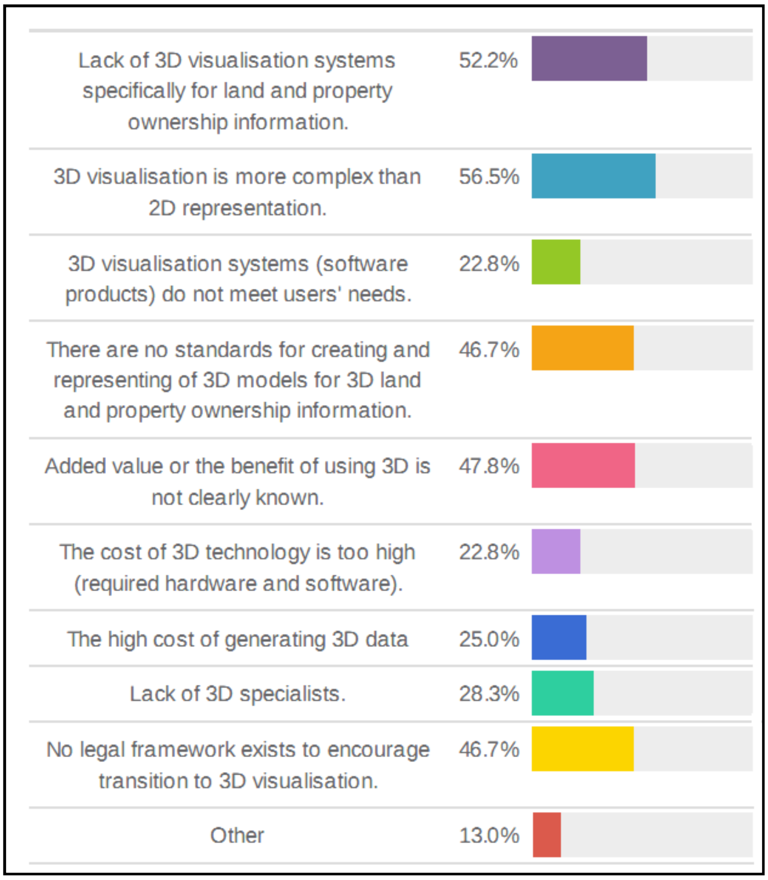


Figure 7.6: Challenges and issues associated with visualising 3D models for land and property information.

According to figure 7.6, the participants mainly highlighted that the main issues are complexity in 3D visualisation and lack of 3D visualisation applications specifically for land

and property ownership information. In addition, participants mentioned the following challenges:

- "*A problem concerning 3D visualisation of complex objects is that no system supports interaction with objects on their different aggregation levels. For example, a click on a building could mean the selection of the entire building (and its properties), a selection of the building part, or just the specific wall object. Appropriate interaction possibilities are missing so far*";
- *"Lack of access to surveying data in 3D";*
- *"[These] challenges and issues actually exist. The most important one I believe is that the added value is not clear".*

The next question investigated the drivers and motivations for an organisation to move from their current representation approach to a 3D digital representation for land and property ownership information. Figure 7.7 represents the ideas (multiple selections) from participants.

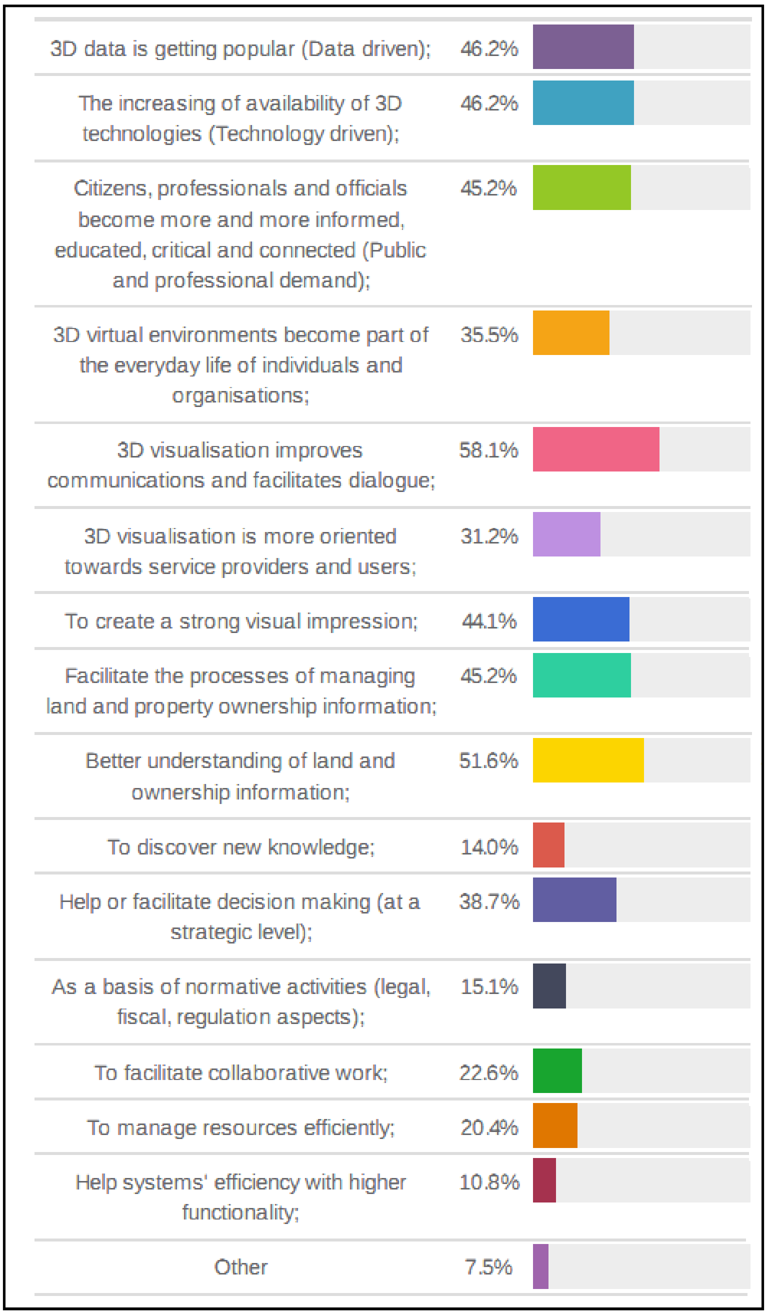


Figure 7.7: Drivers and motivations for an organisation to move from current representation approach to a 3D digital representation for land and property ownership information.

According to figure 7.7, participants highlighted that 3D visualisation improves communications and facilitates dialogue. In addition to these drivers, some of them mentioned the following advantages:

- *"Examining and registering the plans would be much easier";*
- *"Better legal certainty through 3D documentation and visualisation";*
- *"3D is natural for non-specialists";*

These answers provided organisational data characteristics, the current drivers, and challenges to implement 3D land and property information systems. The validation of 3D cadastral visualisation requirements is discussed further in the next section.

7.3.3 Three-Dimensional Cadastral Visualisation Requirements Validation

In this section the results from each survey question are presented. Likert scales (5 levels[99]) were used in the questionnaire and participants reviewed the requirements and gave their strength of agreement with each requirement. Although the scale is ordinal, it is frequently accepted (Jaccard and Wan, 1996) that responses can be analysed as interval data. The average of the Likert scales was computed for each type of users to validate each requirement. Scores represent the importance of each requirement for users.

This section has five parts: data requirements, user interface and system requirements, technical requirements, visualisation requirements, and analytical requirements.

7.3.3.1 Data Requirements

This section reports the survey results (table 7.4) supporting validation of data requirements for representing land and property information.

[99] Strongly agree (5), agree (4), neutral (3), disagree (2), and strongly disagree (1).

Table 7.4: The average computed for each requirement and type of users.

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government
5.2.1.1 5.2.1.2 5.2.1.3 5.2.1.4 5.2.1.5 5.2.1.6 5.2.1.7	***Parcel*** ***Lot*** ***Common property*** ***Roads*** ***Easements*** ***Restrictions*** ***Crown land***	4.41	4.50	4.33	4.30	4.83	4.35	4.60	5.00	4.50	4.60
5.2.1.8	***Depth and height limitations***	4.18	3.50	4.33	3.78	4.61	4.25	4.40	5.00	4.25	3.20
5.2.1.9	***Survey marks***	4.05	3.75	4.33	3.56	4.67	4.11	4.00	5.00	4.67	3.20
5.2.1.10	***Administrative boundary***	4.14	4.00	4.33	4.10	4.44	3.90	4.40	5.00	4.50	4.00
5.2.2.1	***3D building models***	4.05	4.60	4.67	4.67	4.41	4.37	4.60	4.00	4.33	4.20
5.2.2.2	***Digital Terrain Model***	4.35	4.75	4.33	4.56	4.13	4.20	4.50	5.00	5.00	3.80
5.2.2.4	***Building utilities***	3.59	4.20	4.00	4.22	3.27	3.90	4.00	3.00	3.33	2.80
5.2.2.5	***Urban utility networks***	4.09	4.20	3.67	4.56	3.79	4.05	4.40	4.00	4.00	2.80
5.2.2.6	***Building facades***	3.90	4.40	4.67	4.13	4.00	3.67	4.00	3.00	4.25	4.67
5.2.2.8	***City structures***	4.33	4.40	4.00	4.40	3.82	4.05	4.60	5.00	5.00	3.40
5.2.3.1	***Aerial and satellite images***	3.86	4.00	4.33	4.40	4.12	4.11	4.20	5.00	4.75	4.20
5.2.3.2	***Attributes***	4.23	3.75	4.33	4.50	4.72	4.37	4.40	5.00	4.67	4.40
5.2.3.3	***Surveying report***	3.90	3.60	3.67	4.00	4.47	4.06	4.20	5.00	4.33	4.00
5.2.4	***Planning schemes***	4.05	4.00	3.67	4.33	3.81	4.10	4.40	5.00	4.67	4.00

Table 7.4 includes validation of legal data, physical data and administrative information. Users reviewed the data requirements and responded with their agreement with each item The average scores were then calculated for each type of user.

Based on table 7.4, most of the data requirements were chosen by participants as important for 3D cadastres. Participants from State Government returned 2.80 for the importance of building utilities and urban utility networks as they believe that these networks are not important data requirements for their purposes, as they do not need internal data on buildings. They also do not consider urban utility networks for decision making.

The required levels of detail may be different for various types of user. For example, the required details of building utilities are different for land surveyors and building managers. Building managers look at the details for management purposes, however, land surveyors look mainly at the location of the features.

7.3.3.2 User Interface and System Requirements

This section represents the results of survey (table 7.5) to validate user interface and system requirements for representing land and property information.

Table 7.5: The average computed for each requirement and type of users.

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government
5.3.3	***Represent PDF Plans (Subdivision Plans)***	4.27	3.80	4.33	4.13	4.65	4.26	4.20	5.00	4.33	4.20
5.3.3	***Represent PDF Plans (Architectural Plans (e.g. floor plans and cross-sections))***	3.48	4.40	4.33	3.90	3.63	3.63	3.80	-	4.25	2.60
5.3.4	***Import/export 3D models***	4.45	4.60	4.67	4.00	4.53	4.44	4.60	5.00	4.67	4.75
5.3.5	***Mark-up tools***	4.05	4.00	4.33	4.13	4.17	4.05	4.20	4.00	4.25	4.00
5.3.6	***Cartography tools***	3.95	4.50	4.67	4.22	4.44	4.17	4.00	5.00	4.33	3.67
5.3.10	***Layer control***	4.32	4.60	4.67	4.67	4.89	4.74	4.60	5.00	4.50	5.00
5.3.11	***Object control***	4.32	4.60	4.67	4.33	4.61	4.68	4.40	5.00	4.50	4.75
5.3.12	***Identify tool***	4.50	4.60	4.67	4.33	4.78	4.68	4.60	5.00	4.50	5.00
5.3.13	***Manipulation tools***	4.20	4.00	4.33	3.44	4.28	4.06	3.75	5.00	4.25	3.75
5.3.14	***Support various coordinate systems and datums***	4.59	4.25	4.67	4.56	4.83	4.63	4.50	5.00	4.75	4.75
5.3.15	***User profiling***	3.81	4.20	4.67	3.78	4.06	4.05	4.00	5.00	4.33	3.75
5.3.16	***Select objects***	4.27	4.40	4.67	4.44	4.44	4.53	4.40	5.00	4.50	4.75
5.3.17	***Keyboard shortcuts***	3.53	4.40	4.67	3.89	4.11	3.63	3.20	4.00	4.25	3.75

The results show that the subdivision plans are very important for almost all users, as these plans address the ownership boundaries. However, architectural plans (3.80) have a lower importance for most users as they only represent the physical objects. Therefore, the ability to represent PDF plans is very important for all users.

Some of the requirements in table 7.5 are obvious requirements (e.g. layer control, object control, identify tool, and select objects) and all users considered them important requirements. The users returned more than 4.00 for these three requirements.

Based on the comments, some specific user types need to create and update data. Therefore, manipulation tools must be available for these users specifically and the visualisation application must restrict editing of data for other types of users (view-only). However, temporary manipulation tools are useful, for example sliding out one floor of a building to look more closely at it.

7.3.3.3 Technical Requirements (non-functional requirements)

Non-functional requirements define the overall quality of an application and how it must operate. Some non-functional requirements were validated by participants as non-functional requirements are important for most applications and must be considered in design and development phases (table 7.6). The type of questions for the first 3 questions (5.4.10) was not based on the Likert scale (See Appendix 2). Therefore, the answers were averaged based on their agreement with these requirements and presented by percentage.

Table 7.6: The average computed for each requirement and type of users.

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government
5.4.10	***Web-enabled***	72%	40%	100%	70%	83%	65%	100%	0%	100%	60%
5.4.10	***Mobile capability***	50%	20%	100%	50%	56%	50%	60%	0%	100%	60%
5.4.10	***Desktop-based applications***	73%	80%	100%	70%	78%	70%	80%	100%	100%	60%
5.4.10	***Open-source***	3.95	4.00	4.00	3.13	3.44	3.61	3.50	2.00	3.33	3.00

Table 7.6 confirms that architects (72%) are more interested in desktop applications which bring more efficiency in their tasks, as they mainly create and update data. Therefore, desktop

based applications can provide them with more flexibility in their involved tasks. However, land registry (83%) would like to have web-based applications for their purposes as it makes it easier for them to communicate with customers and stakeholders.

Building developers (100%) would like to have all three types of applications as they are involved in the process of development and would like to have access to data in various locations (e.g. in the field and office). They also would like to share data with others, which is mainly feasible using web-base applications. Therefore, they have selected all three approaches.

Accordingly, the results show that different media suit different jobs based on the application/purpose of the tasks and a single media type may limit the capabilities.

Open-source applications are getting popular as these applications are being developed and extended widely to support various needs. However, there are still limitations in terms of capability and support, and limiting users to only open-source or proprietary products is not recommended.

7.3.3.4 Visualisation Requirements

This section looks at the validation of visualisation requirements for representing land and property information (table 7.7).

Table 7.7: The average computed for each requirement and type of users.

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government
5.5.1.2	***City view***	4.14	4.60	4.33	4.50	4.39	4.26	4.40	4.00	5.00	4.25
5.5.1.3	***Model view***	4.10	4.00	4.33	4.75	4.33	4.05	4.00	4.00	4.75	4.75
5.5.1.4	***Underground view***	4.52	4.00	4.33	4.38	4.83	4.63	4.80	5.00	4.50	4.25
5.5.1.5	***Cross-section view***	4.23	4.40	4.67	4.10	4.22	4.37	4.20	5.00	4.33	3.50
5.5.1.6	***Indoor view***	3.71	4.20	4.33	4.13	4.13	4.11	4.00	-	4.50	3.00
5.5.1.7	***Multiple views***	4.05	4.40	4.33	4.25	4.22	4.21	4.00	4.00	4.00	3.75
5.5.1.9	***Wireframe view***	3.80	4.40	4.33	4.00	3.82	4.06	3.20	4.00	4.00	2.75
5.5.1.11	***Explode view***	3.52	4.20	4.33	3.00	3.83	3.39	3.40	-	3.50	3.25
5.5.1.13	***Street view***	3.38	4.00	4.00	4.14	3.72	3.67	3.40	4.00	3.33	3.25
5.5.2	***Labels***	4.10	4.25	4.67	4.29	4.44	4.16	4.20	5.00	4.25	4.00
5.5.4.2 5.5.4.3 5.5.4.4	***Symbology*** ***Colour, thickness and line-style*** ***Transparency***	4.19	4.40	4.67	4.00	4.47	4.26	3.60	5.00	4.25	4.00
5.5.5	***Day and night view***	3.28	4.60	4.33	4.14	3.18	2.84	3.60	3.00	4.50	3.25
5.5.5	***Stereo view***	3.50	3.80	4.33	2.86	3.59	3.21	4.00	4.00	4.00	3.00
5.5.5	***Special effects***	3.60	4.20	4.33	4.43	2.92	2.94	3.40	3.00	4.75	4.00

Table 7.7 presents the importance of visualisation requirements for various types of users. The first part of this table presents the importance of various views for users. Different users gave different scores to these views based on their needs. For example, users from state government gave low scores to the indoor view (3.00), as they do not pay attention to the internal structure of buildings. However, the indoor view is important for other types of users, such as land registry and building developers. State government participants believe that the wireframe view (2.75) is not important for them as they expect detailed and textured 3D

models for their tasks. Labels and visual variables are almost important (more than 4.00) for all users as these features help the clarity of information. The rest of this table looks at some of the features which are not significantly important for all types of users. For example, land surveyors think that day and night view (2.84), and special effects (2.94) are not very helpful for their involved tasks as they are mostly involved in creating and preparing data for other users.

7.3.3.5 Analytical Requirements

This section looks at the validation of analytical requirements in working with land and property information (table 7.8).

Table 7.8: The average computed for each requirement and type of users.

