Developing a 3D Digital Cadastral Survey System for New Zealand

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Abstract

New Zealand currently has a world-class property rights system that underpins the delivery of social, economic, and cultural benefits. This system comprises a land tenure system to provide certainty about property rights and a supporting cadastral survey system to provide certainty about the spatial extent of those rights. However, there is an increasing concern that New Zealand's property rights system will not continue to be optimal in the future. A significant contributing factor to this concern is the inability of the cadastral survey system to handle three-dimensional (3D) information defining the spatial extents of property rights in a digital environment.

The development of 3D cadastral survey systems is the subject of a substantial body of international research and discussion. Despite this, no country in the world has successfully implemented a fully functioning 3D digital cadastral survey system. Also, while New Zealand has an interest in developing a 3D digital cadastral survey system, there is no substantive local research on the matter. The research undertaken as part of this thesis will contribute to the literature by providing a New Zealand perspective on developing such a system and will also feed into the development of New Zealand's cadastral survey system.

This research explores New Zealand's current cadastral survey system and considers the motivation for its enhancement. The literature supporting international research and development is evaluated to determine the characteristics, opportunities, issues and approaches associated with developing a cadastral survey system with 3D digital capabilities. A preferred approach to a 3D digital cadastral survey system is established and then developed at a conceptual level after it was found that an internationally standardised approach was inadequate.

Abbreviations

The following list of abbreviations might be useful to readers interested in specific chapters or sections of the thesis, thereby possibly missing the initial, expanded version. The list may also prove useful to those readers of the whole thesis that wish to refresh their understanding of an abbreviation conveniently at a later point in time.

2D	Two Dimensions *or* Two-Dimensional
3D	Three Dimensions *or* Three-Dimensional
ASaTS	Advanced Survey and Title Services
BIM	Building Information Modelling
CSD	Cadastral Survey Dataset
DCDB	Digital Cadastral Database
FIG	International Federation of Surveyors (Fèdèration Internationale des Gèometres)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
INSPIRE	Infrastructure for Spatial Information in the European Community
ISO	International Organisation for Standardisation
LADM	Land Administration Domain Model
LINZ	Land Information New Zealand
NZGD1949	New Zealand Geodetic Datum 1949
NZGD2000	New Zealand Geodetic Datum 2000
NZIS	New Zealand Institute of Surveyors
NZVD2009	New Zealand Vertical Datum 2009
OGC	Open Geospatial Consortium
UML	Unified Modelling Language

Glossary

alienation	occurs when a landowner (including the Crown) grants certain rights of their land to another person(s)
aspatial survey information	cadastral survey data that is not digitally captured in Landonline and, therefore, incapable of being integrated into the digital cadastre (Standard for lodgement of cadastral survey datasets 2013)
Building Information Modelling (BIM)	a digital representation of physical and functional characteristics of a facility (Eastman, Eastman, Teicholz, & Sacks, 2011)
cadastral survey	the determination and description of the spatial extent (including boundaries) of interests under a tenure system (Cadastral Survey Act 2002)
cadastral survey dataset	the set of cadastral survey data necessary to integrate a cadastral survey into the cadastre (Cadastral Survey Act 2002)
cadastral survey system	the overall framework for the determination and management of the spatial extents of property rights, and includes: the cadastre, physical boundary and survey marks, regulations, rules and standards, required competencies and occupational regulation (Land Information New Zealand, 2014c)
Cadastral Surveyors Licensing Board of New Zealand	a statutory Board, pursuant to the Cadastral Survey Act 2002 with the primary function to administer the licensing of cadastral surveyors to conduct cadastral surveys
cadastre	in New Zealand, means all the cadastral survey data held by or for the Crown and Crown agencies (Cadastral Survey Act 2002)
Crown	'the Crown' is the Government of New Zealand acting on behalf of Her Majesty the Queen (Accident Compensation Act 1972)
Crown land	land vested in Her Majesty the Queen which is not for the time being set aside for any public purpose or held in freehold by any person (Land Act 1948)
ellipsoid	a mathematical approximation of the shape of the Earth formed by rotating an ellipse about an axis

ellipsoidal height	an elevation measured in terms of (above or below) an ellipsoid
Esri	an international supplier of Geographic Information System (GIS) software and related applications
Esri shapefile	a vector data storage format for storing the location, shape and attributes of geometric features (Esri, 2015)
freehold title	the highest form of private property ownership (estate) in New Zealand
general land	land that is not Māori land and that has been alienated from the Crown
geodetic datum	a reference system for describing positions on the curved surface of the Earth
geodetic system	enables positions on the surface of the Earth to be determined by reference to a mathematical model that describes the size and shape of the Earth
geoid	an undulating mathematical surface that is related to the Earth's gravitational field that approximates mean sea level
horizontal datum	a mathematically defined reference surface from which to determine horizontal positions
Intergovernmental Committee on Surveying and Mapping (ICSM)	comprises Australian and New Zealand jurisdictions to coordinate and promote the development and maintenance of key spatial data (Intergovernmental Committee on Surveying and Mapping, 2015)
Landonline	the designated electronic facility for receiving, storing and managing cadastral survey datasets
Least squares adjustment	a statistical technique to evaluate positional coordinates and their errors
licensed cadastral surveyor	a person licensed to undertake cadastral surveys pursuant to Part 3, Cadastral Survey Act 2002
Māori land	land held in indigenous title as Māori customary land or Māori freehold land
national survey control system	a system used to determine the position of points, features, and boundaries in cadastral surveys, other surveys, and land information systems (Cadastral Survey Act 2002)

New Zealand Institute of Surveyors (NZIS)	an incorporated society to monitor and maintain the professional and ethical conduct of surveyors in New Zealand (New Zealand Institute of Surveyors, 2015)
node	the coordinated spatial representation of the location of a survey mark or boundary point in a digital cadastral survey system (Standard for lodgement of cadastral survey datasets 2013)
non-primary parcel	a parcel associated with a primary parcel but with lesser rights (e.g., an access easement)
normal-orthometric height	a height measured in terms of (above or below) a geoid
Open Geospatial Consortium (OGC)	an international voluntary consensus standards organisation (Open Geospatial Consortium, 2015a)
parcel	an area or space that is a single contiguous portion of land separately identified in a cadastral survey dataset or in the integrated cadastre (Rules for Cadastral Survey 2010)
permanent structure	a building or recognisable physical structure that is likely to remain undisturbed for fifty years or more (Rules for Cadastral Survey 2010)
permanent structure boundary	a boundary defined by its relationship to a building or recognisable structure of suitable permanence (Rules for Cadastral Survey 2010)
primary parcel	the main ownership parcel
real property	property that is attached directly to the land and includes the land itself
reduced level	an elevation expressed in terms of a vertical datum
Smart City	a city that uses digital technologies to create a knowledge infrastructure to enhance the quality and performance of its services (Caragliu, Del Bo, & Nijkamp, 2011)
spatial information	in the context of data in the cadastre, is cadastral survey data that is digitally captured in Landonline and, therefore, capable of being integrated into the digital cadastre (Standard for lodgement of cadastral survey datasets 2013)

strata parcel	a parcel defined in the upper and lower extents by either a stratum boundary or permanent structure boundary (Rules for Cadastral Survey 2010)
stratum boundary	a boundary that defines the upper or lower extent of a parcel (Rules for Cadastral Survey 2010)
tenure	the kind of right by which land is held (Cadastral Survey Act 2002)
tenure system	a formal system that provides for the creation, recording and transfer of interests in land (Cadastral Survey Act 2002)
territorial authority	a city council or a district council in New Zealand (Local Government Act 2002)
topology	defines and enforces data integrity rules for geometric features (e.g., 'there should be no overlapping parcels') (Esri, 2015)
Unified Modelling Language (UML)	a de facto industry standard for visualising, specifying and documenting the components of a software-intensive system (Rumbaugh, Jacobson, & Booch, 2004)
vector	a bearing and distance between two points
vertical datum	a mathematically defined reference surface from which to determine elevations

Publication Related to this Research

Gulliver, T., & Haanen, A. (2014). *Developing a Three-Dimensional Digital Cadastral System for New Zealand*. Paper presented at the 25th FIG Congress 2014, Kuala Lumpur.

1 Introduction

1.1 Research Area and Motivation

New Zealand has a three-dimensional (3D) property rights system that is considered to be Accurate, Authoritative and Assured (Grant, Dyer, & Haanen, 2014). This system, which comprises a digital cadastral survey system that supports a digital land tenure system, consistently rates as providing the strongest private property rights in the world. According to Miller and Kim (2015), authors of the Heritage Foundation's annually produced Index of Economic Freedom, New Zealand, alongside Denmark, currently has the strongest property rights out of 186 ranked countries. It is stated in the 2015 Index of Economic Freedom that New Zealand's "private property rights are strongly protected, and contracts are notably secure" (Miller & Kim, 2015, p. 338). Despite this reassurance, Grant et al. (2014) proclaim that the New Zealand system will not be optimal for the next ten to twenty years. A significant contributing factor to this concern is directed at the inability of the cadastral survey system to handle 3D data for the spatial extents of property rights (along with any associated restrictions and responsibilities) digitally.

The primary purpose of the cadastral survey system is to define the spatial extents of rights, described by Grant et al. (2014) as "the where", thus promoting certainty of ownership. New Zealand's system presently caters for the third dimension through two-dimensional (2D) plan and elevation graphics supported by textual descriptions. This portrayal no longer meets the current expectations of government, land professionals and the public, and does not support the efficient collection and presentation of 3D cadastral data offered by modern technologies (Gulliver & Haanen, 2014). With this awareness, Land Information New Zealand (LINZ), the government department responsible for administering the property rights system, is currently investigating enhancing the system, including researching, developing and implementing digital 3D capabilities.

The development of 3D cadastral survey systems is the subject of a substantial body of international research and discussion. Despite the level of enthusiasm for and commitment to the subject, this research confirms that no country in the world has successfully implemented a fully functioning 3D digital cadastral survey system. This could be a reflection of the complexity of 3D cadastral systems as a research topic. Also, although New Zealand has an interest in developing a 3D digital cadastral survey system, there is no substantive local research on the matter.

The research undertaken as part of this thesis will contribute to the international volume of literature by providing a New Zealand perspective on developing a 3D digital cadastral survey system. This research will also provide a valuable contribution to the work being undertaken by LINZ to develop the system.