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government
5.6.1	***Ensure spatial validity***	4.05	3.75	4.67	4.00	4.67	4.21	3.50	4.00	4.33	4.75
5.6.2	***Search methods***	4.36	4.40	4.67	4.80	4.72	4.70	4.60	5.00	4.75	4.50
5.6.3	***Spatial measurement tools***	4.36	4.20	4.67	4.10	4.33	4.00	4.40	4.00	4.75	4.75
5.6.4.2	***3D buffer***	4.14	4.25	4.33	4.00	4.28	4.26	4.20	5.00	4.33	4.25
5.6.5	***Visualisation of results of functions and queries***	4.38	4.00	4.33	4.13	4.33	4.05	4.20	4.00	4.50	4.00
5.6.6	***Augmented reality***	3.60	4.20	4.67	3.70	3.75	3.72	3.60	4.00	3.75	4.33
5.6.7	***Temporal modelling***	4.18	4.00	4.67	4.33	4.29	4.16	4.00	4.00	4.33	4.00
5.6.8	***Logical consistency***	4.14	4.00	4.67	4.20	4.56	4.30	4.20	4.00	4.50	4.50
5.6.9	***Shadow and Shadow analysis***	4.05	4.60	4.33	4.86	3.38	3.25	3.40	3.00	4.67	4.33
5.6.9	***Line of sight and visibility analysis***	3.95	4.40	4.67	4.30	3.11	3.64	3.60	5.00	4.50	4.00
5.6.9	***Vertical exaggeration***	3.95	3.75	4.33	3.40	4.00	3.72	3.75	3.00	3.25	3.75

Based on table 7.8, the analytical requirements were scored by participants to show their importance for different users. In some cases (such as examining spatial validity and logical consistency) the underlying data management application should provide these functionalities and not the visualisation application. Some of the requirements, such as search methods and measurement tools are important (more than 4.00) for all users.

Based on the comments, some of the requirements (such as logical consistency, augmented reality, and temporal modelling) were identified as important, but these requirements will be needed in the future. Although, shadow and shadow analysis, line of sight and visibility analysis, and vertical exaggeration are important for some specific users, these are considered as recommendation as these are not significant requirements for cadastral purposes.

7.3.4 Summary of the Requirements Validation Using the First Questionnaire

In this part, the First Questionnaire was designed and distributed among cadastral users to receive their feedback to validate the requirements. Some identified requirement from chapter 5 was validated by participants through the survey by giving their level of agreement with the proposed requirements.

Based on the feedback, most participants felt that it was not appropriate to attempt to include all these features in a single application. However, this questionnaire was only designed to validate the requirements and not to implement a visualisation application.

Some participants highlighted that there will always be a need for some 2D visualisation to represent legal and physical objects.

They also mentioned the challenges to prepare the required data for 3D cadastres which is outside the scope of this research.

Building subdivision plans in Victoria do not contain survey measurements including height information. The availability of height information in 3D models is not uniform over all areas. In addition, conflict with ellipsoidal height and orthometric heights and level of accuracy exist.

Furthermore, sometimes 3D models are not accurate to describe "as-built" environments. Therefore, a final checking and updating of the designed models with the as-built environment is required to verify the consistency of the 3D models created.

The aim in this research was collecting all related 3D cadastral visualisation requirements, however, some of the above requirements are not pure 3D cadastral visualisation requirements; they support further analysis on 3D models for various users.

Some of these requirements were implemented in the second prototype which was discussed in chapter 6. The next section addresses an evaluation of this prototype.

7.4 Validation Requirements Using the Web-based 3D Cadastral Visualisation Prototype

The prototyping approach was used to validate some of the identified requirements. The second prototype (the Web-based 3D Cadastral Visualisation Prototype- section 6.3) was developed and then evaluated in terms of functionality, usability and efficiency. Similarly to the evaluation of the first prototype, four steps were conducted to complete the evaluation process.

7.4.1 Choosing Prototype Testers

A group of 51 professional users - who are intimately involved in the processes of development of high-rise buildings, were selected for this assessment. They were asked to participate in the prototype evaluation sessions and fill in a survey (see Appendix 3) at the end. 42 of them responded and were invited to six demonstration sessions to see the prototype and evaluate it. All participants were from Victoria, Australia, as the case study is in this state and legislation and regulations in Victoria are different from other states in Australia. A summary of the participants in the evaluation phase is presented in table 7.9.

Table 7.9: The list of participants and their expertise in the evaluation of the prototype.

Specialists	Number of Participants
Land surveyors	13
Land registrars	10
City managers (local councils)	8
Building managers and owners' corporation	11
Total	**42**

7.4.2 Developing Test Scenario

A scenario was designed to facilitate evaluation of the prototype. The scenario was designed to comparing the usability, functionality and efficiency of an existing subdivision plan with the prototype. The System Usability Scale (SUS) method (Brooke, 1996) was chosen for usability evaluation.

The on-line questionnaire (table 7.10) included 37 statements and questions to evaluate the functionality, usability and efficiency of the prototype.

Table 7.10: Questions for evaluating the prototype in the questionnaire.

Category	Question No.	Question
	1	Name of your Organisation and Division/Unit
	2	Your position in your organisation
System functionality	3	I found this 3D visualisation prototype more useful than 2D plans (e.g. architectural plans, subdivision plans, etc) for understanding ownership boundaries.
	4	Integration of physical (walls, doors, ceilings, and floors) and legal objects (lots, easements, common property) in the 3D visualisation prototype facilitates understanding of ownership boundaries.
	5	What do you see as the advantages of integrating legal and physical objects against only representing legal objects?
	6	Visualising some physical building components such as slabs and walls which are considered as common property (shared areas) may increase the complexity of a 3D model; therefore a simpler model without them, is preferred.
	7	Utilising such 3D web-based visualisation prototypes will improve communication of 3D cadastral data among various users.
	8	Utilising such prototypes will improve managing of ownership rights.
	9	Does the 3D visualisation system meet your needs?
	10	If your answer to the previous question was 'No', what other functionalities would you recommend and why?
	11	The 3D presentation of property information is effective in helping me complete my tasks.
	12	How satisfied are you with this prototype as a way of presenting 3D property information (e.g. underground lots) and the available functions? Please include any comments regarding your level of satisfaction.
	13	I believe I quickly became more productive when using this prototype.
	14	I can see that this prototype would potentially contribute to improving productivity in my daily tasks.
	15	I would like to see this 3D visualisation prototype implemented for decision making processes in my organisation.

	16	A web-based visualisation application is more effective than a desktop-based application in my tasks.
	17	Not needing to install a plug-in is beneficial from a security and convenience point of view.
	18	Please list the perceived negative aspects of the 3D visualisation system
	19	Please list the perceived positive aspects of the 3D visualisation system
	20	Please give us at least one good idea to improve the functionality of the 3D visualisation system.
	21	Please give us at least one good idea to improve representation of ownership information in this system.
System usability	22	I feel comfortable using this prototype.
	23	The prototype is user friendly.
	24	The information (such as subdivision plans, on-screen messages, and other documentation) provided with this prototype is clear.
	25	It is easy to find the information I need.
	26	The functions in this prototype are well positioned in the interface.
	27	I like the interface of this prototype.
	28	Please give us at least one suggestion to improve the interface?
	29	I need the support of a technical person to be able to use this prototype.
System efficiency	30	You have been given a subdivision plan of a high-rise building. In this case, how much time did you take to identify the ownership boundaries of an apartment (e.g. Unit 514)?
	31	Also, in this case, how much time did you take to identify the associated common property attached to this apartment (e.g. Unit 514) using the subdivision plans?
	32	In addition, in this case, how much time did you take to identify the associated parking lot attached to this apartment (e.g. Unit 514) using the subdivision plans?
	33	Now, you already have the 3D model of this high-rise building in this 3D visualisation system. In this case, how much time do you approximately spend to identify the ownership boundaries of the apartment (Unit 514)?
	34	Also, in this case, how much time did you take to identify the associated common property attached to this apartment (Unit 514) using this prototype system?
	35	In addition, in this case, how much time did you take to identify the associated parking lot attached to this apartment (Unit 514) using this prototype system?
	36	Using an application like this 3D visualisation prototype will result in saving time for understanding ownership rights and associated information in my organisation.
	37	Using an application like this 3D visualisation prototype may result in cost savings for my organisation.

7.4.3 Executing Test Scenario

At each meeting, the subdivision plan of the second mini case-study (ILK Building on Toorak Road) was provided to participants, and they were asked to read and understand the legal objects and ownership boundaries (approximately 5 minutes). After that, the participants were asked to find “Unit 514” on the subdivision plan and associated rights attached to this unit such as common properties, car parks, and storages. The time for this activity was recorded for each participant. Then, the mini case-study was presented in the prototype (5 minutes). Later, the interactive capabilities such as search, identify, cross-section, measurements and navigation were presented (10 minutes). Finally, they were asked to fill in the online questionnaire.

7.4.4 Documenting Results

This section reviews the participants’ answers to the questions.

The first two questions were asking about the name of organisations and the position of participants. These two questions helped to identify the type of participants. Table 7.9 illustrates the type of participants in the evaluation of the prototype.

In some of the statements and questions in this questionnaire, the respondents were asked to record their agreement with the statements on a five-point scale (Likert Scale) ranging from strongly disagree (1) to strongly agree (5). The average of scores for each question was used for requirement analysis. Table 7.11 presents the results of the questionnaire, including the results from each category of users. Due to the variety of users in the evaluation process, the results for each group are presented separately.

Table 7.11: Analysis of the responses.

Question No.	Discussion	Land Surveyors	Building Managers and owners' corporation	Land Registrars	City Managers (Council)	Overall Average
3	It seems that city managers and land registrars still prefer to work with paper-based plans. The reason is they are comfortable with interpreting ownership boundaries in subdivision plans. However, the majority believe that 3D visualisation is very effective to people who have little or no experience in interpreting subdivision plans.	4.4	4.8	3.5	3.9	4.2
4	All the groups preferred integration of physical and legal objects as it facilitates interpreting of ownership boundaries. One comment emphasised the importance of accuracy of as-built to rely on defining ownership boundaries.	4.6	4.3	4.0	4.3	4.3
6	Very few people felt that they preferred a simpler model without shared areas and from legal perspective they believe that the 3D model should represent the real world with all required details. As with 2D plans, showing common property in its entirety would be incredibly difficult. Showing only non-structure common properties (corridors, stairs) however might be an advantage.	2.5	2.4	2.3	2.4	2.4
7	They would like to have a 3D web-based visualisation application. However, there was a comment regarding the limitations of web-based applications for visualising large scale models.	4.0	4.3	4.0	4.3	4.1
8	Building managers and owners' corporation were mainly agreed with this. However, land registrars and city managers were concerns about the accuracy of the 3D model.	4.0	4.6	3.5	3.3	3.9
11	They mainly confirmed that this prototype can help them in their tasks. However, still this prototype cannot completely replace 2D plans.	3.8	4.5	3.2	3.7	3.8
12	The participants were mostly satisfied with this prototype as it integrates technical resources and information from various sources into a useful visual application.	4.2	4.4	3.8	3.9	4.1
13	City managers and land registrars discussed the prototype should be used on a regular basis to evaluate the productivity.	4.4	4.4	2.9	2.8	3.5
14	They accepted that this prototype would potentially contribute to improving productivity.	3.9	4.0	3.3	3.8	3.8
15	Most of the participants agreed to have this prototype implemented in their organisations. However, land registrars believe they do not have a decision making task as they operate under Acts.	4.2	4.4	3.0	3.4	3.8
16	In some tasks, such as data creation and updating, desktop based applications are more efficient particularly in a large scale. However, accessibility, sharing and reliability are potential advantages.	3.9	4.4	3.7	3.4	3.9
17	They agreed the benefits of plug-ins free applications.	4.0	4.1	3.8	4.1	4.0
22	They feel comfortable with the prototype.	3.7	4.3	3.1	3.7	3.8
23	Nearly all approved this prototype as a user friendly application.	3.8	4.6	3.6	3.6	3.9
24	The information attached to the prototype was clear to understand.	3.6	4.4	3.4	3.7	3.8
25	They found this prototype very easy to use.	3.8	4.2	3.7	3.3	3.8

26	Most of the participants were happy with the current design.	3.6	4.1	3.6	3.0	3.6
27	Most of the participants liked the interface. However, there is room for improvement.	3.7	4.1	3.6	3.3	3.7
29	Very few respondents felt that they needed the support of a technical person to be able to use this prototype (the rates are showing their disagreement with the statement).	2.7	2.8	2.8	2.7	2.8
36	Nearly all accepted using this prototype will result in saving time for understanding ownership rights.	4.1	4.7	3.6	3.7	4.1
37	Most of the participants accepted using this prototype will result in saving cost for understanding ownership rights. However, city managers believe that the high start up costs may make it hard for organisations to implement and use this system.	4.0	4.3	3.4	2.9	3.8

Table 7.12 presents the responses to the other questions in the questionnaire. The responses and comments received from the participants help identify the challenges and opportunities in the prototype. Based on the answers to question 5, integrating physical and legal objects was considered helpful as it brings context to legal objects which makes them easier to interpret. Question 9 and 10 were helpful as the participants could mention their needs which were not satisfied by the prototype.

Table 7.12: Analysis of the responses.

Question No.	**Discussion/Comments**
5	• Visualising physical objects provide greater context to the legal objects as physical objects are closer to reality. It also provides a relationship between physical and legal objects.
9 and 10	• Scalability of the prototype is important to meet business needs and manage large data sources. • Need to be able to turn off entire levels and inspect other levels more closely.
18	• Navigation needs more enhancement; • It would be hard to apply this to a large scale area; • The cross section functionality needs improvement; • Terminology is important to understand the context; • The time and cost required for data preparation may outweigh the benefits; • The interface needs improvement (e.g. designing a menu bar); • Export function is required;
19	These are some of the comments from the participants: • Realistic visualisation of highly conceptual information; • Enables lots to be viewed relative to other lots and common property; • A real time building management tool; • It is a representation of the real world whilst traditional plans and documents are an abstraction; • It accurately conveys ownership and structural information to the user in a logical and aesthetically pleasing manner; • The system minimises the need for going through the paper plans and I believe that this is the main positive achievement of the system; • The system will potentially facilitate the examination and registration of building subdivisions; • Integrating cadastral information with BIM; • A 3D model would be greatly beneficial to those that are looking to invest or own a property and unsure of their entitlement/rights in regards to common property and lot ownership; • Web-based, so easy distribution;
20	• Optimise for large and complex buildings (in terms of loading them on the web); • Improving the user interface; • Having the relationship between the physical and legal objects in the system would help much. In fact, when you query on a lot, its relevant physical objects need to be highlighted in the system as well; • An automated fly by after searching a lot;
21	• It might be useful to include a feature that makes each part stand out more so they can be quickly found without rotating the model and making layers invisible. Perhaps all other lots become semi-transparent; • Include functionality to produce reports directly from model; • The ability to produce 3D PDF's for any given lot; • If you click on a unit associated car parks are also shown; • Eventually include as much information as possible. For example, each owner or manager could have a username and password to access the system which would then give a person who lives there and the area and any other information that may be useful for managing an organisation;

28	• Move all functionality and tools to bars on one side of the top of the interface; • Split screen view - 2D and 3D; • Having a Help Page for users would be helpful; • Larger text to make it more legible, consideration of screen size should be incorporated for user interaction; • More key-in searching and filtering for lot and ownership information;
30	On average it took 3 minutes for this test scenario.
31	On average it took 5 minutes for this test scenario.
32	On average it took 4 minutes for this test scenario.
33	A few seconds
34	Apparent at first glance
35	A few seconds

Base on table 7.12, responses to Questions 19, 20, and 21 brought some positive aspects about the prototype and some suggestions for further development. Question 28 is about interface improvement, and some improvements were suggested by users. Comparing the responses to Questions 30, 31, 32 and 33, 34, 35 shows the effectiveness of the prototype for cadastral purposes. Further requirements are also evident in the comments for further improvements. The following sections review the results of prototype evaluation.

7.4.4.1 System Functionality of the Second Prototype

The first set of opinion questions (questions 3 to 21) were about the functionality of the developed prototype.

The participants were asked to describe their ideas about using the prototype to understand ownership rights, restrictions and responsibilities. Participants gave their feedback by giving scores to each statement and leaving their comments. These are presented in tables 7.11 and 7.12.

In question 3, land surveyors, building managers and owners' corporation prefer 3D visualisation of ownership rights rather than working with 2D paper-based plans. However, land registry and city managers would like to keep their current 2D approaches, which are mainly based on their existing processes. In question 4 and 5, most participants responded that the integration of physical and legal objects would facilitate understanding of RRRs, as visualising physical objects provide greater context to the legal objects.

Question 6 looks at the importance of visualising all legal objects which may cause more complexity in visualisation. In cadastres, all spaces are partitioned as RRRs and recorded. However, representing a large number of RRRs causes complexity and requires an efficient approach to reduce confusion.

Based on question 7, most users would like to have web-based visualisation applications to view 3D models. However, according to question 16, most users believe that desktop applications are required for their tasks. This means that different media are suitable for different tasks, and selecting just one single approach may cause limitations for users.

In questions 8 to 15, participants were asked about their ideas about the effectiveness of the prototype for their tasks. Based on the responses, it is concluded that owners' corporations and building managers would benefit significantly from this prototype. In addition, land surveyors also benefit from the capabilities of this prototype. However, it seems land registry and city councils are concerned about the implications of changing their current processes and replacing their 2D plans with 3D models.

7.4.4.2 System Usability

The next part of the survey (questions 22-29) assessed the usability of the prototype. Each item's score contribution ranged from 0 to 4. The sum of all items is multiplied by 2.5 to obtain the overall value of SU. The scoring of the SUS ranges from 0 to 100. It is important to consider the positiveness and negativeness of each item. For example, the result of the positive questions is the selected score minus 1 and the score of negative questions is 5 minus the scale position (Brooke, 1996).

A customised version of the System Usability Scale (SUS) was designed to evaluate the usability of the prototype. The SUS scores depend on six customised statements (statements 22, 23, 24, 25, 26 and 29 in table 7.10), multiplied by 4.16 for evaluating the usability of this prototype.

Although the number generated by SUS is useful to compare alternatives, interpreting the numerical score is also required. A rule was developed by Bangor *et al.*(2008) to judge the SUS scores based on the typical grading scale used in most schools. According to figure 7.8, an adjective rating scale was proposed including the 'Worst imaginable', 'Poor', 'OK', 'Good', 'Excellent', and 'Best imaginable' ratings, based on the SUS score. In addition, Acceptability Ranges were defined as 'Not acceptable', 'Low marginal', 'High marginal', and 'Acceptable' to present the acceptability of a product based on the SUS score.

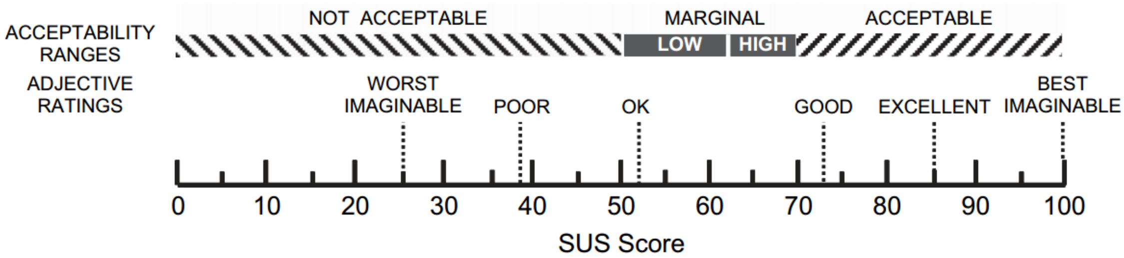


Figure 7.8: A comparison of System Usability Scale (SUS) scores by adjective ratings and acceptability ranges of the SUS score (Bangor *et al.*, 2008).

The SUS scores of the prototype for each type of user are presented in table 7.13.

Table 7.13: System Usability Scale.

Users	Score (100)	Ratings	Acceptability Range
Land Surveyors	65.728	OK and Good	High Marginal
Building Managers and owners' corporation	78.208	Good and Excellent	Acceptable
Land Registrars	60.736	OK and Good	Low Marginal
City Managers (Council)	60.736	OK and Good	Low Marginal
Overall average	66.976	OK and Good	High Marginal

Based on the rule-of-thumb standard, the SUS scores of this prototype are between 'OK' and 'Excellent' ratings. In terms of the acceptability range, the scores of land surveyors, land registrars and city managers are located in 'High' and 'Low marginal'. This means that the prototype needs enhancement and improvement in terms of usability for these specific users to pass at least the SUS score of 70. Scores above 70 are located in the 'Acceptable' range.

On the other hand, the acceptability range of building managers and owners' corporations is in the 'Acceptable' range, which means the prototype has an acceptable level of usability for them.

After evaluating the system usability, the next section describes the system efficiency of the prototype.

7.4.4.3 System Efficiency

This section evaluates the efficiency of the prototype against the existing approaches for representing land and property information.

According to the executive scenario (section 7.4.3), the participants were asked to evaluate the time and cost efficiency of the prototype. As illustrated in table 7.12 (Questions 30 to 35), the participants acknowledged that the prototype could save time for the defined task.

In addition to the time saved, the participants were asked to share their general opinion regarding the role that the prototype system could play in improving the efficiency, in terms of cost, of visualising ownership rights.

According to table 7.11 (Question 37), the participants had different ideas regarding the cost saving of the prototype. The answers reflect the perceived efficiency of the prototype for their daily task, as well as the initial cost of creating and maintaining such a system. For example, city managers believe that the high start-up costs may make it hard for organisations to implement and use this system. Therefore, a cost benefit analysis is required to analyse the effectiveness of replacing the existing approaches (2D paper-based) with 3D visualisation.

Overall, it was considered that the prototype could improve the efficiency of representing land and property information.

7.4.5 Summary of the Requirements Validation Using the Second Prototype

The prototype was evaluated against functionality, usability and efficiency by different types of users and feedback was received through an on-line questionnaire. Implementing this prototype resulted in several requirements and recommendations, which were included in chapter 5. The results from this prototype evaluation helped verify the previous results.

Based on the results, the prototype could satisfy most building managers and owners' corporation officers. Other potential users who are involved in land development processes, such as developers, architects and lawyers, should be included in future analysis. The overall feedback was positive and comments can be a stimulus for future work.

7.5 Requirements Prioritisation

In this section, the results of the above-mentioned requirement validations (7.2, 7.3, and 7.4) are integrated to prioritise the identified requirements. The integration of results is mainly based on the first questionnaire and is supported by two other approaches (7.2 and 7.4).

The raw agreement scores from the first questionnaire were averaged for each user group and these averages were used to prioritise the requirement using MoSCoW designations (IIBA, 2009), which are very effective in documenting user requirements (Kibria, 2008).

The MoSCoW analysis divides requirements into four categories:

- Must: requirements that must be available on the end product;
- Should: high-priority items that should be in the final product if possible;
- Could: requirements which are not necessary but desirable. These will be included if time and resources allow;
- Won't: requirements that users have agreed will not be implemented in the final solution, but may be considered in future.

In this research, if a requirement scored an average of 4.0 or above by one type of user, it is considered as a "Must" requirement. It is defined as "Should" if it scored 3.0 to 4.0. If users agreed with scores from 2.0 to 3.0, it is considered as "Could" and below 2.0 is "Won't". In this section, M, S, C, and W are used for Must, Should, Could and Won't respectively.

However, in a few cases (indicated by "*"), this classification was adjusted based on other inputs such as the prototypes, interviews, placements, and meetings conducted during this research.

7.5.1.1 Prioritisation of Data Requirements

This section reports the priority of data requirements for each type of user for representing land and property information in 3D (table 7.14).

Table 7.14: The list of requirements and their priority for different user groups (M: Must, S: Should, C: Could, and W: Won't).

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government	Comment
5.2.1.1 5.2.1.2 5.2.1.3 5.2.1.4 5.2.1.5 5.2.1.6 5.2.1.7	***Parcel*** ***Lot*** ***Common property*** ***Roads*** ***Easements*** ***Restrictions*** ***Crown land***	M	M	M	M	M	M	M	M	M	M	
5.2.1.8	***Depth and height limitations***	M	S	M	S	M	M	M	M	M	S	
5.2.1.9	***Survey marks***	M	S	M	S	M	M	M	M	M	S	
5.2.1.10	***Administrative boundary***	M	M	M	M	M	S	M	M	M	M	
5.2.2.1	***3D building models***	M	M	M	M	M	M	M	M	M	M	
5.2.2.2	***Digital Terrain Model***	M	M	M	M	M	M	M	M	M	S	
5.2.2.3	***Car park***	M	M	M	M	M	M	M	M	M	M	The result of this came from the second mini case study. Car parks are a part of lots in subdivisions and must be included in the visualisation application.
5.2.2.4	***Building utilities***	S	M	M	M	S	S	M	S	S	C	As users from State Government are not interested in building utilities, this feature is not very important for them.
5.2.2.5	***Urban utility networks***	M	M	S	M	S	M	M	M	M	C	
5.2.2.6	***Building facades***	S	M	M	M	M	S	M	S	M	M	
5.2.2.7	***Underground transport routes***	M	S	S	M	M	W	W	M	M	M	The importance of this requirement was identified according to the discussion with various types of users.
5.2.2.8	***City structures***	M	M	M	M	S	M	M	M	M	S	
5.2.3.1	***Aerial and satellite images***	S	M	M	M	M	M	M	M	M	M	

5.2.3.2	***Attributes***	M	S	M	M	M	M	M	M	M	M	
5.2.3.3	***Surveying report***	S	S	S	M	M	M	M	M	M	M	Based on the comments and interviews, non-spatial dependant encumbrances, covenants and owners' corporation schedule are included here.
5.2.3.4	***Street addressing***	M	M	M	M	M	M	M	M	M	M	This requirement was identified as very important for identification of ownership rights.
5.2.4	***Planning schemes***	M	M	S	M	S	M	M	M	M	M	
5.2.4	***Building footprints***	M	M	M	M	M	M	M	M	M	M	The results of this validation came from discussions with various stakeholders. They refer to building footprints as a projection of 3D models on the ground surface.

Table 7.14 presented the prioritised data requirements based on the feedback in table 7.4 and the findings of the two prototypes. According to table 7.14, most legal objects (e.g. parcels, lots, common properties, and easements) are very important for all cadastral users. 3D building models have been identified as important for all users. 3D building models include physical objects which are integrated with other legal objects to simplify the interpretation of ownership boundaries. Building utilities and urban utility networks refer to utility services in buildings and cities respectively. For some users, these physical objects have different priorities based on their involved tasks. Street addressing as part of administrative information can help users to simply find properties based on their G-NAF[100] address. This information is identified as very important for all types of users.

7.5.1.2 Prioritisation of User Interface and System Requirements

This section looks at the priority of user interface and system requirements for each type of user for representing land and property information in 3D (table 7.15).

[100] Geocoded National Address File

Table 7.15: The list of requirements and their priority for different user groups (M: Must, S: Should, C: Could, and W: Won't).

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government	Comments
5.3.1	***Navigation tools***	M	M	M	M	M	M	M	M	M	M	This is very important for users in 3D visualisation applications.
5.3.2	***Publish 3D models***	S	M	M	S	C	C	S	W	S	S	This requirement was concluded from the first prototype and meetings with other users.
5.3.3	***Represent PDF Plans (Subdivision Plans)***	M	S	M	M	M	M	M	M	M	M	
5.3.3	***Represent PDF Plans (Architectural Plans (e.g. floor plans and cross-sections))***	S	M	M	S	S	S	S	W	M	C	
5.3.4	***Import/export 3D models***	M	M	M	M	M	M	M	M	M	M	
5.3.5	***Mark-up tools***	M	M	M	M	M	M	M	M	M	M	
5.3.6	***Cartography tools***	S	M	M	M	M	M	M	M	M	S	
5.3.7	***Support databases***	M	M	M	M	M	M	M	M	M	M	This is an obvious requirement and the visualisation application must support various databases.
5.3.8	***Support data services***	M	M	M	M	M	M	M	M	M	M	This is an obvious requirement and the visualisation application must support various data services.
5.3.9	***Print***	M	M	M	M	M	M	M	M	M	M	This is an obvious requirement and the visualisation application must support 2D print functions.
5.3.10	***Layer control***	M	M	M	M	M	M	M	M	M	M	
5.3.11	***Object control***	M	M	M	M	M	M	M	M	M	M	

5.3.12	***Identify tool***	M	M	M	M	M	M	M	M	M	M	Including the possibility to choose which aggregation level / which part of an object should be selected.
5.3.13	***Manipulation tools***	M	M	M	S	M	M	S	M	M	S	This requirement depends to the application. Some users (e.g. land surveyors and architects) create and edit data. This feature is a must for them and they may use their own applications for these tasks. However, other users only need to view the data. Therefore, this is not a feature for all users and the visualisation application should not necessarily contain the tools for updating the objects. The visualisation application can be a read-only system. Therefore, 3D data should be managed and maintained through other applications. Please note "temporary manipulation" is useful, e.g. sliding out one floor of a building to look more closely at it and do not occlude other objects.
5.3.14	***Support various coordinate systems and datums***	M	M	M	M	M	M	M	M	M	M	
5.3.15	***User profiling***	S	M	M	S	M	M	M	M	M	S	
5.3.16	***Select objects***	M	M	M	M	M	M	M	M	M	M	
5.3.17	***Keyboard shortcuts***	S	M	M	S	M	S	S	M	M	S	

Table 7.15 presented the priorities of user interface and system requirements. Navigation tools are an important feature in 3D visualisation applications, which move cameras around the scene to provide different views for users. More flexibility in moving provides easier control for users. These tools were identified as very important for all types of users. Similar to navigation tools, the visualisation application must be able to import/export various 3D formats. This feature was identified as a must for a 3D visualisation application. Layer and object control were specified as important for all users, as they enable users to show and hide various objects and layers in the scene. The identify and select object tools are important features for all users to be able to select an object and retrieve its attributes (identify).

7.5.1.3 Prioritisation of Technical Requirements (non-functional requirements)

The following requirements were prioritised by users for representing land and property information in 3D (table 7.16). The responses to the first three requirements in table 7.16 (5.4.10) are based on percentage. For these requirements, Won't, Could, Should, and Must were selected for percentages between 0 to 30, 30 to 50, 50 to 70, and above 70 respectively.

Table 7.16: The list of requirements and their priority for different user groups (M: Must, S: Should, C: Could, and W: Won't).

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government	Comments
5.4.10	***Web-enabled***	M	C	M	M	M	S	M	W	M	S	
5.4.10	***Mobile capability***	S	W	M	S	S	S	S	W	M	S	
5.4.10	***Desktop-based applications***	M	M	M	M	M	M	M	M	M	S	
5.4.10	***Open-Source***	S	S*	S*	S	S	S	S	C	S	S	* In these cases, the results from questionnaire were changed. Based on the question, participants were asked do you "prefer open-source software rather than propriety software". Most preferred open-source products. But this does not mean that users must only use open-source solutions. They can choose between open-source or proprietary products.

Based on table 7.16, architects prefer to have desktop applications as the design process needs efficient applications with creating and editing functionality. Web-based applications have limited capability to create and edit objects compared to professional desktop applications (e.g. Autodesk Revit). However, web-based applications provide them with the opportunity to share their design with other stakeholders. Architects did not show interest in mobile applications as they mainly work at offices. Building developers selected three types of media as they need to have access and process data for various purposes. Mobile applications could provide them with access to data in the field. Web-based applications help to share data with other stakeholders and desktop applications provide the main analysis and computation. City councils, land registries and owners' corporations need to have both web-based and desktop-based applications to handle their tasks, also showed interest in mobile applications for future developments.

Open-source applications are becoming popular in different disciplines. For cadastral purposes, developing open-source applications can reduce the cost of accessing cadastral data. However, proprietary products also need to be considered based on their capabilities.

7.5.1.4 Prioritisation of Visualisation Requirements

This section looks at the priority of visualisation requirements for each type of user for representing land and property information in 3D (table 7.17).

Table 7.17: The list of requirements and their priority for different user groups (M: Must, S: Should, C: Could, and W: Won't).

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government	Comments
5.5.1.1	***Plan view***	M	M	M	M	M	M	M	M	M	M	This is an obvious requirement and the visualisation application must support plan view.
5.5.1.2	***City view***	M	M	M	M	M	M	M	M	M	M	
5.5.1.3	***Model view***	M	M	M	M	M	M	M	M	M	M	
5.5.1.4	***Underground view***	M	M	M	M	M	M	M	M	M	M	
5.5.1.5	***Cross-section view***	M	M	M	M	M	M	M	M	M	S	
5.5.1.6	***Indoor view***	S	M	M	M	M	M	M	W	M	S	
5.5.1.7	***Multiple views***	M	M	M	M	M	M	M	M	M	S	
5.5.1.8	***View points***	M	M	M	M	M	M	M	M	M	M	

5.5.1.9	***Wireframe view***	S	M	M	M	S	M	S	M	M	C	
5.5.1.10	***Flight view***	C	C	C	S	C	C	C	C	C	S	These results are from discussion with users about the benefits of this feature in the visualisation application.
5.5.1.11	***Explode view***	S	M	M	S	S	S	S	W	S	S	
5.5.1.12	***Sliding***	S	S	S	S	S	S	S	S	S	S	These results are from discussion with users for the benefits of this feature in the visualisation application.
5.5.1.13	***Street view***	S	M	M	M	S	S	S	M	S	S	
5.5.1.14	***Swipe***	M	M	M	M	M	M	M	M	M	M	These results are from discussion with users for the benefits of this feature in the visualisation application.
5.5.2	***Labels***	M	M	M	M	M	M	M	M	M	M	
5.5.3	***Magic lens***	S	S	S	S	S	S	S	S	S	S	These results are from discussion with users for the benefits of this feature in the visualisation application.
5.5.4.1	***Level of detail control***	M	M	M	M	M	M	M	M	M	M	These results are from the literature and importance of LoD control for built objects.
5.5.4.2 5.5.4.3 5.5.4.4	***Symbology Colour, thickness and line-style Transparency***	M	M	M	M	M	M	S	M	M	M	
5.5.5	***Day and night view***	S	M	M	M	S	C	S	C	M	S	
5.5.5	***Stereo view***	S	S	M	C	S	S	M	M	M	S	
5.5.5	***Special effects***	S	M	M	M	C	C	S	S	M	M	

Table 7.17 presented the relative priority of the visualisation requirements for various types of users. The first part of this table mainly showed that different views are required for different types of users, as these views facilitate understanding the situation. For example, the plan view, city view, model view, and underground view are high priority for all types of users. In the second part of this table, other requirements such as swipe, labels, and levels of detail have high priority (M). These requirements are important for almost all users and enable important capabilities. Other requirements

have different priority levels for different types of users. For example, sliding can be effective for users to understand internal geometry of developments.

7.5.1.5 Prioritisation of Analytical Requirements

This section looks at the priority of analytical requirements for each type of user for representing land and property information in 3D (table 7.18).

Table 7.18: The list of requirements and their priority for different user groups (M: Must, S: Should, C: Could, and W: Won't).

Reference Section	Feature	Academia	Architects	Building developers	City councils	Land registry	Land surveyors	Owners' corporation	Referral authorities	Software developers	State government	Comments
5.6.1	***Ensure spatial validity***	M	S	M	M	M	M	S	M	M	M	It must be possible to view invalid objects. It should also be possible to highlight where the invalidity exists. However, this is a challenge for land surveying data as it does not result in perfect closure in real observations.
5.6.2	***Search methods***	M	M	M	M	M	M	M	M	M	M	Search characteristics are the key to make land information more accessible.
5.6.3	***Spatial measurement tools***	M	M	M	M	M	M	M	M	M	M	To ensure that any dimensions extracted are accurate to as-built conditions, the 3D models would need to be based upon survey accurate as-built information. This would become cost prohibitively expensive. However, these values cannot be guaranteed by the visualisation application. The legal dimensions are guaranteed by registrars and must be measured by a licensed surveyor
5.6.4.1	***Support of topology***	M	M	M	M	M	M	M	M	M	M	These results are from discussion with users for the benefits of this feature in the visualisation application. However, this is not a pure visualisation feature and is more related to data creation and management.
5.6.4.2	***3D buffer***	M	M	M	M	M	M	M	M	M	M	
5.6.4.3	***Intersect in 3D***	M	M	M	M	M	M	M	M	M	M	These results are from discussion with users for the benefits of this feature in the visualisation application. This can identify intersections in data.