1.2 Research Formulation

New Zealand currently has a 2D digital cadastral survey system that is not digitally representative of the 3D real-world situation. While a desire to enhance the system is supported by a significant volume of international research, there is limited local content to ensure due consideration in terms of the New Zealand context. Therefore, the primary research problem for this thesis is:

> *New Zealand's appreciation for and understanding of 3D digital cadastral survey system characteristics, opportunities, issues and approaches is incomplete thus compromising the ability to determine appropriate solutions for developing a 3D digital cadastral survey system.*

The research will facilitate an understanding of the characteristics, opportunities and issues associated with the New Zealand context, and seek to identify and develop a specific solution to enhance New Zealand's digital cadastral survey system. Hence, the primary objective of the research is to:

> *Identify and consider the key characteristics, opportunities, issues and approaches to establishing a 3D digital cadastral survey system, and apply that knowledge to develop a solution to enhance the 3D capabilities of New Zealand's digital cadastral survey system.*

The research problem and research objective flow into the following research questions:

1. *What is the current status of 3D in New Zealand's digital cadastral survey system?*
2. *What are the characteristics, opportunities and issues of a 3D digital cadastral survey system for New Zealand?*
3. *Should New Zealand develop the existing 2D digital cadastral survey system to allow 3D digital data?*

4. *What are the specific requirements of a 3D digital cadastral survey system for New Zealand?*
5. *Is there an approach to developing a 3D digital cadastral survey system that is best suited to the New Zealand situation?*

1.3 Scope

There are two primary reasons why the development of a 3D digital cadastral survey system for New Zealand requires a very broad scope of research. Firstly, the distinct lack of local literature means that the research scene is yet to be established in terms of the New Zealand context. Secondly, the timing of this research coincides with an intention of the New Zealand government, through LINZ, to undertake a significant enhancement of the current national property rights system. This desire will benefit from research in which the characteristics, opportunities, issues and approaches to establishing a 3D digital cadastral survey system are initially considered holistically and then applied specifically to the New Zealand situation.

The primary objective of this research includes an ambition to develop a solution to enhance the 3D capabilities of New Zealand's digital cadastral survey system. It is not the aim of this research to develop an operational 3D digital cadastral system, as that is considered beyond the scope of this research. Instead, this thesis develops a solution at the conceptual level, which may then be used to form the basis of the development of a 3D digital cadastral survey system.

The New Zealand cadastral survey system has relationships with other systems, including tenure systems and the geodetic system. While the relationships between systems will be explained, this research will maintain a primary focus on the cadastral survey system, including for the development of any solution at the conceptual level.

1.4 Research Approach

This research primarily employed a non-empirical approach based on an extensive review of the literature to develop an in-depth understanding of the characteristics, opportunities and issues of 3D cadastral survey systems. The consideration and development of ideas was assisted through communication with relevant parties and through attendance and contributions at national and international conferences related to the area of research. Key concepts and ideas are presented and evolved with the assistance of case studies.

The review of the literature included relevant international and national research papers, textbooks and New Zealand legislation, statutory rules and published guidelines. The Office of the Surveyor-General was consulted for support and guidance throughout the research. The Office of the Surveyor-General and also the Office of the Registrar-General of Land, which regulates the land tenure registration components of the property rights system, were consulted to seek clarity on the intent and interpretation of relevant legislation. The LINZ Advanced Survey and Title Services project team (responsible for assessing the delivery of property services by LINZ), to which the author is an assigned resource, have been consulted with regard to inputs and outputs of this research.

In 2014 the author attended the XXV FIG (International Federation of Surveyors) Congress in Kuala Lumpur, Malaysia. Together with Deputy Surveyor-General, Anselm Haanen, the author prepared the paper, 'Developing a Three-Dimensional Digital Cadastral System for New Zealand'(Gulliver & Haanen, 2014), which was presented at the congress. Also in 2014, the author attended the NZIS (New Zealand Institute of Surveyors) Conference in New Plymouth, New Zealand. A contribution to this conference was the preparation of a presentation relating to developing 3D capabilities for New Zealand's cadastral survey system. This presentation was delivered by the Surveyor-General for New Zealand, Mark Dyer. This year (2015) the author attended the South East Asian Survey Congress in Singapore. These conferences all provided invaluable opportunities to connect and converse with key 3D data researchers and users from New Zealand and around the world. These communications allowed the author to advance his knowledge by testing ideas and theories for developing a 3D digital cadastral survey system.

This thesis also employs case studies to demonstrate specific areas of research. Two case studies are used to demonstrate to the reader how New Zealand's existing digital cadastral survey system handles information about property rights that are defined in 3D. These case studies articulate the limitations of the existing system. A third and final case study is used to explain how a 3D solution, identified and developed by this research, might be used to enhance New Zealand's digital cadastral survey system.

1.5 Significance of this Research

The New Zealand government has recently given approval for LINZ to develop a business case to advance the cadastral survey system to the next level, including the development of 3D capabilities. The research undertaken as part of this thesis will contribute significantly to the work being undertaken by LINZ. The author is particularly enthusiastic and motivated by the opportunity to provide a tangible contribution to developing the cadastral survey system for the benefit of New Zealand as a whole.

The research area of 3D digital cadastral systems, together with the objective of this research, lends itself to a potentially large audience of interested parties. In addition to fellow researchers, these could include central and local government, surveyors, conveyancers, those with or wishing to obtain a legal interest in land and also the general public. All of these parties would benefit from a system that can reflect the true principle of property rights: property rights entitle people to volumes and not just an area. The benefits are likely to flow beyond New Zealand's borders. Other countries may find the research of use or even inspirational in the development of their own 3D digital cadastral survey system.

1.6 Statement of Positionality

The author, Trent Gulliver, obtained a National Diploma in Surveying from the Unitec Institute of Technology in Auckland, New Zealand, in 2002. In 2005, he graduated with a Bachelor of Surveying with Honours from the National School of Surveying at the University of Otago in Dunedin, New Zealand. This period was followed by five years' post graduate employment with two private practice multi-disciplinary (surveying, engineering & planning) consultancies, during which time the author qualified for and obtained a licence to undertake cadastral surveys from the Cadastral Surveyors Licensing Board of New Zealand. The past five and a half years have been with LINZ in two separate yet related roles.

The author's first role at LINZ was as Technical Advisor – Licensed Cadastral Surveyor with an audit team. This role comprised both external and internal audit functions. External auditing involved assessing compliance of licensed cadastral surveyors with standards required by legislation, specifically the Cadastral Survey Act 2002. These audits, performed on behalf of the Surveyor-General, required field inspections and face-to-face office interviews with surveyors. A focus and highlight of the audit work was to consider and promote good practice as a means to increase and benefit from first-time compliance with cadastral survey system standards. Internal auditing involved being a technical expert in audits throughout LINZ. These external and internal audits had the benefit of increasing the author's understanding of the cadastral survey system and other related systems. The author's interaction with users of the system provided a useful insight into particular benefits and frustrations relating to the functionality of the system.

After over three and a half years in the audit role, the author transitioned into his current role as Senior Cadastral Survey Advisor with the Office of the Surveyor-General. In this regulatory role the author has the privilege and benefit of working closely with staff that collectively have the depth and breadth of knowledge and understanding of the cadastral survey system that he aspires to obtain. This research has provided an ideal medium for the author to engage with these staff to increase his level of knowledge and understanding of the system.

Part-time work towards the Master in Geographic Information Science commenced in 2011 after the author was awarded a LINZ study scholarship. This financial scholarship covers university fees, associated expenses and study leave. LINZ is also credited for the role it played in determining the topic of research. Specifically, Anselm Haanen, Deputy Surveyor-General, who in late 2013 commented to the author that 3D enabling New Zealand's digital cadastral survey system was an area of interest to the Office of the Surveyor-General. This interest in developing the system is reflected in the now published LINZ cadastral strategy (Land Information New Zealand, 2014c).

The author's career in surveying, current role in the Office of the Surveyor-General, knowledge of the system and relationships with its users, is seen as a significant strength to this research. This strength, however, is tempered by a risk that the close connection to the existing system may subliminally bias the author's openness to explore new ways of doing things. The author notes and accepts this as a risk to the outcomes of this research.

1.7 Structure of Chapters

Chapter 1 (this chapter) provides an introduction to the area of research and presents the motivation behind the need for this research. The research is then formulated beginning with a problem statement from which the primary objective and specific research questions are subsequently developed. This is followed by the outlining of an approach to fulfilling the objective of this research. The significance of the research is discussed to emphasise the relevance of the thesis and the potential value that it might add. A statement of positionality is provided to enable readers to understand the relationship that the author has with the subject matter and how that relationship might benefit or bias this research.

Chapter 2 documents the status of 3D in New Zealand's cadastral survey system. The aim of this chapter is to develop an understanding of the current state, thus establishing a baseline for the research to be defined. The knowledge obtained in the course of developing this chapter is applied to progress the development of a 3D digital cadastral survey system for New Zealand in the subsequent chapters. The chapter commences with an investigation into New Zealand's institutional framework of laws, regulations, standards and procedures. The institutional framework provides a platform from which to investigate the development of survey regulation in New Zealand. This look at the past sets the scene for the consideration of the current state. Institutional framework is followed by an overview of the current technical and operational processes, and the role of the integrated survey and title recording and delivery system, 'Landonline', in supporting these processes. Case studies are then used to demonstrate how surveys involving 3D boundaries are currently captured and handled by the system. Following the discussion on the current system, the motivation and support for developing a fully digital cadastral survey system is presented, including a series of LINZ initiatives that either promote or would benefit from a 3D digital cadastral survey system.

Chapter 3 documents the discussion from the review of the literature supporting research and development of 3D cadastral systems. The review commences with a historical overview of cadastral systems and its product, the cadastre. The key characteristics of cadastral systems are then set into the context of land administration. This flows on to an introduction to the concept of 3D cadastre followed by consideration for the development of 3D cadastres on a global scale. Discussion on the international status of 3D cadastres leads into the identification of issues and opportunities of 3D cadastres.

Chapter 4 presents the proposed development of a 3D digital cadastral system for New Zealand based on knowledge obtained and documented in the preceding chapters. Discussion on developing a 3D digital cadastral system commences with the definition of the term '3D digital cadastre' for the New Zealand context. The definition of 3D digital cadastre leads into documenting the generic requirements of a 3D digital cadastral system. These requirements are followed by the identification and examination of approaches to enable a 3D digital solution. Following consideration of the merits associated with each approach a preferred option is selected and subsequently developed through the elaboration of detailed requirements. The detailed requirements of a 3D digital system then allow specific components or impacts of the system to be identified and discussed. From this point the focus of the discussion evolves into developing a preferred approach to enhance the system.