5.6.5	***Visualisation of results of functions and queries***	M	M	M	M	M	M	M	M	M	M	
5.6.6	***Augmented reality***	S	M	M	S	S	S	S	M	S	M	
5.6.7	***Temporal modelling***	M	M	M	M	M	M	M	M	M	M	
5.6.8	***Logical consistency****	C	C	C	C	C	C	C	C	C	C	* It would be great to have this feature and all users provided positive feedback for this feature, however, this is not a high priority for a visualisation application.
5.6.9	***Scenario modelling***	S	M	S	M	W	W	W	S	W	M	These results are from discussion with users for the benefits of this feature in the visualisation application.
5.6.9	***Shadow and Shadow analysis****	M	M	M	M	S	S	S	S	M	M	* The visualisation system must support shadows as this feature helps understanding 3D models better. However, shadow analysis is only important for planning purposes (e.g. councils and state governments).
5.6.9	***Line of sight and visibility analysis***	S	M	M	M	S	S	S	M	M	M	
5.6.9	***Vertical exaggeration***	S	S	M	S	M	S	S	S	S	S	

Analytical requirements have different priorities for different user types. Analytical requirements have been considered from different aspects. In terms of data quality, 3D cadastral objects need to be valid as various types of users have specified the importance of that. Logical consistency controls data quality, using semantic rules to avoid error in data. For example, lots cannot have intersections. However, an easement can be located inside a lot. In terms of functionality, search methods and measurement tools are common requirements in most spatial applications and are a high priority for all users. Different analytical requirements (e.g. buffer and intersect) provide different capabilities in the visualisation application. Temporal modelling has been identified as a high priority for all users, as it allows temporal visualisation of cadastral objects.

7.6 Conclusion and Chapter Summary

This chapter explored the validation of 3D cadastral visualisation requirements to meet the final research objective, to validate and showcase the developed 3D cadastral visualisation requirements.

The first prototype evaluation was conducted as a workshop with twenty participants from academy and industry specialising in cadastre. The prototype was showcased and its capabilities were presented. They discussed their needs and expectations from a 3D cadastral visualisation application. Based on the results, the prototype could satisfy most building managers and owners' corporation officers. The overall feedback was positive and the comments valuable for future work. Based on the feedback and analysis of the requirements, a list of required features for different types of users was developed.

The analysis of 197 responses to the first on-line questionnaire further validated the 3D cadastral visualisation requirements for each type of user. The identified requirements in chapter 5 were verified and validated by participants through the survey. Following the results achieved from the evaluation of the web-based 3D cadastral visualisation prototype, the SUS scores of this prototype were between 'OK' and 'Excellent'. In terms of the acceptability range, the of land surveyors, land registrars and city managers scored the prototype between 'High' and 'Low marginal'. On the other hand, the acceptability range of building managers and owners' corporations was in the 'Acceptable' range, which means the prototype has an acceptable level of usability for them.

The third part of this chapter looked at the validation of requirements though the second prototype and a second on-line questionnaire. 42 specialists were selected from industry to use the second prototype and fill in the second questionnaire. The functionality, usability and efficiency of the second prototype were evaluated.

Finally, the results of these three requirement validations were integrated and prioritised for each type of user.

In these three parts, the identified requirements were checked against the following quality criteria (Kotonya and Sommerville, 1998):

- Consistency: the list of requirements was checked in the first questionnaire and participants gave their agreement with them to avoid any inconsistency. The requirements were also verified using other available resources in this research including meetings, prototypes, placements, and literature;
- Comprehensibility and ambiguity: the requirements were implemented in prototypes to make the requirements clear for participants to understand them. In addition, in the first questionnaire, the requirements were presented with examples and figures to help participants understand the requirements. The final list of requirements was also written with further discussion and explanation including more figures;
- Redundancy: the repeated requirements were removed from the list of requirements.
- Completeness: participants in validation techniques were asked about missing requirements to include them in the list. The missing requirements were added to chapter 5.

The findings of the prototype evaluations and the first questionnaire showed the needs and expectations of cadastral users and the importance of their requirements. Participants could review the requirements and verify and validate the identified requirements by three approaches.

The aim in this research was to collect all related 3D cadastral visualisation requirements, however, some of the above requirements were not strictly 3D cadastral visualisation requirements; they supported further analysis on 3D models. These requirements can be used by software developers to design and implement efficient 3D cadastral visualisation applications.

The next chapter will present the conclusion of this research by examining the overall achievements in response to the objectives. It also discusses possible future research and recommendations.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

"The relationship between what we see and what we know is never settled."

– JOHN BERGER

8 Conclusions and Recommendations

8.1 Introduction

This chapter summarises the results of this research and highlights the outcomes and contribution to knowledge. It explains the aim of the research along with the research objectives for developing 3D cadastral visualisation requirements. Finally, it discusses the key findings as well as potential research topics for future directions in the area of 3D cadastral visualisation.

8.2 Research Aim and Objectives

This research aimed to identify and develop 3D cadastral visualisation requirements for representing RRRs, as discussed in chapter 1.

To achieve the research aim, the requirement engineering process was chosen. The requirement engineering process usually begins with understanding the concept, then proceeds to elicit, analyse, and validate the requirements.

The requirements were elicited from different resources such as papers, books, business documents, meetings with specialists, interviews, a case study, workshops, and industry placements. These requirements were then analysed and validated by different users using a prototyping approach and online questionnaires.

For developing the 3D cadastral visualisation requirements, previous work in this area was reviewed and assessed to understand how they represent land and property ownership information in 3D and what were their shortcomings and their strengths.

Overall, it was concluded that there is no fully developed and documented set of 3D cadastral visualisation requirements which covers the needs of cadastral users. Therefore, the major outcomes and contribution in this research are developing and documenting 3D cadastral visualisation requirements for various types of cadastral users using different approaches including literature review, placements, case study, interviews, prototypes and online questionnaires.

In this research, Melbourne metropolitan areas in Victoria, Australia, was selected as a case study to provide better understanding of the current practice of cadastral data registration in this jurisdiction. The identified requirements were documented and classified into the following categories:

- Data requirements;
- User interface requirements;
- Technical requirements;
- Visualisation requirements; and
- Analytical requirements.

The developed requirements can be utilised for implementing 3D cadastral visualisation applications to query, analyse, and represent RRRs along with their physical counterparts.

The requirements were validated using two approaches (prototypes and the first questionnaire), and feedback and comments were received from users to improve the findings. In addition, the developed prototypes were examined by users in various workshops and meetings and valuable feedback was received to update the list of requirements.

In the following sections, the objectives of the research will be reviewed and discussed further.

8.2.1 Objective 1: To study and understand 3D cadastral concepts

As discussed in chapter 2, it was important to recognise the issues and challenges of existing cadastres, identify cadastral users, and investigate the issues regarding visualisation of RRRs in 3D.

The outcome of Objective 1 was recognition and description of the lack of a comprehensive list of 3D cadastral visualisation requirements, the importance of required data formats for storing, sharing and exchanging cadastral information among users, existing related standards, and available 3D visualisation applications which can be utilised as a basis for systems specification and development. This information significantly helped in developing the requirements and implementing the prototypes.

8.2.2 Objective 2: To study and understand 3D visualisation concepts for cadastral purposes

The qualitative investigation of 3D visualisation applications and techniques provided detailed knowledge of the current status of the available visualisation tools. Reviewing these applications in chapter 2 facilitated the investigation of the advantages and deficiencies of current 3D cadastral visualisation prototypes. Chapter 2 also identified the cadastral users involved in creating, maintaining and using cadastral data. It also discussed the remaining issues in 3D cadastral visualisations.

The outcome of Objective 2 emphasised the importance of visualisation techniques and tools for developing successful 3D cadastral visualisation applications. In addition, none of the developed 3D cadastral visualisation prototypes fully identified and validated 3D cadastral visualisation requirements.

The outcome of Objectives 1 and 2 in particular assisted with the development of 3D cadastral visualisation requirements to address the identified research problem and fulfilment of Objectives 3 and 4.

8.2.3 Objective 3: To identify and develop 3D visualisation requirements for cadastres

Developing 3D cadastral visualisation requirements for representing RRRs in 3D was considered the main challenge identified in this research.

Identifying these requirements is an important step towards designing and implementing 3D cadastral visualisation applications. This objective covers the process of eliciting and validating 3D visualisation requirements for cadastres.

In this research, the requirement engineering process was identified as the best approach for developing the requirements. In this regard, a research approach was designed (chapter 3) and employed. This approach utilised various methods such as a literature review, industry placements, meetings, interviews, workshops, prototypes, a case study, and questionnaires to elicit, analyse, validate and document the requirements.

The outcome of Objective 3 highlighted the user needs and requirements of 3D cadastral visualisation. These requirements were documented in detail in chapter 5.

8.2.4 Objective 4: To validate and showcase the developed 3D cadastral visualisation requirements

The validation of requirements included development of two prototypes based on user requirements, and gathering experts' feedback using two questionnaires. Implementation of prototypes for representing RRRs, and the feedback on these, established the validity and priority of the requirements proposed in chapter 5.

The web-based 3D cadastral visualisation prototype was implemented using three-layer architecture, including a user-interface tier, web-service tier, and data tier. WebGL technology was utilised in the prototype for rendering 3D volume objects.

The outcome of Objective 4 was validation of 3D cadastral visualisation requirements and evaluation of both prototypes for their capacity to query, analyse and represent RRRs.

8.3 Conclusion on Research Problem

Due to the increasing number of overlapped multi-level developments, particularly in densely populated areas, there is a need for an effective and efficient 3D visualisation of RRRs. However, currently stratified and overlapped RRRs are represented in paper-based plans. This method does not efficiently represent the overlapping ownership boundaries in urban populated areas. To design and develop efficient 3D visualisation applications for representing ownership boundaries, there is a need for developing 3D cadastral visualisation requirements. Therefore, the research problem to be investigated in this thesis is summarised:

"Visualisation requirements to support the development of 3D cadastral applications to represent rights, restrictions and responsibilities have not been clearly identified. An agreed set of requirements will support the development of visualisation applications designed to meet users' needs".

This research problem was addressed through development and implementation of the 3D cadastral visualisation requirements for visualising RRRs. These requirements could facilitate implementation of 3D cadastral visualisation applications and increase their usability for different users.

These requirements could facilitate all of the following industry objectives based on the feedback from users:

- Better RRRs registration;
    - Use the visualisation and simulation power of 3D modelling to enhance registration processes for RRRs;
- Better RRRs visualisation;
    - Use the visualisation power to efficiently represent RRRs for users;
- Better decisions;
    - The result systems can facilitate the decision making processes;
- Reduce disputes;
    - By clearly communicating with users using the visualisation applications, disputes will be decreased or resolved easily;
- Engage the community;
    - It opens up new ways to communicate widely with users in a boarder sense as the public can understand the situation easily and any structure (complex or simple) can be explained better to an audience.

8.4 Key Findings and Contribution to Knowledge

In this research, the current theory and practice of 3D cadastre were reviewed and international research activities in 3D cadastral visualisation were investigated. This research identified the limitations of current approaches (paper-based) for representing RRRs and important drivers to use 3D visualisation techniques were addressed. In addition, the available 3D visualisation solutions were introduced and their capabilities and limitations were evaluated.

The findings of the case study have identified a range of complex 3D cadastral visualisation issues, as well as important requirements for cadastral users. Using other techniques, including a literature review, industry placements, prototyping, questionnaires, and interviews, more 3D cadastral visualisation requirements were identified.

These requirements were introduced in five categories, including data requirements, user interface requirements, technical requirements, visualisation requirements, and analytical requirements.

Then, these requirements were validated by users using two questionnaires and two prototypes. The findings were presented in workshops, seminars, and research papers and the received comments enhanced the findings. The proposed 3D cadastral visualisation requirements enable software developers to implement 3D visualisation applications for cadastral users to represent RRRs.

8.5 Recommendation for Future Research

The results of this research highlighted the following directions for future investigations in 3D cadastral visualisation.

1. Investigation of using semantic knowledge for cadastral applications will further improve the development of efficient visualisation applications for cadastral users. Smart visualisation applications can provide efficient tools for users. Smart applications may use semantic knowledge to customise the application and data according to the needs and resources of the user. For example in a smart application for cadastre, a land surveyor with a mobile application and an architect with a desktop application would see different data with different functionality in their applications. In this example, semantic knowledge from users can customise data and functionality of the application to be fit for purpose (see section 5.4.10). Therefore, further investigation in semantic visualisation is important for cadastral purposes.

2. As identified in the validation phase, there is a need to include the possibility to choose which aggregation level (which part of an object) should be selected with the identify tool. For example, by clicking on a wall of a building, the attributes of the wall may be required or the attributes of the building. As a result, an investigation into an appropriate identify tool for visualisation application is suggested.

3. The 3D visualisation requirements, identified in this research, are mainly based on needs in Victoria. However, the findings of this research need to be adapted for other jurisdictions in Australia and internationally. Therefore, the differences in the needs of users in other jurisdictions must be investigated.

4. These requirements should be validated with other users (e.g. lawyers and finance institutions) involved in land development processes, and their needs must be considered for developing 3D cadastral visualisation applications. Their requirements must be investigated and analysed and appropriate applications should be developed.

5. New technologies are becoming more widespread which will change the traditional methods of managing land and property information. Building Information Modelling (BIM) is becoming popular among professionals involved in land development processes. However, BIM only focuses on physical structures and does not support ownership information (see section

6.3.2). Therefore, enriching BIM to support legal objects and investigating its benefit to the land development process is important.

6. Although visualisation was highlighted as an important step for realisation of a 3D cadastre, other technical aspects such as data modelling, data storage, and data acquisition/sourcing, are significant for implementing a successful 3D cadastre. Investigating these aspects has direct effects on 3D visualisation of RRRs.

REFERENCES

References

ABDUL RAHMAN, A., HUA, T. C. & VAN OOSTEROM, P. 2011. Embedding 3D into Multipurpose Cadastre. *FIG Working Week 2011.* Marrakech, Morocco.

ABDUL RAHMAN, A., VAN OOSTEROM, P., CHEE HUA, T., SHARKAWI, K. H., DUNCAN, E. E., AZRI, N. & HASSAN, M. I. 2012. 3D Modelling for Multipurpose Cadastre *3rd International Workshop on 3D Cadastres: Developments and Practices* Shenzhen, China.

ABS. 2014. *3101.0 - Australian Demographic Statistics, Jun 2013* [Online]. Available: http://www.abs.gov.au/AUSSTATS/abs@.nsf/mf/3101.0.

ACHARYA, B. R. 2011. Prospects of 3D Cadastre in Nepal. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

ADITYA, T., ISWANTO, F., WIRAWAN, A. & LAKSONO, D. P. 2011. 3D Cadastre Web Map: Prospects and Developments. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

ADITYA, T., SUBARYONO, WALJIYANTO, ISTARNO, DIYONO, UNTUNG, R., ROCHMAD, M. & FEBRI, I. 2009. Understanding the Urgency for 3D Cadastre in Indonesia: Development & Visualization of a Hybrid 3D Cadastre Model. *10th South East Asian Survey Congress.* Bali, Indonesia.

AIEN, A. 2013. *3D Cadastral Data Modelling.* PhD Thesis, The University of Melbourne, Victoria, Australia.

AIEN, A., KALANTARI, M., RAJABIFARD, A., WILLIAMSON, I. & SHOJAEI, D. 2012. Developing and Testing a 3D Cadastral Data Model: A Case Study in Australia. *In:* ISPRS ANNALS OF THE PHOTOGRAMMETRY, R. S. A. S. I. S. (ed.) *XXII ISPRS Congress.* Melbourne, Australia.

AIEN, A., KALANTARI, M., RAJABIFARD, A., WILLIAMSON, I. & WALLACE, J. 2013. Towards Integration of 3D Legal and Physical Objects in Cadastral Data Models. *Land Use Policy,* 35**,** 140-154.

AIEN, A., RAJABIFARD, A., KALANTARI, M. & WILLIAMSON, I. 2011. Aspects of 3D Cadastre- A Case Study in Victoria. *FIG Working Week 2011.* Marrakech, Morocco.

ALFORD, M. W. 1977. A Requirements Engineering Methodology for Real-Time Processing Requirements. *Software Engineering, IEEE Transactions on,* SE-3**,** 60-69.

AMMAR, R. K. & NEERAJ, D. 2013. SLRB Bahrain – 3D Property Registration System *5th Land Administration Domain Model Workshop* Kuala Lumpur, Malaysia.

ANDRIENKO, G., ANDRIENKO, N., DYKES, J., MOUNTAIN, D., NOY, P., GAHEGAN, M., ROBERTS, J. C., RODGERS, P. & THEUS, M. 2005. Chapter 5 - Creating Instruments for Ideation: Software Approaches to Geovisualization. *In:* JASON, D., ALAN, M. M., MENNO-JAN KRAAKA2 - JASON DYKES, A. M. M. & MENNO-JAN, K. (eds.) *Exploring Geovisualization.* Oxford: Elsevier, 101-125.

ARENS, C., STOTER, J. & VAN OOSTEROM, P. 2005. Modelling 3D Spatial Objects in a Geo-DBMS Using a 3D Primitive. *Computers & Geosciences,* 31**,** 165-177.

AUERBACH, C. & SILVERSTEIN, L. B. 2003. *Qualitative Data: An Introduction to Coding and Analysis,* New York, NYU Press.

AYDıN, C. C., DEMIR, O. & ATASOY, M. 2004. Third Dimension (3D) Cadastre and Its Integration with 3D GIS in Turkey. *FIG Working Week 2004.* Athens, Greece.

AZUMA, R. T. 1997. A Survey of Augmented Reality. *Teleoperators and Virtual Environments.*

BALZER, M. & DEUSSEN, O. 2007. Level-of-detail Visualization of Clustered Graph Layouts. *Visualization, 2007. APVIS '07. 2007 6th International Asia-Pacific Symposium on.*

BANGOR, A., KORTUM, P. T. & MILLER, J. T. 2008. An Empirical Evaluation of the System Usability Scale. *International Journal of Human-Computer Interaction,* 24**,** 574-594.

BATTY, M. 1997. Virtual geography. *Futures,* 29**,** 337-352.
BATTY, M., DODGE, M., DOYLE, S. & SMITH, A. 1998. Modeling Virtual Urban Environments. *UCL Working Paper Series (p. 29).* London: UCL Center for Advanced Spatial Analysis.
BEEN, K., DAICHES, E. & YAP, C. 2006. Dynamic Map Labeling. *IEEE Transactions on Visualization and Computer Graphics,* 12**,** 773-780.
BENHAMU, M. 2006. A GIS-Related Multi Layers 3D Cadastre in Israel. *XXIII FIG Congress.* Munich, Germany.
BENHAMU, M. & DOYTSHER, Y. 2003. Toward a Spatial 3D Cadastre in Israel. *Computers, Environment and Urban Systems,* 27**,** 359-374.
BENNETT, R., RAJABIFARD, A., KALANTARI, M., WALLACE, J. & WILLIAMSON, I. 2010. Cadastral Futures: Building a New Vision for the Nature and Role of Cadastres. *XXIV International FIG Congress.* Sydney, Australia.
BERENBACH, B., PAULISH, D. J., KAZMEIER, J. & RUDORFER, A. 2009. *Software and Systems Requirements Engineering In Practice*, he McGraw-Hill Companies.
BIERNACKI, P. & WALDORF, D. 1981. Snowball Sampling: Problems and Techniques of Chain Referral Sampling. *Sociological Methods & Research,* 10**,** 141-163.
BISHOP, I. D. 1992. Data Integration for Visualization: Application to Decision Support. *AURISA 92.* Gold Coast, Australia.
BITMANAGEMENT. 2014. *BS Contact* [Online]. Available: http://www.bitmanagement.com/products/interactive-3d-clients/bs-contact [Accessed 13/5/2014.
BONDI, A. B. 2000. Characteristics of Scalability and Their Impact on Performance. *Proceedings of the 2nd international workshop on Software and performance.* Ottawa, Ontario, Canada: ACM.
BORREGO, M., DOUGLAS, E. P. & AMELINK, C. T. 2009. Quantitative, Qualitative, and Mixed Research Methods in Engineering Education. *Journal of Engineering Education,* 98**,** 53-66.
BROOKE, J. 1996. SUS: A Quick and Dirty Usability Scale. *In:* JORDAN, P. W., WEERDMEESTER, B., THOMAS, A. & MCLELLAND, I. L. (eds.) *Usability Evaluation in Industry.* London: Taylor and Francis, 189-194.
BUDISUSANTO, Y., ADITYA, T. & MURYAMTO, R. 2013. LADM Implementation Prototype for 3D Cadastre Information System of Multi-Level Apartment in Indonesia. *5th Land Administration Domain Model Workshop.* Kuala Lumpur, Malaysia.
CADASTRAL-TEMPLATE. 2013. *Australia* [Online]. Available: http://www.cadastraltemplate.org/countrydata/au.htm [Accessed 10.01.13.
ÇAĞDAŞ, V. 2013. An Application Domain Extension to CityGML for immovable property taxation: A Turkish case study. *International Journal of Applied Earth Observation and Geoinformation,* 21**,** 545-555.
CARD, S., MACKINLAY, J. & SHNEIDERMAN, B. 1999. *Readings in Information Visualization: Using Vision to Think*, Morgan Kaufmann Publishers.
CARD, S. K. & MACKINLAY, J. 1997. The structure of the information visualization design space. *Information Visualization, 1997. Proceedings., IEEE Symposium on.*
CHAI, C. S. 2006. *Towards a 3D Cadastre in Malaysia, An Implementation Evaluation.* MSc MSc thesis, Delft University of Technology, Delft, the Netherlands.
CHIANG, H.-C. 2012. Data Modelling and Application of 3D Cadastral in Taiwan. *3rd International Workshop on 3D Cadastres: Developments and Practices* Shenzhen, China.
CITY OF MELBOURNE 2012. Service Specification - 3D Modelling Service. Melbourne, Australia: The City of Melbourne.
COM 2010. Subdivision Approval Process. The City of Melbourne.
COM 2012a. Explanation of Subdivision Plan Registration (Blue sheet). The City of Melbourne.
COM 2012b. Land Survey Team Subdivision Application Processes. The City of Melbourne.

CONSUMER AFFAIRS VICTORIA. 2013. *Company Title and Stratum Title* [Online]. Available: http://www.consumer.vic.gov.au/housing-and-accommodation/owners-corporations/buying-into-an-owners-corporation/company-title-and-stratum-title [Accessed 21-02-2014.

COORS, V. 2003. 3D-GIS in networking environments. *Computers, Environment and Urban Systems,* 27**,** 345-357.

CORRÊA, W. T. 2004. *New Techniques for Out-Of-Core Visualization of Large Datasets.* PhD thesis, Princeton University.

CREMERS, A. B. & ALDA, S. 2011. Organizational Requirements Engineering.

CRESWELL, J. W. & PLANO CLARK, V. L. 2011. Choosing a Mixed Methods Design. *Designing and Conducting Mixed Methods Research.* Thousand Oaks, California: SAGE Publications, Inc.

CZERWINSKI, A., KOLBE, T. H., PLÜMER, L. & STÖCKER-MEIER, E. 2006. Interoperability and Accuracy Requirements for EU Environmental Noise Mapping. *InterCarto – InterGIS 12.* Berlin.

DALRYMPLE, K., WILLIAMSON, I. P. & WALLACE, J. 2003. Cadastral systems within Australia. *The Australian Surveyor,* 1**,** 37-49.

DEVLIN, A. S. 2006. *Research Methods: Planning, Conducting and Presenting Research,* Belmont, CA, Thompson Wadsworth.

DIMOPOULOU, E. & ELIA, E. 2012. Legal Aspects of 3D Property Rights, Restrictions and Responsibilities in Greece and Cyprus. *3rd International Workshop on 3D Cadastres: Developments and Practices* Shenzhen, China.

DIMOPOULOU, E., GAVANAS, I. & ZENTELIS, P. 2006. 3D Registrations in the Hellenic Cadastre. *Shaping the Change, XXIII FIG Congress.* Munich, Germany.

DIMOVSKI, V., BUNDALESKA-PECALEVSKA, M., CUBRINOSKI, A. & LAZOROSKA, T. 2011. WEB Portal for Dissemination of Spatial Data and Services for the Needs of the Agency for Real Estate Cadastre of the Republic of Macedonia (AREC). *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

DÖLLNER, J. & HAGEDORN, B. 2007. Integrating Urban GIS, CAD, and BIM Data By Service-Based Virtual 3D City-Models. *In:* RUMOR, M., COORS, V., FENDEL, E. M. & ZLATANOVA, S. (eds.) *Urban and Regional Data Management: UDMS 2007 Annual.* Stuttgart, Germany: Taylor & Francis Ltd, 157–170.

DONER, F., THOMPSON, R., STOTER, J., LEMMEN, C., PLOEGER, H. & VAN OOSTEROM, P. 2008. 4D Land Administration Solutions in the Context of the Spatial Information Infrastructure. *Integrating Generations FIG Working Week 2008.* Stockholm, Sweden.

DÖNER, F., THOMPSON, R., STOTER, J., LEMMEN, C., PLOEGER, H., VAN OOSTEROM, P. & ZLATANOVA, S. 2010. 4D cadastres: First analysis of Legal, organizational, and technical impact - With a case study on utility networks. *Land Use Policy,* 27**,** 1068-1081.

DPCD 2010. Advisory Note – 3D Digital Modelling. Department of Planning and Community Development.

DPCD 2012. Subdivision ACT User Guide. Department of Planning and Community Developement.

DSE 2003. Building Envelopes Information Kit. *In:* EDITION, F. (ed.). Department of Sustainability and Environment.

DSE 2010a. Business Case-Implementation of electronic plans of subdivision. Department of Sustainability and Environment - Land Victoria.

DSE 2010b. ePlan Victoria - Detailed Plan Examination Rules - Stage 1 - Requirements Documentation. Department of Sustainability & Environment.

DSE 2012. Your Guide to Lodging a Plan of Subdivision. Department of Sustainability and Environment.

DSILVA, M. G. 2009. *A Feasibility Study on CityGML for Cadastral Purposes.* Masters Thesis, Eindhoven University of Technology, Eindhoven, The Netherlands.

DTPLI. 2013. *Planning Applications* [Online]. Department of Transport, Planning and Local Infrastructure. Available: http://www.dpcd.vic.gov.au/planning/planningapplications [Accessed 28-02-2014.

DTPLI. 2014a. *About the Surveyor-General of Victoria* [Online]. Available: http://www.dse.vic.gov.au/property-titles-and-maps/surveying-home-page-archived/government-survey-services/surveyor-general-of-victoria [Accessed 17/2/2014.

DTPLI. 2014b. *Torrens title system* [Online]. Available: http://www.dtpli.vic.gov.au/property-and-land-titles/land-titles/150-years-of-torrens-title-in-victoria-1862-2012 [Accessed 15/02/2014.

DTPLI. 2014c. *Valuer-General Victoria* [Online]. Available: http://www.dtpli.vic.gov.au/property-and-land-titles/valuation/government-valuations/valuer-general-victoria [Accessed 14/2/2014.

EASTMAN, C., TEICHOLZ, P., SACKS, R. & LISTON, K. 2011. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors (2nd ed.),* New Jersey, NY, Wiley, (Chapter 3).

EKBERG, F. 2007. *An Approach for Representing Complex 3D Objects in GIS Applied to 3D Properties.* Master, University of Gavle.

EL-MEKAWY, M. 2010. *Integrating BIM and GIS for 3D City Modelling, the Case of IFC and CityGML.* Royal Institute of Technology (KTH), Stockholm, Sweden.

EL-MEKAWY, M. & ÖSTMAN, A. 2012. Feasibility of Building Information Models for 3D Cadastre in Unified City Models. *International Journal of E-Planning Research (IJEPR),* 1**,** 35-58.

ELIZAROVA, G., SAPELNIKOV, S., VANDYSHEVA, N., PAKHOMOV, S., OOSTEROM, P. V., VRIES, M. D., STOTER, J., PLOEGER, H., SPIERING, B., WOUTERS, R., HOOGEVEEN, A. & PENKOV, V. 2012. Russian-Dutch Project "3D Cadastre Modelling in Russia". *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.

ELLUL, C. & HAKLAY, M. 2006. Requirements for Topology in 3D GIS. *Transactions in Gis,* 10**,** 157-175.

ENEMARK, S. 2009. Sustainable Land Administration Infrastructures to support Natural Disaster Prevention and Management *UN Regional Cartoghraphic Conference for the Americas.* New York.

ERBA, D. A. & PIUMETTO, M. A. 2012. Modern representation technologies for the implementation of 3D cadastres in Latin America *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.

ESCALONA, M. J. & KOCH, N. 2004. Requirements Engineering for Web Applications: A Comparative Study. *Journal of Web Engineering,* 2**,** 193-212.

FEAGIN, J. R., ORUM, A. M. & SJOBERG, G. 1991. *A Case for the Case Study*, University of North Carolina Press.

FENDEL, E. 2001. Registration of Properties in Strata. *International Workshop on 3D Cadastres.* Delft, the Netherlands.

FIG 1995. Statement on the Cadastre. *publication prepared for the International Federation of surveyors by Commission 7 (Cadastre and Land Management).*

FOX, D. 1998. Composing Magic Lenses. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* Los Angeles, California, USA: ACM Press/Addison-Wesley Publishing Co.

FRÉDÉRICQUE, B., RAYMOND, K. & VAN PROOIJEN, K. 2011. 3D GIS as Applied to Cadastre - A Benchmark of Today's Capabilities. *FIG Working Week 2011.* Marrakech, Morocco.

FRIENDLY, M. 2009. Milestones in the history of thematic cartography, statistical graphics, and data visualization. *13th International Conference on Database And Expert Systems Applications (Dexa 2002), Aix En Provence.* Press, 59-66.

FUNKHOUSER, T. A. & SEQUIN, C. H. 1993. Adaptive Display Algorithm for Interactive Frame Rates During Visualization of Complex Virtual Environments. *Proceedings of* *the 20th annual conference on Computer graphics and interactive techniques.* Anaheim, CA: ACM.

GARMER, K., YLVÉN, J. & MARIANNE KARLSSON, I. C. 2004. User Participation in Requirements Elicitation Comparing Focus Group Interviews and Usability Tests for Eliciting Usability Requirements for Medical Equipment: A Case Study. *International Journal of Industrial Ergonomics,* 33**,** 85-98.

GAUSE, D. C. & WEINBERG, G. M. 1989. *Exploring Requirements: Quality Before Design,* New York, Dorset House Publishing.

GERSHON, N., EICK, S. G. & CARD, S. 1998. Information visualization. *interactions,* 5**,** 9-15.

GOOGLE MAPS. 2012. *Google Maps* [Online]. Melbourne CBD. Available: http://maps.google.com.au [Accessed 05.06.12.

GOOGLE MAPS. 2014. *Google Maps* [Online]. South Yarra. Available: http://maps.google.com.au [Accessed 05.02.14.

GREENE, J. C., CARACELLI, V. J. & GRAHAM, W. F. 1989. Toward a Conceptual Framework for Mixed-Method Evaluation Designs. *Educational Evaluation and Policy Analysis,* 11**,** 255-274.

GRIFFITH-CHARLES, C. & SUTHERLAND, M. 2013. Analysing the costs and benefits of 3D cadastres with reference to Trinidad and Tobago. *Computers, Environment and Urban Systems*.

GRINSTEIN, A. 2001. Aspects Of A 3d Cadastre In The New City Of Modi'in, Israel. *International Workshop on 3D Cadastres.* Delft, the Netherlands.

GRÖGER, G., KOLBE, T. H. & CZERWINSKI, A. 2008. OpenGIS® City Geography Markup Language (CityGML) Encoding Standard. *Open Geospatial Consortium.*

GUO, R., LI, L., HE, B., LUO, P., YING, S., ZHAO, Z. & JIANG, R. 2011. 3D Cadastre in China - a Case Study in Shenzhen City. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands

GUO, R., LI, L., YING, S., LUO, P., HE, B. & JIANG, R. 2013. Developing a 3D cadastre for the administration of urban land use: A case study of Shenzhen, China. *Computers, Environment and Urban Systems*.

HAO, M., ZHENGJUN, L. & YUSHAN, S. 2011. Assessment of Mobile Laser Scanning Data for Building Reconstruction in 3D Cadastre. *Image and Data Fusion (ISIDF), 2011 International Symposium on.*

HASSAN, M. I. & ABDUL RAHMAN, A. 2011. Unique Identifier for 3D Cadastre Objects Registration. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

HE, J., HU, J., TANG, Q. & GUO, S. 2010. Layout Optimization of Urban Underground Pipeline Based on 3D Digital City. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.

HECKBERT, P. S. 1986. Survey of Texture Mapping. *Computer Graphics and Applications, IEEE,* 6**,** 56-67.

HERE. 2014. *Here Map* [Online]. Nokia. Available: http://here.com/-37.81753,144.96715,13,0,0,normal.day [Accessed 29/04/2014.

HESSE-BIBER, S. N. 2010. *Mixed Methods Research: Merging Theory with Practice,* New York, London, The Guilford Press.

HILBURN, T. B., TOWHIDNEJAD, M., NANGIA, S. & LI, S. 2006. A Case Study Project for Software Engineering Education. *Frontiers in Education Conference, 36th Annual.*

HILDEBRANDT, D. & DÖLLNER, J. 2010. Service-oriented, Standards-based 3D Geovisualization: Potential and Challenges. *Computers, Environment and Urban Systems,* 34**,** 484-495.

HO, S. & RAJABIFARD, A. 2012a. 3D Land and Property Information System: A Multi-level Infrastructure for Sustainable Urbanization and a Spatially Enabled Society. *GSDI 13 World Conference - Spatially Enabling Government, Industry and Citizens.* Quebec City, Canada.

HO, S. & RAJABIFARD, A. 2012b. Delivering 3D Land and Property Management in Australia: A Preliminary Consideration of Institutional Challenges. *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.

HO, S., RAJABIFARD, A., STOTER, J. & KALANTARI, M. 2013. Legal barriers to 3D cadastre implementation: What is the issue? *Land Use Policy,* 35**,** 379-387.

IEEE STANDARD 1990. IEEE Standard Glossary of Software Engineering Terminology. *IEEE Std 610.12-1990***,** 1-84.

IEEE STD 830 1998. IEEE Recommended Practice for Software Requirements Specifications. *IEEE Std 830-1998***,** 1-40.

IIBA 2009. *A Guide to the Business Analysis Body of Knowledge (Babok Guide)*, International Institute of Business Analysis.

INSPIRE 2010. D2.8.I.6 INSPIRE Data Specification on Cadastral Parcels – Guidelines. INSPIRE Thematic Working Group Cadastral Parcels.

ISIKDAG, U. & ZLATANOVA, S. 2009. Towards Defining a Framework for Automatic Generation of Buildings in CityGML Using Building Information Models. *In:* LEE, J. & ZLATANOVA, S. (eds.) *3D Geo-Information Sciences.* Springer Berlin Heidelberg, 79-96.

ISO19152/TC211 2012. Geographic information — Land Administration Domain Model (LADM).

ISO 9241-11 1998. Ergonomic requirements for office work with visual display terminals (VDTs) - Part 11: Guidance on usability.

ISO 16739:2013 2013. Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.

ISO 32000:2008 2008. Document management -- Portable document format.

ISO/IEC19777:2006 2006. Information technology -- Computer graphics and image processing -- Extensible 3D (X3D) language bindings.

ISO/PAS 17506:2012 2012. Industrial automation systems and integration -- COLLADA digital asset schema specification for 3D visualization of industrial data.

JACCARD, J. & WAN, C. K. 1996. *LISREL Approaches to Interaction Effects in Multiple Regression,* Thousand Oaks, Calif., Sage Publications.

JACKSON, S. L. 2008. *Research Methods: A Modular Approach,* US, Thomson Wadsworth.

JACOBSON, I., BOOCH, G. & RUMBAUGH, J. E. 1999. *The Unified Software Development Process - the Complete Guide to the Unified Process from the Original Designers*, Addison-Wesley Longman Publishing Co., Inc.,.