Data modelling principles are applied to advance the concepts associated with the preferred approach to developing the system. An existing land administration data model is initially evaluated with regard to its applicability to New Zealand. A completely new data model to account for the New Zealand context is then presented and documented at a conceptual level. This data model provides the structure from which a case study demonstrates how analogue processes might be transformed to enable a fully digital 3D system.

Chapter 5 begins by revisiting the problem statement and primary objective of this research. The key findings of the research, which are incorporated within each chapter, are then reiterated and discussed further. Findings are examined in the light of the previous research with final conclusions based on what has been learnt from this research. Conclusions are structured to address the research questions. The research is concluded with a look to the future and how this thesis might influence subsequent research.

2 Status of 3D Cadastral Survey System in New Zealand

The administration of New Zealand's land resources is facilitated by a property rights system that is considered by its administrative authority, LINZ, to be Accurate, Authoritative and Assured (e.g., Grant et al., 2014; Gulliver & Haanen, 2014). This self-proclaimed AAA rating is justified to some extent through the analysis of data published by The Heritage Foundation and The Wall Street Journal about the quality of a country's property rights. In the annually produced Index of Economic Freedom (The Heritage Foundation and Wall Street Journal, 2015), New Zealand ranks as either first outright or first equal out of 186 countries for each year of publication's twenty-year history (1995 to 2015 inclusive), in the category associated with the strength and security of property rights.

The Index of Economic Freedom emphasises the importance of property rights to a country's economic and social status, and hence, the value of its underlying survey and tenure systems. This chapter demonstrates how New Zealand's cadastral survey system contributes to the property rights system and interacts with other systems, including tenure systems. An examination of the cadastral survey system is presented both in a general sense and with special consideration for property rights that are defined in 3D. The following discussion is divided into six primary sections, commencing with New Zealand's institutional framework of laws, regulations, standards and procedures. The institutional framework provides a platform from which to investigate the development of survey regulation in New Zealand. This look at the past sets the scene for the consideration of the current state. Institutional framework is followed by an overview of the current technical and operational processes, and the role of the integrated survey and title recording and delivery system, Landonline, in supporting these processes. Case studies are then used to demonstrate how surveys involving 3D boundaries are currently captured and handled by the system.

The first three sections provide the context for the fourth section which outlines the motivation and support for developing a fully digital cadastral survey system. A fifth section identifies a series of LINZ initiatives that either promote or would benefit from a 3D digital cadastral survey system. The chapter is concluded with a summary of the status of 3D in New Zealand's cadastral survey system.

2.1 Institutional Framework

2.1.1 Development of Survey Regulation in New Zealand

In common with most countries that have an organised system of land ownership, New Zealand has a well-developed cadastral survey system that is founded on a well-educated and competent profession with an effective system of administration (Bevin & Haanen, 2002; Hawkey, 1977). While this statement provides additional support for statements about quality, New Zealand's property rights system has not always been well organised and robust. This is particularly due to issues that surfaced during the formative years of the cadastral survey system.

The origin of New Zealand's cadastral survey system can be traced back to instructions that Queen Victoria gave to Governor Hobson in 1840 when the country was first established as a British colony:

> *Now we do hereby authorize and require you to cause a survey to be made, in the manner hereafter mentioned, of all the Land within our said Colony; and you are for this purpose from time to time to issue Instructions to the Surveyor General for the time being of our said Colony…*
>
> (Royal Instructions 5 December 1840, p. 19)

These Royal Instructions authorised the first surveys of New Zealand, the creation of reserves for public purposes, and the private sale of land to individuals. Despite this, the period from 1840 to the mid-1870s is associated with a non-standardised and poorly coordinated approach to cadastral surveying throughout New Zealand. Bevin and Haanen (2002) describe the situation at the time as a laissez-faire system and note that there was no requirement to establish the qualification or test of a person's competence to carry out surveys. Some responsibility for these issues is directed toward The New Zealand Company, which was formed without Government approval to establish settlements (e.g., Rinckes & Blaikie, 1997). The New Zealand Company effectively operated a survey system in competition with the Government scheme, with its own surveyors and under their own Surveyor-General. Although the New Zealand Company was eventually officially recognised by Government, it continued to conduct surveys in its own way until the company was wound up in 1858 (Rinckes & Blaikie, 1997).

Issues with a non-uniformed approach to surveying were further compounded in 1853 by the division of New Zealand into provinces under the Constitution Act 1852. Provincial Chief Surveyors were established to administer surveying within each province and the role of Surveyor-General was disestablished meaning there was no official with the authority to control surveys of the whole of New Zealand (Rinckes & Blaikie, 1997). With a rapidly increasing rate of settlement of the country by British immigrants and development of a land market, there arose growing concern at the poor state of surveys and their impact on the level of confidence in the ownership of land (Bevin & Haanen, 2002). This concern is documented in 1870 by W.S. Moorehouse, the Registrar-General at the time, in his annual report to Parliament where he voiced significant dissatisfaction over the quality of surveys to define extents of land ownership for registration (Blackman et al., 2009).

The concerns voiced by Moorehouse appear to have been a catalyst leading to contracting the services of Major H.S. Palmer, of the Ordnance Survey of Great Britain, to visit the Provincial Survey Offices and report on the status of surveys in New Zealand. In his report presented to Parliament in 1875, Palmer commented that surveys were being done piecemeal and each piece in a different way. Palmer expressed that it was necessary to bring the whole within the grasp of one exact and comprehensive system (Palmer, 1875). Following the Palmer report, a series of initiatives were introduced to rectify the poor state of affairs:

> 1879 – Survey regulations were introduced and required unification of the provincial survey systems and development of a national system under the control of the re-established position of Surveyor-General (Regulations and Instructions of the Survey Department of New Zealand 1879). Regulations also introduced a requirement for surveys to be subject to examination and approval by a Chief Surveyor before a survey could be used for any legal purpose (Land Transfer Survey Regulations 1879).
>
> 1888 – The formation of the New Zealand Institute of Surveyors (NZIS) as a national body to develop the integrity of and status of the profession of surveying (New Zealand Institute of Surveyors, 1889).
>
> 1896 – Establishment of a Board of Examiners that set examinations and standards for all cadastral surveyors and for surveying (Department of Lands and Survey, 1896).

1909 – A geodetic survey of New Zealand was commenced. This survey eventually resulted in the country's first geodetic datum, New Zealand Geodetic Datum 1949 (NZGD1949), which modelled the shape of the earth for more accurate positioning at a national level. The survey also joined up many of the local triangulation systems already being used in the provinces and improved the integrity of existing survey work (L. Lee, 1978).

Following this period of significant change, the practice of surveying in New Zealand has been relatively well organised and highly regulated. The result has been an integrated system of survey and mapping for all tenures – Crown land, public lands, Māori land (indigenous title) and general or private land, with very few boundary disputes (Bevin & Haanen, 2002). Bevin and Haanen (2002) also note that there have been very few cases of serious incompetency or error by surveyors. This observation provides more tangible evidence to support LINZ's high level of confidence in the quality of the current cadastral system.

2.1.2 The Current Cadastral System & Related Systems

The cadastral survey system in New Zealand is a core component in the national property rights system managed by LINZ that promotes efficiency and confidence in transacting property rights. Land Information New Zealand (2014c) describes the essential features of a property rights system as being able to define:

- **what** rights, restrictions and responsibilities are in law
- **who** (or which organisation) holds rights, restrictions and responsibilities or are subject to them
- **when** rights, restrictions and responsibilities come into effect or when they cease to apply
- **where** the land or real property is that rights, restrictions and responsibilities apply to, including their spatial extent.

The primary purpose of the cadastral survey system is to define the 'where' in the property rights system – the last point above. The other essential features above are primarily managed by various land tenure systems. In addition to being a repository of information about the current and historical extents of rights, the cadastral survey system includes boundary and survey marks, regulations, rules and standards, required competencies and professional regulation (Land Information New Zealand, 2014c). The cadastral survey system enables the extents of the rights in property to be confidently established and understood in the real world.

Closely associated with cadastral survey system is the term ‘cadastre’. The Cadastral Survey Act 2002 (s. 4) defines cadastre as meaning “…all the cadastral survey data held by or for the Crown and Crown agencies”. This legislative definition of cadastre, which is somewhat simplistic, is refined by Land Information New Zealand (2014c, p. 8) through the identification of specific contents. Firstly, the term ‘fundamental cadastre’ is used to describe “…the repository of cadastral survey datasets lodged with LINZ and integrated into its database [i.e., Landonline], and which are regulated by the Cadastral Survey Act 2002…”. Secondly, the term ‘broader cadastre’ is used to describe other rights, restrictions and responsibilities in land which are “…created and managed in terms of other legislation or rules of law and which are not clearly part of the fundamental cadastre…”. Examples of other rights, restrictions and responsibilities that can be associated with the broader cadastre include licenses, such as for mining, and responsibilities to maintain public drains on private property.

The New Zealand cadastral survey system is based on physical marks in the ground (monuments) and survey observations (bearings and distances) between those marks. This monument and observation centric system means that New Zealand has a legal cadastre where property boundaries defined on a cadastral survey dataset certified and submitted by a licensed cadastral surveyor to LINZ, remains the authoritative source of survey data. A digital cadastre provides a spatial representation of the legal cadastre through coordinated points based on the survey data that has been captured, validated, integrated and subsequently maintained in the electronic system. These coordinates, however, are not authoritative and do not define property boundaries.

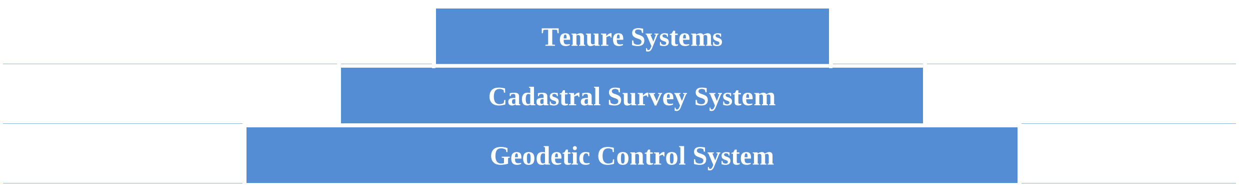

Figure 2.1: Relationship between systems in New Zealand

Underpinning the cadastral survey system is a geodetic system that provides essential horizontal control and maintenance of spatial positions which are ultimately reflected by the digital cadastre (the relationship between systems is demonstrated in Figure 2.1, above). The current official geodetic datum for cadastral survey, and also commonly used for a large range of other mapping and GIS applications, is New Zealand Geodetic Datum 2000 (NZGD2000). NZGD2000 was introduced in 2000 after deficiencies of NZGD1949 became apparent during the 1980s and 1990s with technological advances, especially the advent of Global Positioning Systems (GPS), and better understanding of the dynamism of the New Zealand landmass (Blick & Grant, 1998).