JAMIL, H., MOHD YUSOFF, M. Y. & ABDUL HALIM, N. Z. 2013. Discovering Possibilities of Implementing Multipurpose Cadastre in Malaysia *FIG Working Week 2013* Abuja, Nigeria.

JARROUSH, J. & EVEN-TZUR, G. 2004. Constructive Solid Geometry as the Basis of 3D Future Cadastre. *FIG Working Week 2004.* Athens, Greece.

JAZAYERI, I., RAJABIFARD, A. & KALANTARI, M. 2014. A geometric and semantic evaluation of 3D data sourcing methods for land and property information. *Land Use Policy,* 36**,** 219-230.

JOKELA, T., KOIVUMAA, J., PIRKOLA, J., SALMINEN, P. & KANTOLA, N. 2006. Methods for quantitative usability requirements: a case study on the development of the user interface of a mobile phone. *Personal and Ubiquitous Computing,* 10**,** 345-355.

JORGENSEM, D. L. 1989. *Participant Observation: A Methodology for Human Studies,* US, SAGE Publication Inc.

KALANTARI, M. 2008. *Cadastral Data Modelling - A Tool for e-Land Administration.* PhD, The University of Melbourne, Melbourne, Australia.

KALANTARI, M., RAJABIFARD, A., WALLACE, J. & WILLIAMSON, I. 2008. Spatially referenced legal property objects. *Land Use Policy,* 25**,** 173-181.

KARKI, S. 2013. *3D Cadastre Implementation Issues in Australia.* Master of Spatial Science, University of Southern Queensland.

KARKI, S., THOMPSON, R. & MCDERBY, M. 2010. Data validation in 3D cadastre. *Developments in 3D Geo-Information Sciences, Lecture Notes in Geoinformation and Cartography*. Springer, 92-122.

KARKI, S., THOMPSON, R. & MCDOUGALL, K. 2013a. Development of validation rules to support digital lodgement of 3D cadastral plans. *Computers, Environment and Urban Systems*.

KARKI, S., THOMPSON, R. & MCDOUGALL, K. 2013b. Representing 3D data in a Cadastral Database – Queensland Case. *SIRC NZ 2013 – GIS and Remote Sensing Research Conference.* University of Otago, Dunedin, New Zealand.

KARKI, S., THOMPSON, R., MCDOUGALL, K., CUMERFORD, N. & VAN OOSTEROM, P. 2011. ISO Land Administration Domain Model and LandXML in the Development of Digital Survey Plan Lodgement for 3D Cadastre in Australia. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

KAUFMANN, J. & STEUDLER, D. 1998. A Vision for a Future Cadastral System. *Working Group 1 of FIG Commission 7.* FIG.

KHOO, V. H. S. 2011. 3D Cadastre in Singapore. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

KHOO, V. H. S. 2012. Towards "Smart Cadastre" That Supports 3D Parcels. *3rd International Workshop on 3D Cadastres: Development and Practices.* Shenzhen, China.

KIBRIA, MAHMUD S. 2008. *Functionalities of Geo-virtual Environments to Visualize Urban Projects.* Master, TU Delft.

KIMMOND, R. M. 1995. Survey Into the Acceptance of Prototyping in Software Development. *Sixth IEEE International Workshop on Rapid System Prototyping.*

KLIMA, M., HALABALA, P. & SLAVIK, P. 2004. Semantic Information Visualization. *CODATA Workshop.* Prague, Czech Republic.

KOLBE, T. H., GRÖGER, G. & PLÜMER, L. 2005. CityGML – Interoperable Access to 3D City Models. *The First International Symposium on Geo-Information for Disaster Management.* Delft, The Netherlands: Springer Verlag.

KOTONYA, G. & SOMMERVILLE, I. 1998. *Requirements Engineering: Processes and Techniques,* New York, John Wiley & Sons Ltd.

LAND-VICTORIA. 2011. *Detailed Property Report* [Online]. Available: http://services.land.vic.gov.au/landchannel/content/addressSearch [Accessed 05.06.2011.

LAND VICTORIA 2012a. General Law Land.

LAND VICTORIA 2012b. History of Building Subdivisions. Department of Sustainability and Environment.

LANDVICTORIA 2012. Building Subdivision Guidelines - Use of buildings to define boundaries. Melbourne: Department of Sustainability and Environment.

LEECH, N. L. & ONWUEGBUZIE, A. J. 2009. A Typology of Mixed Methods Research Designs. *Quality & Quantity,* 43**,** 265-275.

LEMMEN, C., VAN OOSTEROM, P., THOMPSON, R., HESPANHA, J. & UITERMARK, H. 2010. The Modelling of Spatial Units (Parcels) in the Land Administration Domain Model (LADM). *FIG Congress 2010.* Sydney, Australia.

LEMMEN, C., VAN OOSTEROM, P., UITERMARK, H., ZEVENBERGEN, J. & COOPER, A. 2011. Interoperable domain models: The ISO land administration domain model LADM and its external classes. *28th Urban Data Management Symposium (UDMS 2011).* Delft, The Netherlands.

LISLE, J. D. 2011. The Benefits and Challenges of Mixing Methods and Methodologies: Lessons Learnt From Implementing Qualitatively Led Mixed Methods Research Designs in Trinidad and Tobago. *Caribbean Curriculum,* 18**,** 87-120.

LLOYD, D. & DYKES, J. 2011. Human-Centered Approaches in Geovisualization Design: Investigating Multiple Methods Through a Long-Term Case Study. *IEEE Transactions on Visualization and Computer Graphics,* 17**,** 2498-2507.

MACEACHREN, A. M., BUTTENFIELD, B. P., JAMES, B., CAMPBELL, J. & MONMONIER, M. 1992. Visualisation. *In:* ABLER, R., MARCUS, M. AND OLSON,

J. (ed.) *Geography's Inner Worlds: Pervasive Themes in Contemporary American Geography.* New Brunswick, NJ: Rutgers University Press, 99-137.

MACEACHREN, A. M. & KRAAK, M.-J. 2001. Research Challenges in Geovisualization. *Cartography and Geographic Information Science,* 28**,** 3-12.

MENDEZ, E., SCHALL, G., HAVEMANN, S., FELLNER, D., SCHMALSTIEG, D. & JUNGHANNS, S. 2008. Generating Semantic 3D Models of Underground Infrastructure. *Computer Graphics and Applications, IEEE,* 28**,** 48-57.

MERRIAM, S. B. 2009. *Qualitative Research: A Guide to Design and Implementation,* San Francisco, CA, Jossey-Bass.

MÉTRAL, C., FALQUET, G. & KARATZAS, K. 2008. Ontologies for the Integration of Air Quality Models and 3D City Models. *In:* TELLER, J., TWEED, C. & RABINO, G. (eds.) *2nd Workshop COST Action C21.* Società Editrice Esculapio.

MITROVIC, N., ROYO, J. A. & MENA, E. 2005. Adaptive User Interfaces Based on Mobile Agents: Monitoring the Behavior of Users in a Wireless Environment. *Symposium on Ubiquitous Computation and Ambient Intelligence.* Thomson-Paraninfo, ISBN 84-9732-442-0.

MOSER, J., ALBRECHT, F. & KOSAR, B. 2010. Beyond Visualisation - 3D GIS Analyses for Virtual City Models. *In:* KOLBE, T., G. KÖNIG & C. NAGEL (EDS.) (ed.) *ISPRS Conference - International Conference on 3D Geoinformation.* Berlin.

MYERS, M. D. 1997. Qualitative Research in Information Systems. *MIS Quarterly,* 21**,** 241-242.

MYERS, M. D. 2009. *Qualitative Research in Business & Management*, SAGE Publications Ltd.

NIELSEN, J. (ed.) 1993. *Usability Engineering,* New York: Academic Press.

OGC 2005. Web 3D Service. Open Geospatial Consortium Inc.

OGC 2007. Styled Layer Descriptor profile of the Web Map Service Implementation Specification. Open Geospatial Consortium Inc.

OGC CITYGML 2012. OpenGIS® City Geography Markup Language (CityGML) Encoding Standard. Open Geospatial Consortium.

OGC GML 2012. OGC® Geography Markup Language (GML) — Extended schemas and encoding rules.

OGC KML 2008. OGC® KML.

OLIVARES GARCÍA, J. M., VIRGÓS SORIANO, L. I. & VELASCO M-VARÉS, A. 2011. 3D Modeling and Representation of the Spanish Cadastral Cartography. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

PAASCH, J. M. & PAULSSON, J. 2011. Terminological Aspects Concerning Three-dimensional Real Property. *Nordic Journal of Surveying and Real Estate Research,* 8**,** 81-97.

PANCHAUD, N. 2012. *Service-Driven 3D Atlas Cartography.* Master Degree, ETH Zürich, Zürich.

PAPAEFTHYMIOU, M., LABROPOULOS, T. & ZENTELIS, P. 2004. 3-D Cadastre in Greece – Legal, Physical and Practical Issues, Application on Santorini Island. *FIG Working Week 2004.* Athens, Greece.

PAULSSON, J. 2007. *3D Property Rights – An Analysis of Key Factors Based on International Experience.* PhD, Royal Institute of Technology (KTH) Stockholm, Sweden.

PAULSSON, J. 2011. 3D Property in Sweden. *Conference of Surveying Sciences, The Finnish Society of Surveying Sciences & Finnish Association of Geodetic and Land Surveyors, Special Series no. 48.* Helsinki.

PAULSSON, J. & PAASCH, J. M. 2011. 3D Property Research – a Survey of the Occurrence of Legal Topics in Publications *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

PEREIRA, K. 2013. *Water Simulation on WebGL and Three.js.* Bachelor of Science, The University of Southern Mississippi, Hattiesburg, USA.

PERES, N. & BENHAMU, M. 2009. 3D Cadastre GIS - Geometry, Topology and Other Technical Considerations. *FIG Working Week 2009.* Eilat, Israel.

PIETSCH, S. M. 2000. Computer Visualisation in the Design Control of Urban Environments: a Literature Review. *Environment and Planning B: Planning and Design,* 27**,** 521-536.

PITTMAN, K. 1992. A Laboratory for the Visualization of Virtual Environments. *Landscape and Urban Planning,* 21**,** 327-331.

POE, G. L., BISHOP, R. C. & COCHRANE, J. A. 1992. Benefit-Cost Principles for Land Information Systems. *Journal of the Urban and Regional Information Systems Association,* 4.

PONTIGGIA, M., DERUDI, M., ALBA, M., SCAIONI, M. & ROTA, R. 2010. Hazardous Gas Releases in Urban Areas: Assessment of Consequences Through CFD Modelling. *Journal of Hazardous Materials,* 176**,** 589-596.

POSADA-VELÁSQUEZ, J.-L. 2006. *A Methodology for the Semantic Visualization of Industrial Plant CAD Models for Virtual Reality Walkthroughs.* PhD, Technischen Universität Darmstadt.

POTTS, K. E. 2013. *Using Land Administration for Land Risk Management.* PhD, The University of Melbourne, Melbourne, Austraia.

POULIOT, J. 2011. Visualization, distribution and delivery of 3D parcels. *2nd International Workshop on 3D Cadastres.* Delft, The Netherlands.

POULIOT, J., ROY, T., FOUQUET-ASSELIN, G. & DESGROSEILLIERS, J. 2010. 3D Cadastre in the province of Quebec: A First experiment for the construction of a volumetric representation. *5th International 3D GeoInfo Conference.* Berlin.

POULIOT, J., VASSEUR, M. & BOUBEHREZH, A. 2011. Spatial Representation of Condominium/Co-ownership: Comparison of Quebec and French Cadastral System based on LADM Specifications. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

POULIOT, J., VASSEUR, M. & BOUBEHREZH, A. 2013. How the ISO 19152 Land Administration Domain Model performs in the comparison of cadastral systems: A case study of condominium/co-ownership in Quebec (Canada) and Alsace Moselle (France). *Computers, Environment and Urban Systems,* 40**,** 68-78.

PROOIJEN, K. V., FRÉDÉRICQUE, B. & RAYMOND, K. 2011. Bentley's support for 3D cadastre development. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

QIN, C., ZHOU, C. & PEI, T. 2003. Taxonomy of visualization techniques and systems - concerns between users and developers are different. *Asia GIS Conference 2003.*

ROSS, D. T. & SCHOMAN, K. E. 1977. Structured Analysis for Requirements Definition. *IEEE Transactions on Software Engineering,* 3**,** 6-15.

ROSS, L. 2010. *Virtual 3D City Models in Urban Land Management, Technologies and Applications.* PhD.

SAQI, S. B. & AHMED, S. 2008. *Requirements Validation Techniques Practiced in Industry: Studies of Six Companies.* Masters Degree, Sweden.

SCHULTE, C. & COORS, V. 2008. Development of a CityGML ADE for Dynamic 3D Flood Information. *3th International ISCRAM Workshop.* Harbin, China.

SHOJAEI, D., KALANTARI, M., BISHOP, I. D., RAJABIFARD, A. & AIEN, A. 2013. Visualization requirements for 3D cadastral systems. *Computers, Environment and Urban Systems,* 41**,** 39-54.

SHOJAEI, D., RAJABIFARD, A., KALANTARI, M., BISHOP, I. & AIEN, A. 2014. Design and Development of a Web-based 3D Cadastral Visualisation Prototype. *International Journal of Digital Earth.*

SHOJAEI, D., RAJABIFARD, A., KALANTARI, M., BISHOP, I. D. & AIEN, A. 2012. Development of a 3D ePlan/LandXML Visualisation System in Australia. *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.

SHOSHANI, U., BENHAMU, M., GOSHEN, E., DENEKAMP, S. & BAR, R. 2004. Registration of Cadastral Spatial Rights in Israel - a Research and Development Projects. *In Proceedings of FIG working week.* Athens, Greece.

SINNING-MEISTER, M., GRUEN, A. & DAN, H. 1996. 3D City Models for CAAD-supported Analysis and Design of Urban Areas. *ISPRS Journal of Photogrammetry and Remote Sensing,* 51**,** 196-208.

SKM 2011. Business Case for A Spatially Accurate Map Base. Melbourne.

SMITH, D. & PARADIS, A. 1989. *Three Dimensional GIS for The Earth Sciences,* London, Taylor. & Francis.

SOON, K. H. 2012. A Conceptual Framework of Representing Semantics for 3D Cadastre in Singapore *3rd International Workshop on 3D Cadastres: Developments and Practices* Shenzhen, China.

SØRENSEN, E. M. 2011. 3 Dimensional Property Rights in Denmark. 3D Property Design is Working – Visualization not. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

SPIROU-SIOULA, K., IOANNIDIS, C. & POTSIOU, C. 2011. Proposal for the Development of a 3D Hybrid Model for the Hellenic Cadastre. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

STOTER, J. 2000. Needs, Possibilities and Constraints to Develop a 3D Cadastral Registration System. *Proceedings of UDMS 2000—22nd Urban Data Management Symposium.*

STOTER, J. 2002. UML Modelling: From a 2D to a 3D Cadastre. *3rd international workshop 'Towards a Cadastral Core Domain Model' of COST action G9.* Delft, the Netherlands.

STOTER, J., KLUIJVER, H. & KURAKULA, V. 2008. Towards 3D Environmental Impact Studies: Example of Noise. *In:* VAN OOSTEROM, P., ZLATANOVA, S., PENNINGA, F. & FENDEL, E. (eds.) *Advances in 3d Geoinformation Systems.* Springer Berlin Heidelberg, 341-359.

STOTER, J., PLOEGER, H. & LOUWMAN, W. 2011. Registration of 3D Situations in Land Administration in the Netherlands. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

STOTER, J., PLOEGER, H. & VAN OOSTEROM, P. 2012a. 3D cadastre in the Netherlands: Developments and international applicability. *Computers, Environment and Urban Systems*.

STOTER, J. & SALZMANN, M. 2001. Towards a 3D Cadastre: Where do cadastral needs and technical possibilities meet? *International Workshop on 3D Cadastres.* Delft, the Netherlands.

STOTER, J. & SALZMANN, M. 2003. Towards a 3D cadastre: where do cadastral needs and technical possibilities meet? *Computers, Environment and Urban Systems,* 27**,** 395-410.

STOTER, J. & VAN OOSTEROM, P. 2002. Incorporating 3D geo-objects into a 2D geo-DBMS. *Proceedings FIG ACSM/ASPRS.* Washington DC, USA.

STOTER, J., VAN OOSTEROM, P. & PLOEGER, H. 2012b. The phased 3D Cadastre implementation in the Netherlands. *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China

STOTER, J., VAN OOSTEROM, P., PLOEGER, H. & AALDERS, H. 2004. Conceptual 3D Cadastral Model Applied in Several Countries. *In Proceedings of the FIG Working Week.* Athens, Greece.

STOTER, J. E. 2004. *3D Cadastre.* PhD Thesis, TU Delft, Delft, the Netherlands.

STOTER, J. E. & VAN OOSTEROM, P. 2006. *3D Cadastre in an International Context: Legal, Organizational and Technological Aspects*, CRC Press, Taylor & Francis Group.

STOTER, J. E. & VAN OOSTEROM, P. J. M. 2005. Technological aspects of a full 3D cadastral registration. *International Journal of Geographical Information Science,* 19**,** 669-696.

STREILEIN, A. 2011. 3D Data Management – Relevance for a 3D Cadastre. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

TASHAKKORI, A. & TEDDLIE, C. 2003. *Handbook of Mixed Methods in Social and Behavioral Research,* California, Thousand Oaks, SAGE Publications.

THOMAS, P. 1996. CSCW Requirements and Evaluation. *Computer-Supported Cooperative Work.* London: Springer, 1-9.

THOMPSON, R. & VAN OOSTEROM, P. 2011. Axiomatic Definition of Valid 3D Parcels, Potentially in a Space Partition. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

THOMPSON, R. J. 2007. *Towards a Rigorous Logic for Spatial Data Representation.* PhD, Delft University of Technology, Delft, The Netherlands.

TING, L. & WILLIAMSON, I. 2000. Spatial Data Infrastructures and Good Governance: Frameworks for Land Administration Reform to support Sustainable Development. *4th Global Spatial Data Infrastructure Conference.* Cape Town, South Africa.

TSILIAKOU, E. & DIMOPOULOU, E. 2011. Adjusting the 2D Hellenic Cadastre to the Complex 3D World – Possibilities and Constraints *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands

VAN OOSTEROM, P. 2012. Summary of the Third International FIG Workshop on 3D Cadastres – Developments and practices. *Third International FIG Workshop on 3D Cadastres – Developments and practices.* Shenzhen, China.

VAN OOSTEROM, P. 2013. Research and development in 3D cadastres. *Computers, Environment and Urban Systems,* 40**,** 1-6.

VAN OOSTEROM, P., PLOEGER, H. & STOTER, J. 2005. Analysis of 3D Property Situations in the USA. *From Pharaohs to Geoinformatics, FIG Working Week 2005 and GSDI-8.* Cairo, Egypt

VAN OOSTEROM, P., STOTER, J., PLOEGER, H., THOMPSON, R. & KARKI, S. 2011. World-wide inventory of the status of 3D Cadastres in 2010 and expectations for 2014. *FIG Working Week 2011.* Marrakech, Morocco.

VAN DRIEL, N. J. 1989. Three Dimensional Display of Geologic Data. *In:* RAPER, J. (ed.) *Three Dimensional Applications In GIS.* CRC Press, 1-10.

VANDYSHEVA, N., IVANOV, A., PAKHOMOV, S., SPIERING, B., STOTER, J., ZLATANOVA, S. & VAN OOSTEROM, P. 2011. Design of the 3D Cadastre Model and Development of the Prototype in the Russian Federation. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

VANDYSHEVA, N., SAPELNIKOV, S., VAN OOSTEROM, P., DE VRIES, M., SPIERING, B., WOUTERS, R., HOGEVEEN, A. & PENKOV, V. 2012. The 3D Cadastre Prototype and Pilot in the Russian Federation. *FIG Working Week 2012.* Rome, Italy.

VICTORIAN EPLAN 2012. ePlan Handbook - Victoria.

WALENCIAK, G., STOLLBERG, B., NEUBAUER, S. & ZIPF, A. 2009. Extending Spatial Data Infrastructures 3D by Geoprocessing Functionality - 3D Simulations in Disaster Management and environmental Research. *Advanced Geographic Information Systems & Web Services, 2009. GEOWS '09. International Conference on.*

WAMMES, H. 2011. Land Information Management and its (3D) database foundation. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.

WANG, C., POULIOT, J. & HUBERT, F. 2012. Visualization Principles in 3D Cadastre: A first Assessment of Visual Variables *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.

WEIDENHAUPT, K., POHL, K., JARKE, M. & HAUMER, P. 1998. Scenarios in System Development: Current Practice. *Software, IEEE,* 15**,** 34-45.

WERGLES, N. & MUHAR, A. 2009. The role of computer visualization in the communication of urban design-A comparison of viewer responses to visualizations versus on-site visits. *Landscape and Urban Planning,* 91**,** 171-182.

WILLIAMSON, I., ENEMARK, S., WALLACE, J. & RAJABIFARD, A. 2008. Understanding Land Administration Systems. *International Seminar on Land Administration Trends and Issues in Asia and The Pacific Region.* Kuala Lumpur, Malaysia.

WILLIAMSON, I., ENEMARK, S., WALLACE, J. & RAJABIFARD, A. 2010. *Land Adminstration for Sustainable Development,* Redlands, California, ESRI Press Academic, (Chapter 9).

WILLIAMSON, I. & WALLACE, J. 2007. New Roles of Land Administration Systems. *Proceedings, International Workshop on Good Land Administration – Its Role in Economic Development.* Ulaanbaatar, Mongolia.

WILLIAMSON, I. P. 1984. The Development of the Cadastral Survey System in New South Wales. *The Australian Surveyor,* 32**,** 2-19.
XNAVIGATOR. 2014. *XNavigator Wiki* [Online]. Available: http://xnavigator.sourceforge.net/doku.php [Accessed 13/5/2014.
YIN, R. K. 1994. *Case Study Research: Design and Methods*, Thousand Oaks: SAGE Publications.
YING, S., GUO, R., LI, L. & HE, B. 2012. Application of 3D GIS to 3D Cadastre in Urban Environment. *3rd International Workshop on 3D Cadastres: Developments and Practices.* Shenzhen, China.
YING, S., GUO, R., LI, L., VAN OOSTEROM, P., LEDOUX, H. & STOTER, J. E. 2011. Design and Development of a 3D Cadastral System Prototype based on the LADM and 3D Topology. *2nd International Workshop on 3D Cadastres.* Delft, the Netherlands.
ZEVENBERGEN, J. & STUBKJÆR, E. 2005. Real Property Transactions: Challenges of Modeling and Comparing. *FIG Working Week 2005 and GSDI-8.* Cairo, Egypt.
ZULKIFLI, N. A., ABDUL RAHMAN, A. & VAN OOSTEROM, P. 2013. Developing 2D and 3D Cadastral Registration System based on LADM: Illustrated with Malaysian Cases *5th Land Administration Domain Model Workshop.* Kuala Lumpur, Malaysia.

Personal Communications

- (Land Registry, personal communication, November 5, 2012)
- (Land Registry, personal communication, November 7, 2012)
- (Land Registry, personal communication, November 12, 2012)
- (Land Registry, personal communication, November 14, 2012)
- (Land Registry, personal communication, November 20, 2012)
- (Land Registry, personal communication, November 23, 2012)
- (Land Registry, personal communication, April 3, 2013)
- (Building Manager, personal communication, April 24, 2013)
- (Building Manager, personal communication, May 9, 2013)
- (Building Manager, personal communication, May 15, 2013)
- (State Planning, personal communication, October 16, 2013)
- (State Planning, personal communication, October 29, 2013)
- (City Council, personal communication, October 31, 2013)

APPENDIX (1)

PUBLICATIONS

RELATING TO RESEARCH

APPENDIX 1 - PUBLICATIONS RELATING TO RESEARCH

- ## Journal Papers:

Shojaei, D., Rajabifard, A., Kalantari, M., Bishop, I., and Aien, A., 2014, **Design and Development of a Web-based 3D Cadastral Visualisation Prototype**; the International Journal of Digital Earth, pp., 1-20.

Shojaei, D., Kalantari, M., Bishop, I., Rajabifard, A., Aien, A., 2013, **Visualization requirements for 3D cadastral systems**, Journal of Computers, Environment and Urban Systems, Volume 41, pp. 39-54.

Aien, A., Rajabifard, A., Kalantari, M., Williamson, I., and Shojaei, D., 2014, **A Review of Cadastral Data Models Which Support 3D Cadastres**, Survey Review, (under review process).

- ## Book Chapters

Shojaei, D., 2012, **3D Visualisation as a Tool to Facilitate Managing Land and Properties**, In A. Rajabifard *et al*. (eds.), A National Infrastructure for Managing Land Information- Research Snapshot (Ch. 9). pp. 88-94.

- ## Conference Papers

Aien, A., Rajabifard, A., Kalantari, M., Williamson, I., and Shojaei, D., 2014, **Development of XML Schemas for Implementation of a 3D Cadastral Data Model**, 4th International FIG 3D Cadastre Workshop, Dubai, United Arab Emirates.

Shojaei, D., Rajabifard, A., Kalantari, M., Bishop, I. and Aien, A., 2012, **Development of a 3D ePlan\LandXML Visualisation System in Australia**, 3rd International Workshop on 3D Cadastres: Developments and Practices, 25-26 October 2012, Shenzhen, China.

Aien, A., Kalantari, M., Rajabifard, A., Williamson, I., Shojaei, D., 2012, **Developing and Testing a 3D Cadastral Data Model- A Case Study in Australia**, ISPRS Annals of Photogrammetry, Remote Sensing and the Spatial Information Sciences. Volume I-4, pp.1-6, Melbourne, Australia.

- **Professional Magazines and Newsletters**

Shojaei, D., Rajabifard, A., Kalantari, M., Bishop, I., 2013, **3D Visualisation of 3D Cadastre**, Traverse Magazine, Volume 292, pp. 22-24.

Shojaei, D., Rajabifard, A., 2013, **Time to Visualise Cadastre in 3D**, geospatial TODAY, June Issue 2013, pp. 40-43.

Aien, A., Rajabifard, A., Kalantari, M., Williamson, I., Shojaei, D., 2011, **3D Cadastre in Victoria, Converting Building Plans of Subdivision to LandXML**, GIM International, Volume 25, Number 8, August.

Shojaei, D., 2013, **Time to Utilise 3D Visualisation Technologies in Cadastre**, Spatial Data Infrastructure Asia & the Pacific Newsletter, 10(8), p.3.

Shojaei, D., 2012, **3D Cadastre and Visualization**, Spatial Data Infrastructure Asia & the Pacific Newsletter, 9(7), p.3.

Shojaei, D., 2011, **3D Cadastral Visualization**, Spatial Data Infrastructure Asia & the Pacific Newsletter, 8(8), p.3.

APPENDIX (2)

QUESTIONNAIRE (1)

THE UNIVERSITY OF MELBOURNE

APPENDIX 2 – QUESTIONNIRE (1)

3D Cadastral Visualisation

Questionnaire Survey

Part 1- Introduction

The 3D Land and Property Information Project in the Centre for Spatial Data Infrastructure and Land Administration (CSDILA) investigates visualisation requirements for representing land and property ownership information in 3D.

This project is an Australian Research Council (ARC) Linkage Project (LP110200178) involving researchers from the CSDILA at the University of Melbourne and industry partners. The research team has prepared a questionnaire to identify the requirements of various users for developing a 3D visualisation system to support the land development process.

In addition to this introduction, the questionnaire is made up of three other parts: Participant's Information, Organisational Spatial Data Characteristics, and Visualisation Requirements Identification.

Specifically, part four (which has five sections) seeks information on: required data elements, user interface and system requirements, technical requirements, visualisation requirements, and analytical requirements. The questionnaire will take about 30 minutes and questions are multiple-choice selections or require only short answers, however, in some instances an option for further explanation is also provided.

Please be advised that your participation in this study is completely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so without prejudice. Due to the small sample size, you may be identifiable as a participant. However, the confidentiality of the information you provide will be safeguarded, subject to any legal requirements. In addition, please note that if you are in a dependent relationship with any of the researchers your involvement in the project will not affect ongoing assessment and management. The questionnaire will be stored at University of Melbourne and will be destroyed after five years. If you would like to participate, please indicate that you have read and understood this information by signing the accompanying consent form.

Please return the completed survey by:

- ***Fax***: + 61-3-9347 2916
- ***Post***: Davood Shojaei, Centre for Spatial Data Infrastructures and Land Administration, Dept of Infrastructure Engineering, the University of Melbourne, Victoria 3010, Australia.
- ***In person***: If we are already scheduled to have a meeting, you may choose to hand this survey back during my meeting with you.
- ***Scan***: email to: shojaeid@unimelb.edu.au
- ***Online:*** Please visit the following link if you would like to complete the survey online.

http://www.surveygizmo.com/s3/1354912/3D-Cadastral-Visualisation

Any additional information you may wish to provide by way of background or to promote discussion would be most welcome.

Your participation in this study is much appreciated.

Davood Shojaei

On behalf of Research Team (ARC-Linkage Project, Land and Property Information in 3D)

PhD Candidate

The University of Melbourne

Tel: (+61) 4 2626 5751

Email: shojaeid@unimelb.edu.au

Part 2: Participant Information

1. Name of your organisation:

2. Division/unit and position title:

3. How do you rate your experience in land and property ownership information?

☐ Less than a year ☐ 1 to 3 years ☐ 4 to 10 years ☐ More than 10 years ☐ Prefer not to say

4. What is your expertise?

☐ Land Surveyor ☐ Civil Engineer ☐ Architect ☐ Information Technology/Software Engineer ☐ Lawyer	☐ Developer ☐ GIS Specialist ☐ Other (please specify)……………………..

5. Which category describes your organisation accurately? (Please tick the most appropriate one).

☐ Local government (e.g. City council) ☐ Land registration services ☐ Land surveying ☐ Owners corporation ☐ Referral authority ☐ Architecture ☐ Planning consultant ☐ Legal consultant ☐ Real estate agency ☐ Academic/Research	☐ Financial institution (e.g. bank) ☐ Roads and transport ☐ Utility provider company ☐ Notaries ☐ The public/property owner ☐ Insurance Company ☐ Risk management ☐ Valuation and taxation ☐ Other (please specify)……………………..

6. If your organisation is not in Australia, please let us know your country of residence?

Part 3 – Land and property in 3D

Land and property information includes ownership information which is important for managing rights in land and buildings.

1. What are your organisation's activities regarding land and property ownership information?

☐ Create architectural plans
☐ Generate subdivision plans
☐ Examine and check plans to issue a plan permit
☐ Examine plans to validate them for registration
☐ Title registration
☐ View and explore land and property information only for your own needs (please specify your needs in comment section)
☐ Building management
☐ Research/Education
☐ Other (please specify) ……………………..

2. What kind of visualisation media do you think is best suited for your tasks in your opinion?(You may choose more than one)

☐ Paper-based plans (printed plan)
☐ Plan on computer screen (2D)-PDF version of plans which you can zoom in/out and pan
☐ 3D model on computer screen-a 3D model of the development with all details in 3D and use interactive tools such as measuring distances and creating cross-sections
☐ 3D model on mobile devices (iPhone, iPad, etc)- a 3D model of the development with all details in 3D and use interactive tools such as measuring distances and creating cross-sections.
☐ Other (please specify) ……………………..

3. What visualisation systems (software products) do you currently use in your organisation? and what is the purpose of using them?

Visualisation tool (software)	Purpose

4. What are the challenges and issues associated with visualising 3D models for land and property ownership information? (You may choose more than one)

□ Lack of 3D visualisation systems specifically for land and property ownership information. □ 3D visualisation is more complex than 2D representation. □ 3D visualisation systems (software products) do not meet users' needs. □ There are no standards for creating and representing of 3D models for 3D land and property ownership information. □ Added value or the benefit of using 3D is not clearly known. □ The cost of 3D technology is too high (required hardware and software) □ The high cost of generating 3D data □ No legal framework exists to encourage transition to 3D visualisation □ Lack of 3D specialists □ Other (please specify) ……………………..

5. If your organisation would like to move from current representation approach to a 3D digital representation for land and property ownership information, what are the drivers and motivations? (You may choose more than one).

□ 3D data is getting popular (Data driven); □ The increasing of availability of 3D technologies (Technology driven); □ Citizens, professionals and officials become more and more informed, educated, critical and connected (Public and professional demand); □ 3D virtual environments become part of the everyday life of individuals and organisations; □ 3D visualisation improves communications and facilitates dialogue; □ 3D visualisation is more oriented towards service providers and users □ To create a strong visual impression □ Facilitate the processes of managing land and property ownership information □ Better understanding of land and ownership information □ To discover new knowledge

☐ Help or facilitate decision making (at a strategic level)
☐ As a basis of normative activities (legal, fiscal, regulation aspects)
☐ To facilitate collaborative work
☐ To manage resources efficiently
☐ Help systems' efficiency with higher functionality
☐ Other (please specify) ……………………..

6. Do you utilise any type of 3D data in your organisation? What are the data formats?

☐ If yes, please specify......................

7. Does your organisation have any standard/regulation/guideline for data representation (2D/3D) which defines how data is delivered or represented, for example Building Subdivision Guidelines?

☐ If yes, please specify......................

Part 4: Visualisation Requirements Identification

Section 1: Data Requirements

8. To what extent do you agree with the following statement? I need to be able to visualise the following objects. If you require any of the examples given in each object category, even if not all, then base your answer on that requirement.

Legal Data

Class	Subclass	Comment
Spatial property unit (2D/3D parcel such as parcels, lots, common property, roads, easements, restrictions, crown land)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
Air and underground space (which define the ownership rights	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree -----------------	

above or below the ground)	(5) I am not sure (6) N/A	
Survey marks (e.g. reference marks, survey marks, cadastral marks)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Administrative boundaries (e.g. city or service boundary)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

9. To what extent do you agree with the following statement? I need to be able to visualise the following objects. If you require any of the examples given in each object category, even if not all, then base your answer on that requirement.

Physical Data

Class	Subclass	Comment
3D Building Models (Building structures e.g. walls, windows, doors, roofs, slabs, columns)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Topographical data (e.g. Digital Terrain Model, Contours)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Building utilities (e.g. pipes, cables, meters)	(0) Strongly disagree (1) Disagree (2) Neutral	

	(3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
City utilities (e.g. pipes, cables, sewage systems)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Building Facades I need to see façade of the buildings in the visualisation system. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
City structures (e.g. roads, railways, bridges, tunnels)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Aerial and satellite images	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

10. To what extent do you agree with the following statement? I need to be able to visualise the following ATTRIBUTES and ASSOCIATED DOCUMENTS. If you

require any of the examples given in each object category, even if not all, then base your answer on that requirement.

Attributes

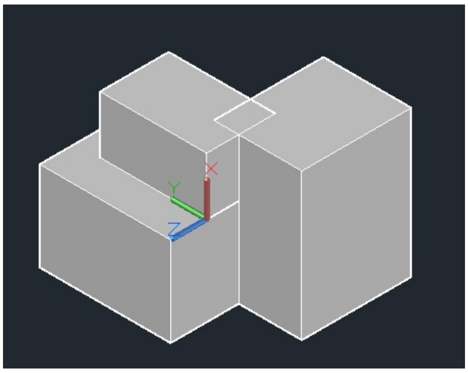
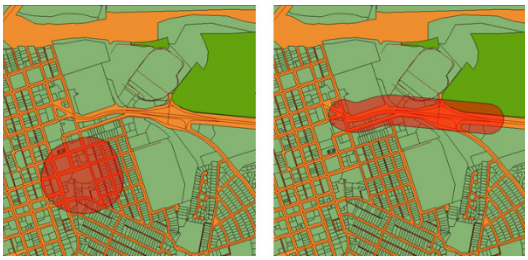
Class	Subclass	Comment
Annotations on subdivision plans (e.g. parcel information, address, restrictions and easements information, surveyor's firm, title information)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Survey Observations (e.g. official bearing and distances, areas)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Planning zones, schemes, controls, schedules	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

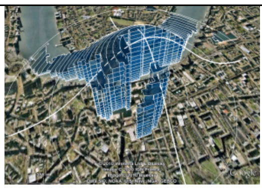
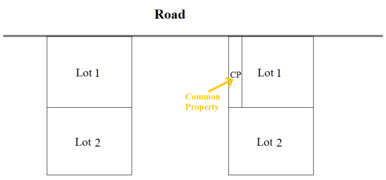
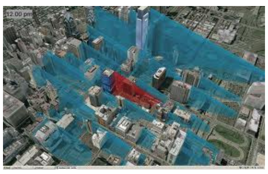
Part 4: Visualisation Requirements Identification

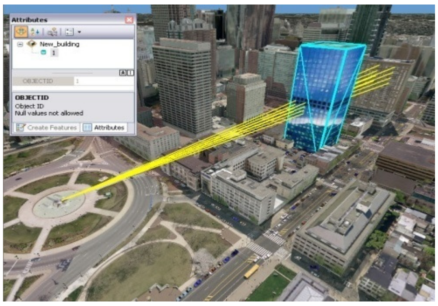
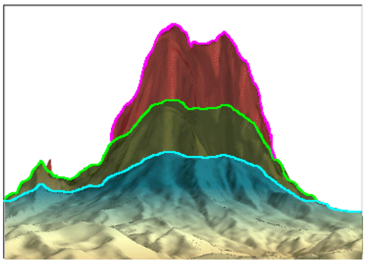
Section 2- Analytical Requirements

In your opinion, what analytical requirements should be supported by a system that you would use for visualising land and property ownership information in 3D?