New Zealand is literally a dynamic nation as it straddles the Australian-Pacific tectonic plate boundary. Ground movements across the country in the order of 5 centimetres per year have been observed, disregarding the effects of large earthquakes (Walcott, 1984). This movement could not be addressed by NZGD1949, being a static datum with the coordinates of its initial network marks held fixed at the time it was established, being 1949. The static nature of this datum meant that positional coordinates became unsynchronised with the true on-the-ground location over time. In its fiftieth and final year as the official national datum the positional discrepancy of NZGD1949 calculates to approximately 2.5 metres.

NZGD2000 is a more robust geodetic datum that counters the limitations of NZGD1949 through the ability to account for ground movement and distortion (through updates to coordinates), and with better compatibility with GPS along with other Global Navigation Satellite Systems (GNSS) that now exist. NZGD2000 is a 3D geocentric datum with geodetic network control marks having assigned horizontal coordinates (latitude and longitude) and heights all in terms of a reference ellipsoid that approximates the surface of the earth. While ellipsoidal heights are necessary for maintenance of the geodetic survey control network, they are not currently used for cadastral survey purposes.

The Rules for Cadastral Survey 2010 require information about height (reduced levels) on a cadastral survey dataset to be in terms of an official vertical datum where a vertical control mark exists within a specified distance of a survey. If a vertical control mark does not exist, the survey may be in terms of an alternative, non-official datum or an assumed datum that is unique to that survey. New Zealand has fourteen official vertical datums; of these, thirteen are regional and one, the New Zealand Vertical Datum 2009 (NZVD2009) is national. All of these vertical datums are based on a geoid model that approximates mean sea level through normal-orthometric heights. Seldom does the more meaningful geoidal surface (mean sea level) used for cadastral survey height data coincide with the NZGD2000 ellipsoidal surface used for horizontal measurements. Land Information New Zealand (2010) reports that ellipsoidal heights can be up to 35 metres different from normal-orthometric heights and sea level throughout New Zealand.

2.1.2.1 Legislative Support of 3D Cadastral System

An understanding of the term 'land' is important in the context of legislation to support the administration of property rights in New Zealand. To a layperson land can simply be considered to be what can be seen on the ground or perhaps a surface section of the earth's crust. In the legal sense the definition of land is more complex and also more revealing of its true 3D nature.

The spatial extents of a landowner's property rights is summed up by the maxim accredited to the Italian law academic, Accursius: *cujus est solum ejus est usque ad coelum et ad inferos* (for whoever owns the soil, it is theirs up to heaven and down to hell) (Abramovitch, 1961). This maxim became accepted English common law doctrine through the sixteenth century judgement in the case, *Bury v. Pope* (1586) (Abramovitch, 1961). This judicial precedent then became applicable to New Zealand when The English Laws Act 1858 retrospectively declared that:

> *...the laws of England as existing on the 14th day of January 1840, shall, so far as applicable to the circumstances of the said Colony of New Zealand, be deemed and be taken to have been in force therein on and after that day, and shall continue to be therein applied in the administration of Justice accordingly.*

The maxim, therefore, is part of New Zealand law and the term land in legal theory means everything on, over or under the ground. However, the reality is that the legal system is also placing restrictions on the spatial extents of a landowner's rights. For example, case law has limited rights to the air space "to such height as is necessary for the ordinary use and enjoyment of his land and the structures upon it" (*Bernstein of Leigh (Baron) v. Skyviews and General Ltd*, [1978] QB479). The Judge (Griffiths) in this case went on to state that above the height he has referred to, a landowner has no greater rights in the air space than any other member of the general public.

In addition to legal precedent through case law, there is legislation that has some impact on the air space above a landowner's property. The Civil Aviation Act 1990 (s. 97) permits aircraft to fly above the air space at reasonable heights without liability for an action for trespass or nuisance by a landowner. The Public Works Act 1981 (s. 31) enables the Crown or territorial authority (city or district council) to acquire (voluntarily) or take (compulsorily) such part of the air space as necessary for any public work.

It is also worth noting that the air space above a unit development and also the subsoil below is deemed to be common property belonging to the owners of the units. This is because under the Unit Titles Act 2010 (s. 5) common property means all the land and associated fixtures (e.g., buildings) that are part of the unit title development but are not contained in a unit. This definition, when considered in terms of the meaning of land described above, implies that common property accounts for the remaining volume of space that is not explicitly incorporated into the unit title development. The Unit Titles Act 2010 is discussed in more detail below.

The 3D nature of land as implied by its common law definition, and subsequently developed (restricted) through case law and legislation, is reflected by the ability to register rights that are limited in height and/or depth and incorporate the associated 3D survey data into the cadastral survey system, albeit in a limited way. The primary legislative framework of New Zealand's cadastral system is summarised in Table 2.1, below, and subsequently discussed in detail.

Table 2.1: Legislation to support cadastral survey system

Name of Legislation	Primary Purpose
Cadastral Survey Act 2002	To develop and maintain a cadastral survey system in New Zealand.
Land Transfer Act 1952	To specify and administer a system of land registration in New Zealand.
Unit Titles Act 2010	To provide the framework for the ownership and management of land and associated buildings and facilities.
Te Ture Whenua Maori Act 1993	To support and promote retention and use of Māori land by its owners.
Land Act 1948	To administer Crown land.
Resource Management Act 1991	To promote the sustainable management of natural and physical resources.

The Cadastral Survey Act 2002 provides the legislative basis for New Zealand's cadastral survey system. The purpose of the Act is:

(a) to promote and maintain the accuracy of the cadastre by—

(i) requiring cadastral surveys to be done by, or under the direction of, licensed cadastral surveyors; and

(ii) requiring cadastral surveyors to meet standards of competence to be licensed; and

(iii) providing for the setting of standards for cadastral surveys and cadastral survey data; and

(b) to provide, either on an optional or mandatory basis, for the electronic lodging and processing of cadastral surveys; and

(c) to provide for a national geodetic system and a national survey control system to be maintained.

(Cadastral Survey Act 2002, s. 3)

This Act places the responsibility of licensing surveyors on the Cadastral Surveyors Licensing Board of New Zealand. The setting of standards for cadastral surveys (s. 7(1)(c)) and cadastral survey data (s. 7(1)(f)) is a function required of the Surveyor-General, as is the maintenance of national geodetic and survey control systems (s. 7(1)(a; b)). The Chief Executive of LINZ is responsible for: providing facilities to receive cadastral survey datasets (s. 9(b)) and setting conditions for their use (s. 9(c)); integrating new cadastral surveys into the cadastre (s. 9(d)) to standards set by the Surveyor-General; and determining the structure, storage and access to cadastral survey datasets (s. 9(e)) to standards set by the Surveyor-General. The primary tool to carry out these functions is the electronic survey and title system, Landonline.

The Land Transfer Act 1952, which occupies a central position in New Zealand land law, enacts a system of registration of private land ownership known as the 'Torrens system'. This system was developed in South Australia in 1857 by Sir Robert Torrens (Kelly, 1971). Kelly (1971) declares that the essential feature of the Torrens system is exactness. If the ownership of land is to be determined accurately, the measurement of the land is required to be shown with precise correctness on the plans of title. Therefore, the role of the surveyor, being a spatial measurement expert, is of prime importance. This is particularly true for a country like New Zealand, where land boundaries have not been fixed by passage of time over centuries and beyond legal memory (time immemorial) as in England, but have arisen from numerous grants of land in unsurveyed and unmarked territory.

The Land Transfer Act 1952, with the support of the associated Land Transfer (Computer Registers and Electronic Lodgement) Amendment Act 2002 and Land Transfer Regulations 2002, sets out how title to land must be issued, provides for the registration of interests in land against land titles and provides a guarantee of title by the Crown. There are various forms of tenure or ownership (sometimes referred to as 'estate') under the Land Transfer Act with the two most common being freehold and leasehold. Freehold tenure is also known as 'fee simple' and is the highest form of private ownership in New Zealand. The term freehold is often incorrectly used by the general public to mean mortgage free. Leasehold is an interest in land resulting from an agreement between two parties for the occupation of land at rental for a term of years. Leases can be registered as a separate leasehold title or simply as a memorial (note) on the freehold title of the land.

The Unit Titles Act 2010 is the law governing building developments where multiple owners hold a type of property ownership known as a unit title. Residential unit title developments are typically apartment blocks, townhouses and flats. Commercial and industrial types include office blocks, industrial or retail complexes and shopping malls. The Act provides a legal framework for the ownership and management of land and associated buildings and facilities on a socially and economically sustainable basis by communities of individual owners. The Act enables the subdivision of land and buildings into unit title developments comprising units that are individually owned and common property that is owned by the body corporate on behalf of the unit owners. The Act is supported by the Unit Titles Regulations 2011 by setting out operational guidelines.

It is interesting to note that the Unit Titles Act 2010 repealed and replaced the Unit Titles Act 1972 (the 1972 Act) which had become inadequate to cover the full range and diversity of unit titles developments. A review of the 1972 Act found that it lacked clarity, transparency and accountability and in many circumstances that meant that people were unaware of their rights and responsibilities with land professionals unclear about how the Act applies to modern developments (Ministry of Building, 2010). The 2010 Act was introduced to counter these deficiencies by ensuring the diverse and complex range of unit title developments are able to be managed more effectively, and provide a mechanism for simple and complex developments to be created in the future. These aims are in harmony with the benefits of a 3D digital cadastral system.