Feature	Importance	Comment
The visualisation system must be able to examine spatial validity. For example, control volumes are closed, do not overlap, do not intersect with neighbour volumes, there are no unwanted gaps.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------	

	(5) I am not sure (6) N/A	
The visualisation system must support various search method (e.g. search by address, plan numbers, Volume folio). The visualisation system must support Non-Spatial Query (e.g. To find properties larger than 200 m2).	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
The visualisation system must have spatial measurement tools such as finding specific locations based on coordinates, calculating area, calculating volume, measuring angle/bearing, measuring distance.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
The visualisation system must have 3D buffer to query neighbour parcels to a 3D object, vertically as well as horizontally. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
The visualisation system should be able to visualise the result of functions and queries.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	

		
Using augmented reality facilitates representation of 3D land and property ownership information. Augmented reality is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data. Video	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
The visualisation system must able to represent temporal data and show the changes over the time. Video	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
The visualisation system must be able to control logical consistency among objects (e.g. 3D parcels (lots) are accessible through common property or roads). 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
The visualisation system must support shadow and shadow analysis. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure	

	(6) N/A	
The visualisation system must have tools for Line of sight and visibility analysis. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
The visualisation system must be able to use vertical exaggeration to emphasize height differences. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

Please add any other requirements if we did not mention in the above list.

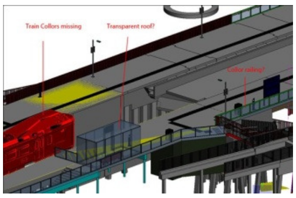
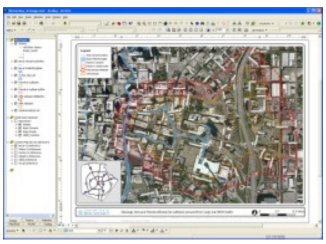
Feature	Details/Components	Importance	Comment
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	

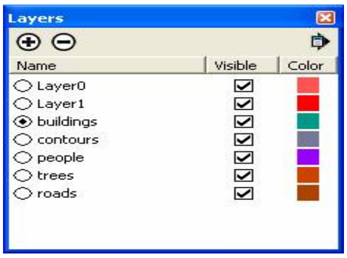
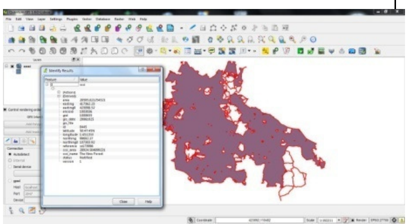
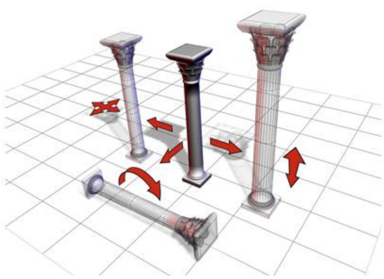
Part 4: Visualisation Requirements Identification

Section 3-User Interface and System Requirements

In your opinion, what interactive features should be supported by a system that you would use for visualising land and property ownership information in 3D? Use the space on the Comment column to add any comment.

Feature	Importance	Comment
Represent PDF Plans (e.g. Subdivision Plans	(0) Strongly disagree (1) Disagree (2) Neutral	

(PDF))	(3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
Represent PDF Plans (e.g. Architectural Plans including floor plans and cross-sections)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
I need to import/export popular 3D formats (e.g. 3D PDF, IFC, CityGML, KMZ).	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
I need commenting tools in the visualisation system to highlight an object for further review, to comment on objects, to mark a location.  	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	
I need Cartography tools (2D/3D map making tools) for reporting or documentation. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ----------------- (5) I am not sure (6) N/A	

I need to control layers. For example, I should be able to turn some layers (e.g. satellite image, roads) on or off.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I need to control objects. For example, I should be able to turn 3D objects (e.g. walls, doors, windows, lots) on or off.  	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I need to access to attributes of objects by clicking on each objects (identify tool). 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I need to manipulate objects (e.g. Rotate, Move, Scale objects, remove, add, and move nodes or divide or merge 3D objects). 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

The 3D visualisation system should support popular coordinate systems and datums.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I prefer to be able to create a user profile in the 3D visualisation system which is customised according to my requirements and preferences.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I should be able to select objects by mouse click.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
I need Keyboard shortcuts in the 3D visualisation system.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

Please add any other requirements if we did not mention in the above list.

Feature	**Details/Components**	**Importance**	**Comment**
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	

Part 4: Visualisation Requirements Identification

Section 4- Technical Requirements (non-functional requirements)

In your opinion, what technical requirements should be supported by a system that you would use for visualising land and property ownership information in 3D?

Feature	Importance	Comment
What type of visualisation system do you prefer? (You may choose more than one) 	☐ Desktop-based 3D visualisation systems ☐ Web-based 3D visualisation systems ☐ Mobile-based 3D visualisation systems (Mobile Application) ☐ Not Applicable ☐ I am not sure	
I prefer open-source software rather than propriety software.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

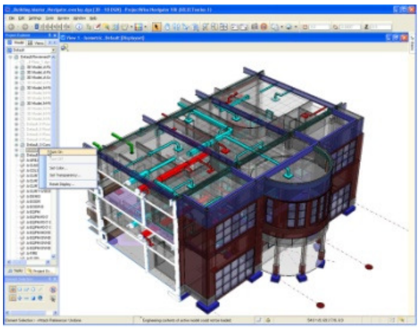
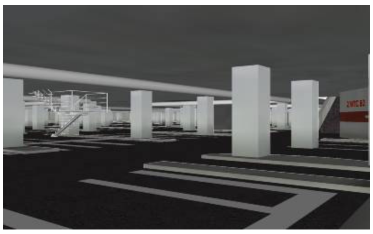
Please add any other requirements if we did not mention in the above list.

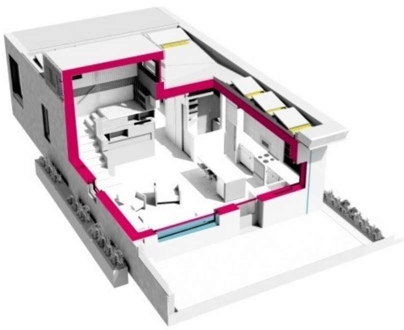
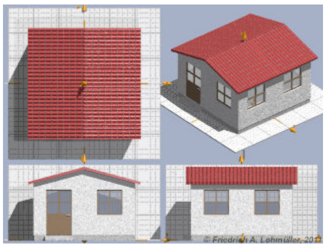
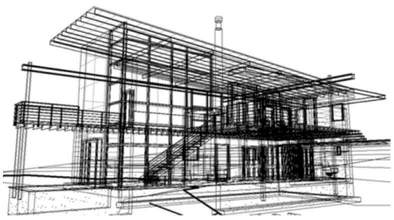
Feature	Details/Components	Importance	Comment
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	

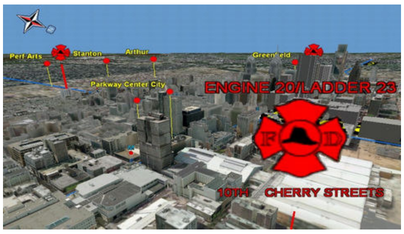
Part 4: Visualisation Requirements Identification

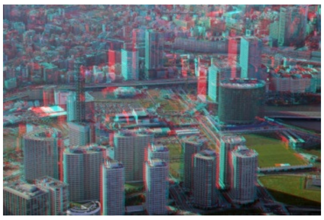
Section 5- Visualisation Requirements

In your opinion, what visualisation requirements should be supported by a system that you would use for visualising land and property ownership information in 3D?

Feature	Importance	Comment
City view (to see the city and location of the development in the city) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Model view (to see the development individually and not with neighbouring developments) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Visualisation system must be able to represent underground developments (e.g. underground car parks). 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
The visualisation system must have Cross-section tool to create section views.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree	

	------------------ (5) I am not sure (6) N/A	
Indoor view (to see inside the development) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Top, bottom, front, rear view 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Wireframe view (to see how the development looks without texture and material) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Explode view (to show the components of an object slightly separated by distance)	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

		
I need to have Google street view (up-to-date) in the visualisation system. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Users must be able to manage labels in 2D and 3D in the visualisation system. 2D labels are fixed to the scene and 3D labels are rotated based on the user's view. 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Users must be able to change visual variables such as thickness, colour, transparency, symbol, line-style in the 3D visualisation system.	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Day and Night view (to see how the development looks at night) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

Stereo view (to see real 3D models using 3D glasses) 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Atmospheric effects	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Sun & moon light effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Season effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Fog effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Cloud effects	(0) Strongly disagree (1) Disagree (2) Neutral	

	(3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Air pollution effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Wind effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Rain effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	
Visibility range effects 	(0) Strongly disagree (1) Disagree (2) Neutral (3) Agree (4) Strongly agree ------------------ (5) I am not sure (6) N/A	

Please add any other requirements if we did not mention in the above list.

Feature	**Details/Components**	**Importance**	**Comment**
		(2) Neutral (3) Agree (4) Strongly agree	

		(2) Neutral (3) Agree (4) Strongly agree	
		(2) Neutral (3) Agree (4) Strongly agree	

5- Are there any features you think would be desirable in a 3D visualisation system for cadastral applications?

Thank you for taking our survey. Your response is very important to us.

APPENDIX (3)

QUESTIONNAIRE (2)

APPENDIX 3 – QUESTIONNIRE (2)

RESEARCH QUESTIONNAIRE FOR EVALUATING THE 3D CADASTRAL VISUALISATION SYSTEM

Land and Property Information in 3D Project
Centre for SDIs and Land Administration
Department of Infrastructure Engineering
The University of Melbourne

Part 1- Introduction

The Land and Property Information in 3D Project[101] in the Centre for Spatial Data Infrastructures and Land Administration[102] explores implementation of 3D land and property information. As part of the objectives of this project, the research team have designed and developed a 3D visualisation system for visualisation of property information. In this questionnaire we seek your feedback regarding the functionality, usability and efficiency of the system.

This questionnaire consists of 4 sections including 35 questions regarding participant's information, and evaluation of the functionality, usability, and efficiency of the 3D visualisation system. The questions are designed for short answers or selection of multi-choice answers; however, in some instances we encourage you to provide extended comments. It takes about 15 minutes to be completed, after a period of usage of the system.

The 3D visualisation system can only be tested on a single property which has been modelled for testing purposes. In a wider implementation, the system might be used to gain an understanding of the property information of an individual building, or to explore property details across a multi-building development, or a city block. When answering the questions, please consider the situation in which a full set of 3D data is available for a region of interest.

Please be advised that your participation in this study is completely voluntary. Should you wish to withdraw at any stage, or to withdraw any unprocessed data you have supplied, you are free to do so without prejudice. The confidentiality of the information you provide will be safeguarded, subject to any legal requirements. In addition, please note that if you are in a dependent relationship with any of the researchers your involvement in the project will not affect ongoing assessment and management. The questionnaire will be stored at the University of Melbourne and will be destroyed after five years. Please indicate that this information will be kept confidential and without use of your name.

In advance we would like to thank you for your participation and input to this survey.

[101] http://csdila.unimelb.edu.au/projects/3dwebsite/
[102] http://csdila.unimelb.edu.au/

I hereby provide INFORMED CONSENT to take part in the Questionnaire.

Davood Shojaei
Email: shojaeid@unimelb.edu.au, Tel: 04 2626 5751
Address: Centre for SDIs and Land Administration
C416, Level 4, Engineering Block C,
The University of Melbourne
Parkville 3010 VIC Australia

Part 2- Participant's Information

1. Name of your organisation and Division/Unit:

2. Your Position in your organisation:

Part 3- Evaluation of System Functionality

This section aims at evaluating the functionality of the '3D Cadastral Visualisation Prototype System'.

3. To what extent do you agree with the following statement?

"I found this 3D visualisation system more useful than 2D plans (e.g. architectural plans, subdivision plans, etc) for understanding ownership boundaries."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

4. To what extent do you agree with the following statement?

"Integration of physical (walls, doors, ceilings, and floors) and legal objects (lots, easements, common property) in the 3D visualisation system facilitates understanding of ownership boundaries."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

5. What do you see as the advantages of integrating legal and physical objects against only representing legal objects?

6. To what extent do you agree with the following statement?

"Visualising some physical building components such as slabs and walls which are considered as common property (shared areas) may increase the complexity of a 3D model; therefore a simpler model without them, is preferred."

Strongly disagree						Strongly agree
	1	2	3	4	5	

7. To what extent do you agree with the following statement?

"Utilising such 3D web-based visualisation systems will improve communication of 3D cadastral data among various users".

Strongly disagree						Strongly agree
	1	2	3	4	5	

8. To what extent do you agree with the following statement?

"Utilising such a system will improve managing of ownership rights."

Strongly disagree						Strongly agree
	1	2	3	4	5	

9. Does the 3D visualisation system meet your needs?
10. If your answer to this question is 'No', would you explain why?

11. To what extent do you agree with the following statement?

"The 3D presentation of property information is effective in helping me complete my tasks."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

12. How satisfied are you with this system as a way of presenting 3D property information (e.g. underground lots) and the available functions? Please include any comments regarding your level of satisfaction.

Strongly dissatisfied						**Strongly satisfied**
	1	2	3	4	5	

13. To what extent do you agree with the following statement?

"I believe I quickly became more productive when using this system."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

14. To what extent do you agree with the following statement?

"I can see that this system would potentially contribute to improving productivity in my daily tasks."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

15. To what extent do you agree with the following statement?

"I would like to see this 3D visualisation system implemented for decision making processes in my organisation."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

16. To what extent do you agree with the following statement?

"A web-based visualisation system is more effective than a desktop-based system."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

17. To what extent do you agree with the following statement?

"Not needing to install a plug-in is beneficial from a security and convenience point of view."

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

18. Please list the perceived negative aspects of the 3D visualisation system:

19. Please list the perceived positive aspects of the 3D visualisation system:

20. Please give us at least one good idea to improve the functionality of the 3D visualisation system.

    •

21. Please give us at least one good idea to improve representation of ownership information in this system.

Part 4 - Evaluation of System Usability

This section aims at evaluating the usability of the '3D Cadastral Visualisation Prototype System'.

22. To what extent do you agree with the following statement?

    - ***"I feel comfortable using this system."***

Strongly disagree						Strongly agree
	1	2	3	4	5	

23. To what extent do you agree with the following statement?

    - ***"The system is user friendly."***

Strongly disagree						Strongly agree
	1	2	3	4	5	

24. To what extent do you agree with the following statement?

    - ***"The information (such as subdivision plans, on-screen messages, and other documentation) provided with this system is clear."***

Strongly disagree						Strongly agree
	1	2	3	4	5	

25. To what extent do you agree with the following statement?

    - ***"It is easy to find the information I needed."***

Strongly disagree						Strongly agree
	1	2	3	4	5	

26. To what extent do you agree with the following statement?

    - ***"The functions in this system are well positioned in the interface."***

Strongly disagree						Strongly agree
	1	2	3	4	5	

27. To what extent do you agree with the following statement?

    - ***"I like the interface of this system."***

Strongly disagree	Strongly agree

1	2	3	4	5

28. Please give us at least one suggestion to improve the interface?

29. To what extent do you agree with the following statement?

- ***"I need the support of a technical person to be able to use this system."***

Strongly disagree						**Strongly agree**
	1	2	3	4	5	

Part 5 - Evaluation of System Efficiency

This section aims at evaluating the efficiency of the '3D Cadastral Visualisation Prototype System'.

30. You have been given a subdivision plan of a high-rise building. In this case, how much time did you take to identify the ownership boundaries of an apartment (e.g. Unit 514)?

31. Also, in this case, how much time did you take to identify the associated common property attached to this apartment (e.g. Unit 514) using the subdivision plans?

32. In addition, in this case, how much time did you take to identify the associated parking lot attached to this apartment (e.g. Unit 514) using the subdivision plans?

33. Now, you already have the 3D model of this high-rise building in this 3D visualisation system. In this case, how much time do you approximately spend to identify the ownership boundaries of the apartment (Unit 514)?

34. Also, in this case, how much time did you take to identify the associated common property attached to this apartment (Unit 514)?

35. In addition, in this case, how much time did you take to identify the associated parking lot attached to this apartment (Unit 514)?

36. To what extent do you agree with the following statement?

"Using a system like this 3D visualisation system will result in saving time for understanding

ownership rights and associated information in my organisation."

Strongly disagree	1	2	3	4	5	**Strongly agree**

37. To what extent do you agree with the following statement?

"Using a system like this 3D visualisation system may result in cost savings for my organisation."

Strongly disagree	1	2	3	4	5	**Strongly agree**

Finally, please let us know if you have any comments.

If you are happy to talk further about the 3D visualisation system, please leave your contact details in this box.

Thank you for taking our survey. Your response is very important to us.