Māori land is governed by Te Ture Whenua Maori Act 1993 (the Maori Land Act 1993) which recognises that land is taonga tuku iho (an heirloom) with special significance for Māori. The primary objective of the Act is for Māori land to be retained as taonga tuku iho in the hands of its owners and their whanau (family – immediate and wider), hapu (sub-tribe linked by a common ancestor) and descendants. To achieve these goals the Act requires that almost all dealings with Māori land must be examined and approved by the Māori Land Court. The Act's focus on retaining Māori land in the hands of its owners and bloodline is a reversal of the direction taken through earlier legislation regarding the dealing with Māori land, when there was a drive to individualise ownership of customary land (e.g., Native Lands Act 1862).

Crown land in New Zealand, administered through the Land Act 1948, is land vested in Her Majesty the Queen (being the Head of State) that is not set aside for any public purpose (e.g., state housing – Housing Act 1955 ; conservation area – Conservation Act 1987 ; pastoral lease – Crown Pastoral Land Act 1998) or held by any person in fee simple (Land Act 1948, s. 2). In New Zealand the Crown retains absolute ownership (alloidal) of land. While registered proprietors of land described in a certificate of title are free to do with their land as they wish (provided it is within the law), they only have a passing interest or estate in the land derived originally from the Crown. This is illustrated by the Crown's right to resume (compulsorily take) land for its purposes (land taken under the Public Works Act 1981 for roading is a common example) and that if a registered proprietor of land dies intestate (without having made a will) without heirs, the land reverts back to Crown ownership either through common law or legislation such as the Public Finance Act 1989

The Resource Management Act 1991 promotes the sustainable development of natural and physical resources such as land, air and water. Territorial authorities (local governments) are required to prepare district plans to carry out their functions in order to achieve the purpose of the Act. District plans include rules relating to the subdivision and development of land, including provisions that impact on the configuration of new legal boundaries, in three dimensions.

2.1.2.2 Standards and Guidelines

In addition to the legislation discussed above, there are various supporting standards and guidelines that promote a consistent methodology, outputs and quality of cadastral survey work. The primary standard and guideline documents are summarised in Table 2.2, below, and are then discussed further.

Table 2.2: Standards and guidance to support cadastral survey system

Name of Document	Primary Purpose
Rules for Cadastral Survey 2010	Rules which provide requirements that licensed cadastral surveyors must meet when carrying out and then lodging a cadastral survey dataset with LINZ.
Interpretation guide to the Rules for Cadastral Survey 2010	A guide to assist licensed cadastral surveyors with the interpretation of the Rules for Cadastral Survey 2010.
Standard for lodgement of cadastral survey datasets 2013	A standard which specifies electronic capture requirements for the lodgement of cadastral survey datasets.

The functions and duties of the Surveyor-General, as stipulated in the Cadastral Survey Act 2002 (s. 7(1)), include the requirement to set standards to "determine how the spatial extent (including boundaries) of interests under a tenure system must be defined and described…". These standards are currently provided in the form of the Rules for Cadastral Survey 2010. The Rules are used by cadastral surveyors and LINZ staff and provide requirements (including those related to 3D) that surveyors must meet when carrying out a cadastral survey and lodging a cadastral survey dataset with LINZ for processing and eventual integration into the cadastre. The Rules are supplemented by the Interpretation guide to the Rules for Cadastral Survey 2010 to facilitate correct interpretation of the Rules.

The Cadastral Survey Act 2002 (s. 7(1)) also requires the Surveyor-General to "...set standards for the structure, storage, and provision of cadastral survey data by the chief executive [of LINZ]". This responsibility is discharged through the Standard for integration and provision of cadastral survey data 2010. This standard describes the requirements for integrating cadastral surveys into the cadastre, including topological, spatial relationship and accuracy. The standard is for use by LINZ staff acting for the Chief Executive under the Cadastral Survey Act 2002 (s. 9).

The Standard for lodgement of cadastral survey datasets 2013 is issued by the Chief Executive pursuant to the Cadastral Survey Act 2002 (s. 9(c)). It sets the minimum capture requirements for the lodgement of cadastral survey datasets using Landonline to assist with efficient and consistent processing and integration into the cadastre. The requirements are in addition to the Rules for Cadastral Survey 2010 and surveyors must comply with this standard when lodging cadastral survey datasets, including those that contain 3D information.

2.2 Current Technical & Operational Processes

2.2.1 Automated Survey and Title System – 'Landonline'

In 1996 the New Zealand government instructed LINZ to develop a proposal to automate the survey and title systems. The subsequent automation project aimed to integrate all survey and title processes, to provide them in digital form, to reduce the costs of provision and compliance, to utilise advancements in technology and to satisfy increasing community demand for improved quality and delivery (Bevin, 1999). The proposal to integrate and automate the survey and title systems was developed and then realised through the introduction of Landonline in the early 2000s.

Landonline remains in use to this present day, enabling the electronic capture, lodgement, recording, and supply of cadastral survey data. The bespoke system is an application and database that can be considered as being the core component of a 2D digital cadastral system where the vertical extents of a land parcel are not digitally defined. The accuracy of this horizontal digital cadastre is maintained within Landonline through the adjustment of survey observations which are connected to cadastral survey and geodetic control marks already integrated into the cadastre. Horizontal distance observations are reduced to a common platform (approximately mean sea level) to facilitate adjustment of data and integration into the cadastre. This is required as the distance between two points increases proportionally to the distance above mean sea level. Adjustment and integration procedures would fail if horizontal distances were not corrected to be in common terms.

Vertical observations are currently not digitally captured in the cadastral survey datasets that are submitted into Landonline and, therefore, not included in the adjustment and integration processes. Where the vertical extents of rights are defined by survey, details (often both horizontal and vertical) are captured through scanned plan and elevation graphics (scaled drawings) supported by textual descriptions. Cadastral surveyors, licensed under the Cadastral Survey Act 2002, must comply with standards when undertaking cadastral surveys and lodging resultant cadastral survey datasets with LINZ. These standards, presently the Rules for Cadastral Survey 2010, require the vertical extent of a parcel, where the vertical extent is limited, to be defined by either a ‘stratum boundary’ or a ‘permanent structure boundary’ (r. 6.5(b)). These options are summarised in Table 2.3 and subsequently discussed in further detail.

Table 2.3: Types of vertical boundary

Vertical Boundary Type	Definition (Rules for Cadastral Survey 2010)
Stratum	A mathematically described surface in terms of a vertical datum.
Permanent Structure	A boundary defined by its relationship to a building or recognisable structure of suitable permanence.

2.2.2 Stratum Boundaries

A stratum boundary is defined as a surface that is mathematically described and related to a reduced level (normally in terms of mean sea level) or is either the surface or bed of a water body (Rules for Cadastral Survey 2010, r. 6.8). Stratum boundaries can be used for primary parcels (i.e., main ownership parcel) and for non-primary parcels (e.g., easements and covenants associated with a primary parcel). When a stratum primary parcel is being created, all the space occupied by the underlying parcel/s that are being replaced must be included in new parcels (Rules for Cadastral Survey 2010, r. 5.1(a)(ii)). This usually means 'down to the centre of the earth and up to the heavens above'.

In most cases these boundaries are defined by right-line boundaries (i.e., straight lines between points), similar to '2D' primary parcel boundaries, but have the added third dimension. They are usually defined by bearings and distances and reduced levels, but can be defined by mathematical formulae or similar information (Rules for Cadastral Survey 2010, r. 9.6.10). These must be sufficient to enable the relationship between the points on the stratum boundary and any other boundaries to be ascertained.

Every intersection of a primary parcel stratum boundary with any other primary parcel boundary must be defined by survey (Rules for Cadastral Survey 2010, r. 6.10). Every new stratum point defined in a survey must be connected to witness marks and permanent reference marks (which are in turn connected to the national survey control network) and those connections must be recorded in the cadastral survey dataset to enable the relationship with other boundaries to be determined and to enable recreation of the rights (Rules for Cadastral Survey 2010, rr. 7.3, 7.4).

2.2.3 Permanent Structure Boundaries

The location of a permanent structure boundary is determined by its relationship to a building or recognisable structure that is likely to remain undisturbed for fifty years or more (Rules for Cadastral Survey 2010, r. 2). In its simplest case this might be 'middle of wall', 'external face of wall', or 'middle of concrete floor slab', for example. This is in contrast to a stratum boundary, where the location is determined by the relationship to witness marks and permanent references marks using bearings and distances, reduced levels, and similar 'mathematical' specifications.

Permanent structure boundaries cannot be used for primary land parcels, and can only be used for parcels whose rights are expressly dependent on the existence of the related permanent structure (Rules for Cadastral Survey 2010, r. 6.9). For example, they may be used for a right created under the Unit Titles Act 2010 (for ownership of part of a building) where, if the related building were to be demolished, the boundary would not need to be capable of being relocated.

The ‘Diagram of Survey’ that is part of a cadastral survey dataset must depict the permanent structure boundary and clearly show and describe its relationship to the permanent structure, which must itself be described (Rules for Cadastral Survey 2010, r. 9.6.9). The Diagram of Survey must also show the relationship between permanent structure boundaries and nearby parcel boundaries. While permanent structure boundaries can be used for boundaries that are not limited by height, they are commonly used to define the vertical extents of property rights.

2.2.4 Height Restricted Easement & Covenant Areas

Easement and covenant areas (sometimes referred to as ‘non-primary’ or ‘secondary’ parcels) relate to rights and restrictions on the use of property. For example, rights to convey services (such as water, electricity, telecommunications) may be established to provide legal protection of services that run through one land parcel for the benefit of another. A primary land parcel may also have a restrictive height covenant to protect the outlook from a neighbouring property, for example. Stratum and permanent structure boundaries, defined above, can be used to define height restricted easement and covenant areas.

2.2.5 Forms of Horizontal Boundary

The Rules for Cadastral Survey 2010 provide a range of approaches to define the horizontal extents of property rights. These approaches are summarised in Table 2.4, below, and depicted in Figure 2.2, below. It can be seen that permanent structure boundaries may be used to define the spatial extents of a parcel both horizontally and vertically (s. 2.2.3, above). It is also worth noting that right-line and arc boundaries can be used in a mathematical definition of a stratum boundary (s. 2.2.2, above).

Table 2.4: Forms of horizontal boundary

Horizontal Boundary Type	Definition (Rules for Cadastral Survey 2010)
Right-line	A boundary that follows the shortest distance between two boundary points.
Arc	A boundary that follows part of the circumference of a circle.
Water	A boundary set at the landward margin of a river or a stream bed, a lake bed, or the common marine and coastal area or other tidal area.
Irregular	A boundary that is depicted as an irregular line but is not a water boundary.
Permanent structure	A boundary defined by its relationship to a building or recognisable structure of suitable permanence.

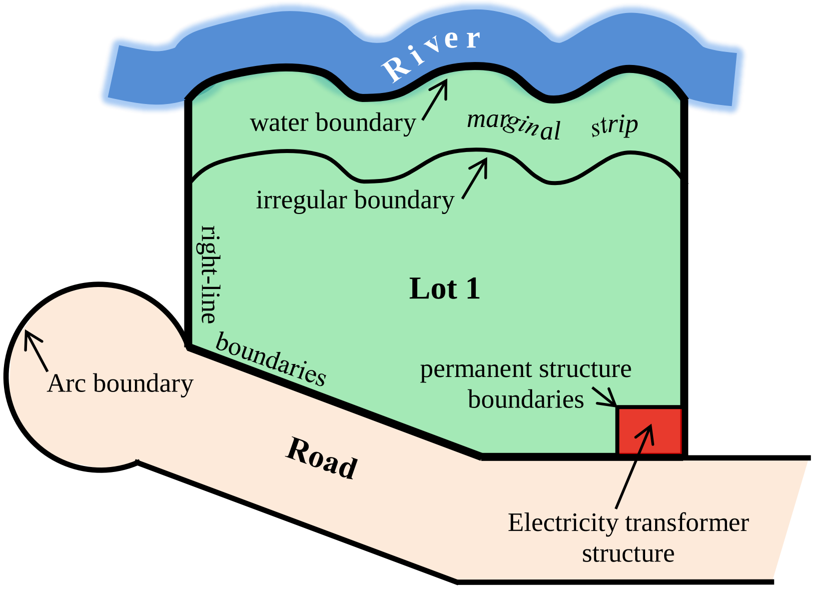

Figure 2.2: Forms of horizontal boundary

2.2.6 Digital Surveying Processes

As indicated earlier, New Zealand already has a system for defining 3D property rights, with the support of current legislation and rules, through a combination of digital spatial and non-digital aspatial processes. The workflow of a cadastral survey involving ordinary primary (underlying) boundaries, stratum boundaries and permanent structure boundaries is discussed below.

2.2.6.1 Undertake the Survey and Prepare Cadastral Survey Dataset

The way in which cadastral surveyors interact with Landonline is depicted in Figure 2.3. A cadastral survey typically starts with a spatial search in Landonline to identify the information about the existing underlying boundaries, the geometry of affected land parcels, relevant geodetic and cadastral survey marks, underlying and historic survey plans and associated supporting documents, including title information.

'LandXML' is the file format currently used to electronically transfer 2D digital cadastral survey data from the system for use in external software applications and survey equipment. LandXML data includes survey observations (typically bearings and distances), topology, parcels and coordinate system information. Data relating to existing 3D rights must be manually captured from aspatial (i.e., scanned image of paper plan) plan graphics held in Landonline.

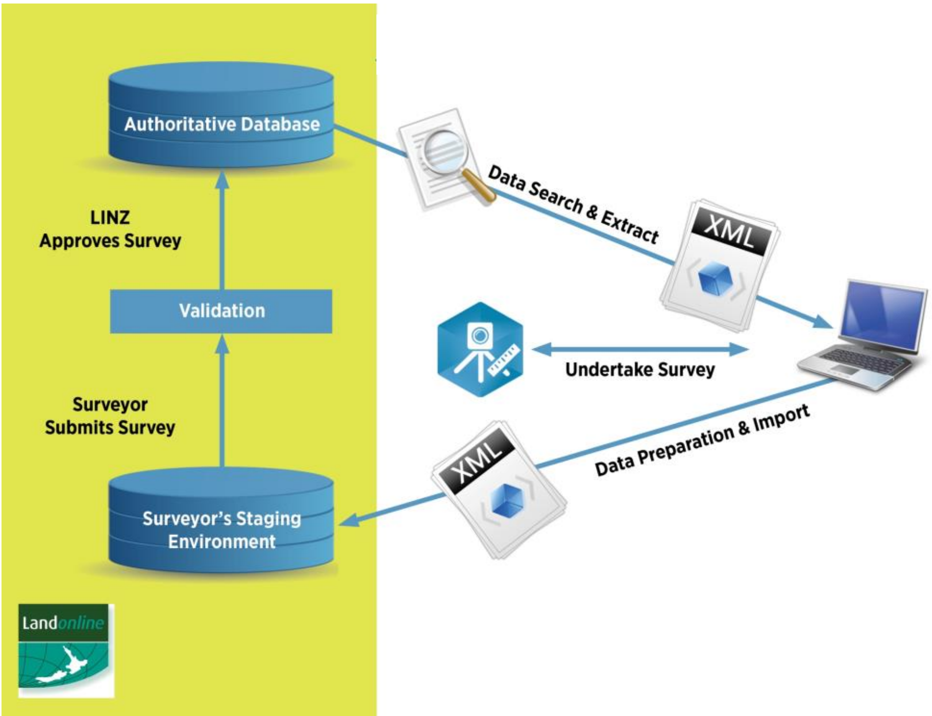

Figure 2.3: Digital survey processes

Surveyors often refer to architectural and engineering designs when establishing the boundaries of features. Design dimensions are then verified with as-constructed 3D measurements to ensure the correct relationship between features and underlying land parcel boundaries.

2.2.6.2 Data Capture and Plan Generation

Primary Land Parcel Boundaries

Primary land parcels are captured and integrated into the cadastre through bearing and distance (reduced to a common height – as described above) observations and calculations which are connected to cadastral and geodetic survey marks. These may be captured either directly in Landonline or through external software with data subsequently uploaded into Landonline using a LandXML file.

For surveys that are captured spatially, plans detailing survey and title information are generated in Landonline through a combination of automated and user-controlled processes. The system generates an overall diagram (plan view - based on input bearings, distances, marks, boundaries, and parcels) and the user then identifies areas where additional diagrams and annotations need to be generated for clarity.

Stratum Boundaries

Stratum parcels at 'ground level' are captured as for ordinary primary land parcels (as above). A strata parcel immediately above or below that ground level parcel is also captured, but not integrated into the primary land parcel layer (in which there are no gaps or overlaps). No height data is captured. Any other strata parcel boundaries are not captured, but are required to be defined on a plan graphic (Standard for lodgement of cadastral survey datasets 2013). These provisions are effectively a compromised way of recording 3D information in the existing cadastre.

Permanent Structure Boundaries

For 3D surveys involving permanent structure boundaries, plans including cross-section and elevation views are drafted using external software and then uploaded into Landonline as a graphic image. The data collected by the surveyor is not captured spatially in Landonline. 3D parcel details are linked to the underlying land parcel but are not portrayed digitally in Landonline's spatial view other than through a reference to the relevant cadastral survey dataset.

2.2.6.3 Validation

Primary Parcel Boundaries

For cadastral survey datasets containing captured 2D data the majority of validation checks are embedded within the Landonline application and are applied by the surveyor before certifying the dataset. Once the dataset is lodged, LINZ also applies the validation checks as part of its statutory role in approving the dataset. There is a requirement for surveyors and LINZ staff to perform a series of manual checks in addition to those performed through the automated business rules. These manual checks are a reflection of particular limitations of the current system and also the complex nature of surveying, for which automated checks to cater for every scenario is not always practicable or economic to build.

Stratum Boundaries

Where horizontal data is captured for these boundaries, similar validation checks are performed as if it were 2D data (as above). All validation of the third dimension is manual, using the information depicted on the plan graphic.

Permanent Structure Boundaries

Validation of these cadastral survey datasets is almost entirely performed manually by the surveyor prior to lodgement and again by LINZ staff once the dataset is lodged, as the information is only presented in the form of a plan graphic.

2.2.6.4 Integration into the Cadastre

The surveyor's role is complete once the cadastral survey dataset is 'approved as to survey' by LINZ (other than ongoing liability for the cadastral survey dataset certified by the surveyor). For data associated with a primary parcel/s there is a final and important step - to integrate the survey into the cadastre. The parcels and data have already been 'fitted' into the integrated parcel and survey network as part of the capture process. LINZ staff apply a least squares adjustment (a statistical technique) to the area to update the coordinates of the marks and boundaries and assign an 'order' based on the accuracy of those coordinates.

Any captured stratum data (i.e., relating to its horizontal extents) is integrated into the network in a similar manner to primary land parcels (above), except that only one layer of primary parcel can be integrated into the primary parcel layer (no gaps or overlaps). Other captured parcels are placed in a separate ('2D') strata layer depicting the 3D rights. 3D information that is not captured but only depicted on a plan graphic is not able to be integrated into the network.

2.3 Case Studies

2.3.1 Permanent Structure Boundaries

This case follows the development of a site as it progresses from a routine survey to define its perimeter boundaries through to a 3D unit development.

Figure 2.4 is the spatial representation of a survey captured into the Landonline system. The black line work represents the parcel boundaries of Lot 1 while the blue line work are new and old survey observations which are connected to cadastral and geodetic control marks (i.e., the black circles).

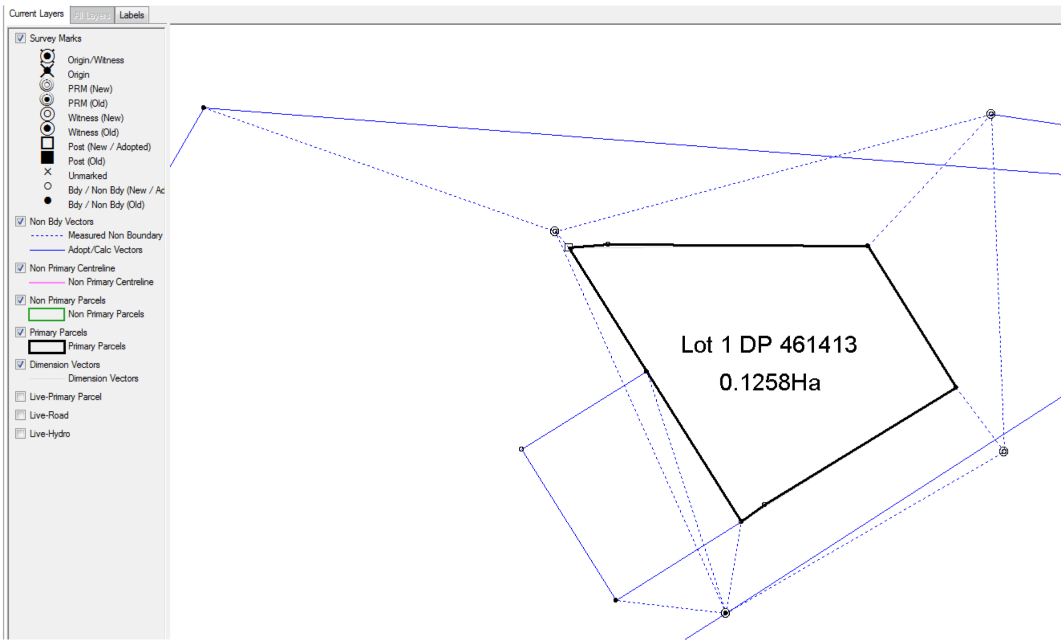

Figure 2.4: Landonline spatial view (depiction)

Figure 2.5, below, is the ‘2D’ plan of Lot 1 (being a 3D right by definition) which is predominately system-generated from the digital data captured by the user and shown in Figure 2.4, above. The level of user-input is limited to tasks to clearly and unambiguously represent the information, such as identifying where additional diagrams are required, shifting text and line work (i.e., distortion) and adding textual annotations.

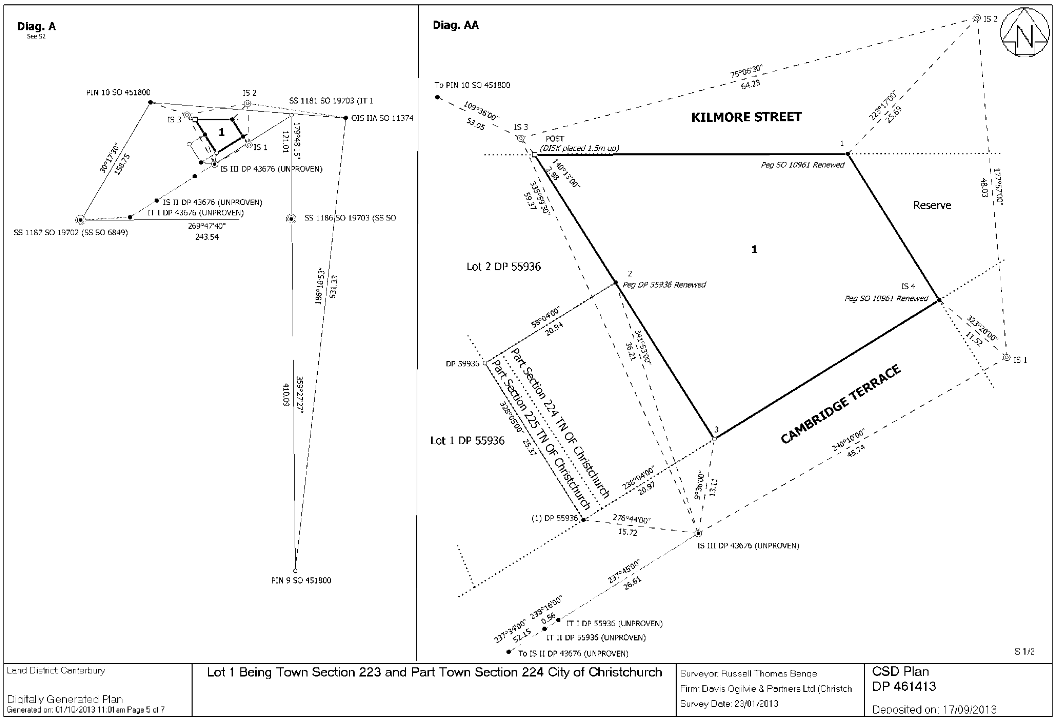

Figure 2.5: Digital survey plan

Figure 2.6 shows how Lot 1 is spatially represented by the 2D digital cadastre after the integration of the data.

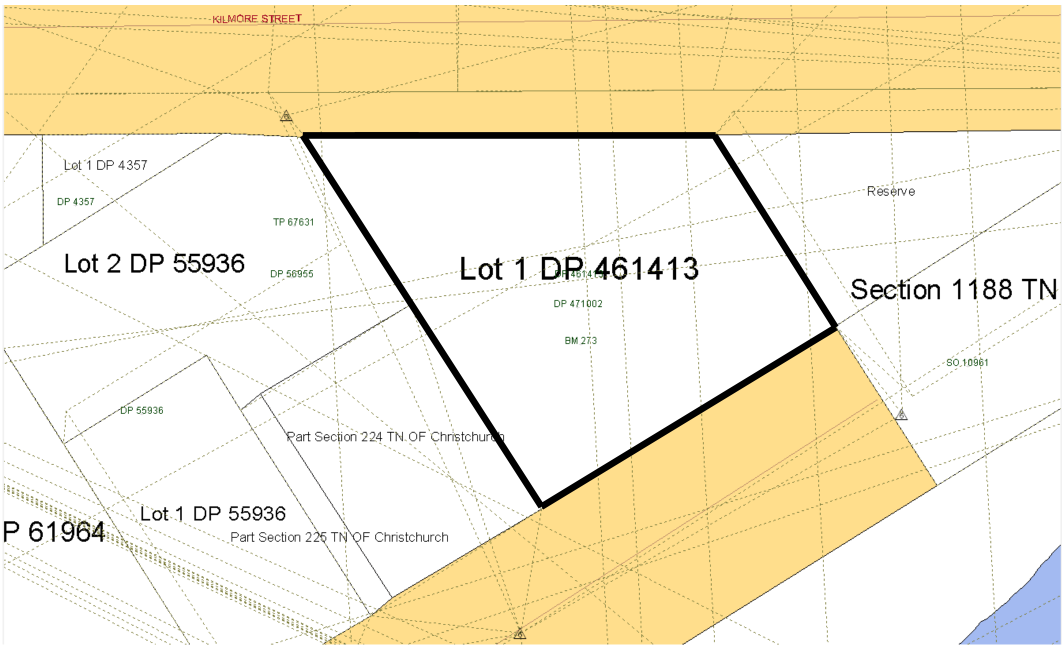

Figure 2.6: Integration into the digital cadastre

Following the survey of Lot 1, a multi-storey unit title development (apartment complex) is completed at the site (Figure 2.7). Due to limitations in Landonline the surveyor is required to represent their 3D electronic data through paper-based 2D plan and elevation views. These plans, portrayed in Figure 2.8 and Figure 2.9, document the relationship between the underlying legal boundaries of Lot 1 and the new unit boundaries associated with the apartment. Where the spatial extents of units are defined by way of permanent structure boundary the relationship is described through textual annotations on the face of the place (e.g., encircled red).

Figure 2.7: Subject apartment complex
(Photo courtesy: Jeremy Severinson, 2014)

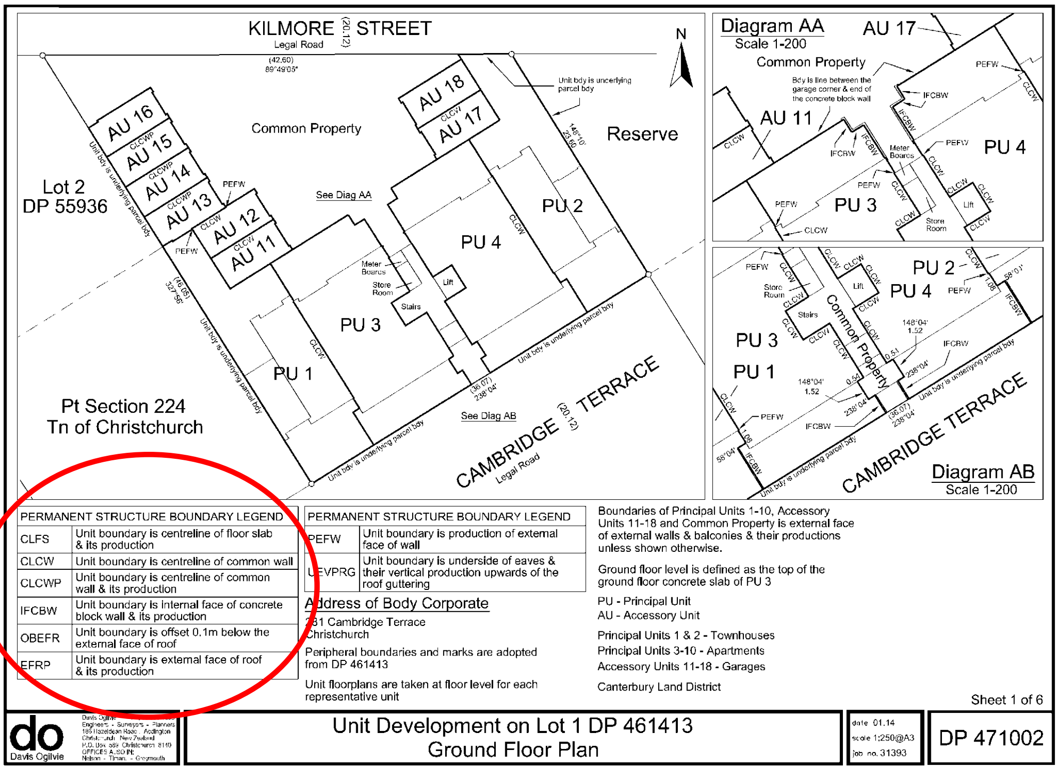

Figure 2.8: Paper-based 3D unit development – plan view

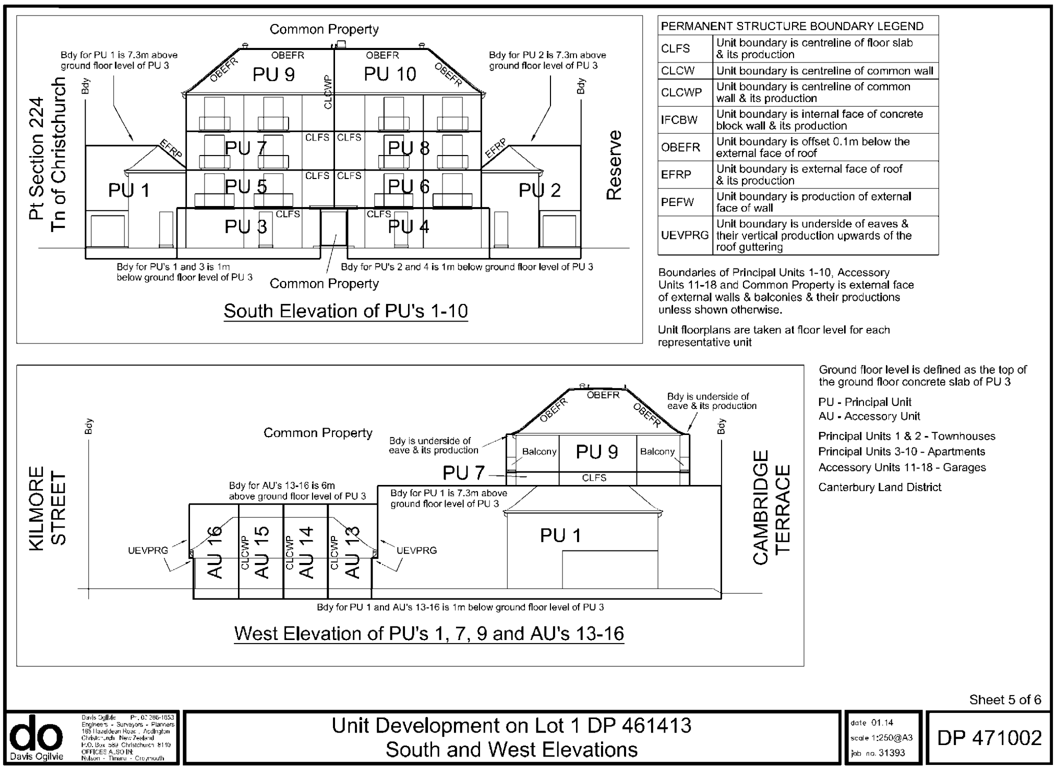

Figure 2.9: Paper-based 3D unit development – elevation views

The 3D data is held in Landonline as scanned plan and elevation graphic. As the 2D digital cadastre is incapable of reflecting these data, a plan reference is added as an annotation within the underlying lot to alert search users to its existence, as portrayed by Figure 2.10.

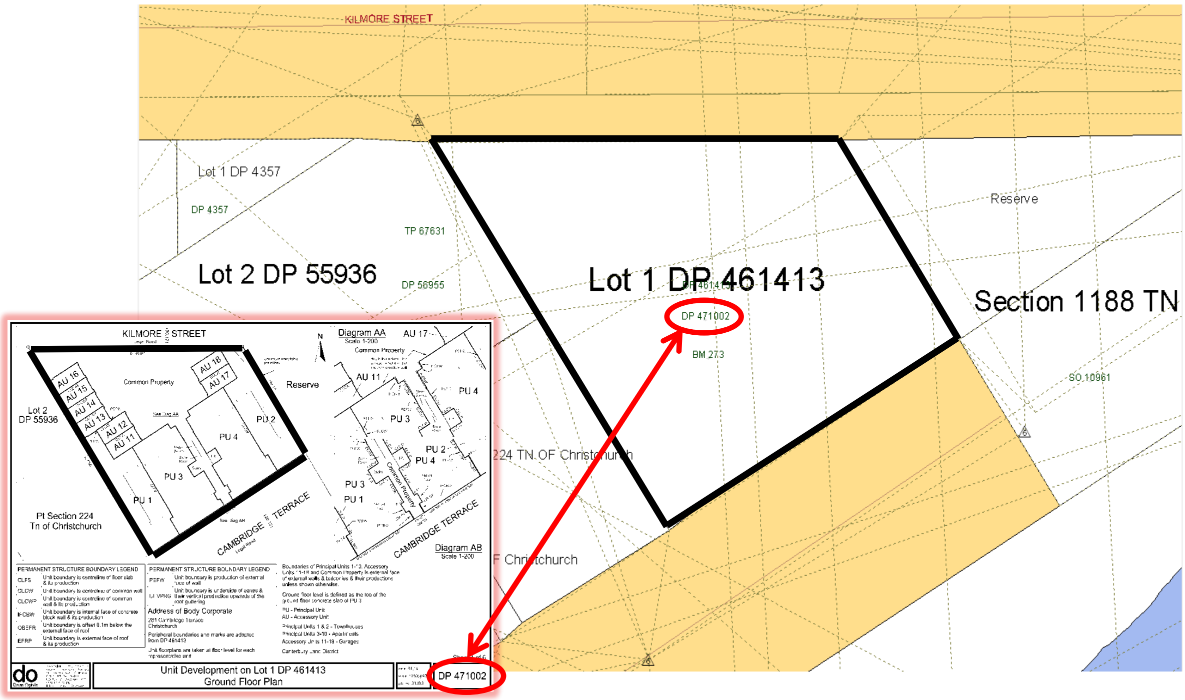

Figure 2.10: 3D data as reflected in 2D digital cadastre

2.3.2 Creation of Stratum Parcels

This case is an example of how new stratum parcels are created to subdivide the airspace within its underlying land parcel. Figure 2.12, below, shows the Landonline spatial view of a survey that creates stratum parcel boundaries for the control gates at Lake Taupō in the central North Island of New Zealand (Figure 2.11). The green line work represents the horizontal extents of the stratum parcels located within its primary land parcel (black line work). These stratum parcels are captured as a '2D ground level' layer in Landonline and are connected by survey observations (blue dashed line work) to geodetic and cadastral survey control marks, as required by the Rules for Cadastral Survey 2010.

Figure 2.11: Photo of Taupō control gates
(Source: Mighty River Power, 2015)

Figure 2.12: Landonline spatial view (depiction)

Figure 2.13 is the ‘2D ground level’ survey plan showing relationship between stratum and primary parcel boundaries, generated from the digital data shown in Figure 2.12, above.

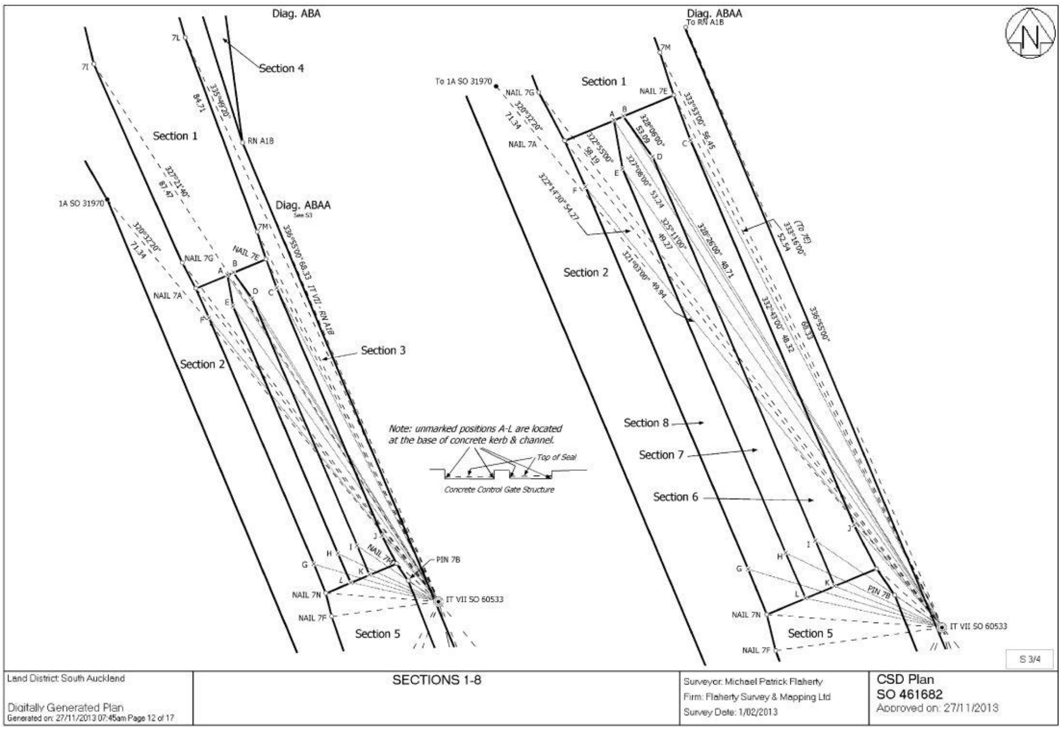

Figure 2.13: Digital survey plan

Figure 2.14 is the ‘2D’ representation of ‘ground level’ stratum boundaries after integration into the digital cadastre.

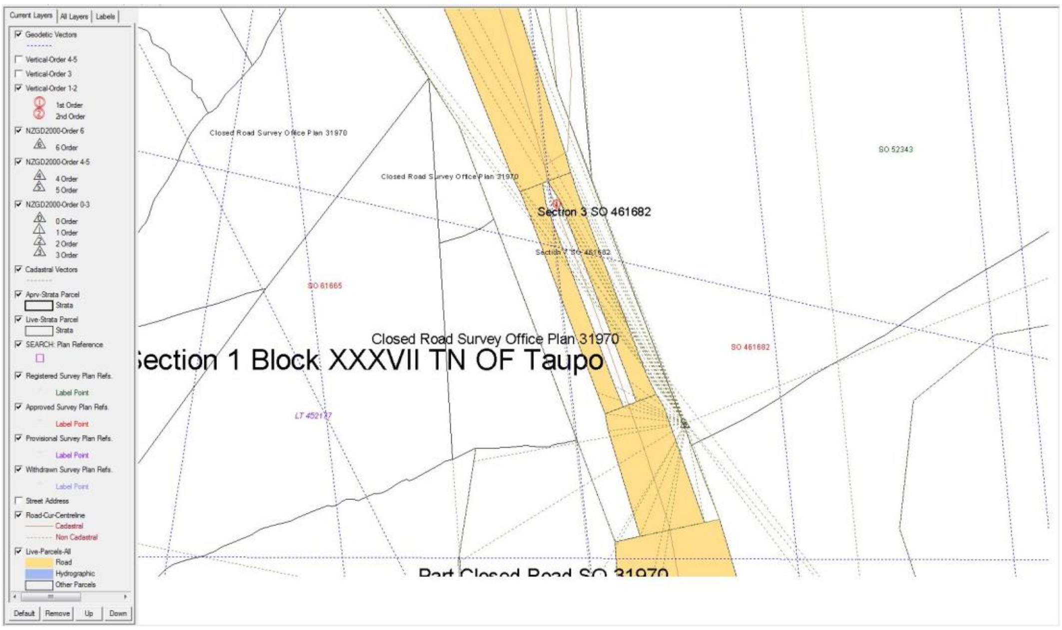

Figure 2.14: Integration into the digital cadastre

In order to completely define the spatial extents of the stratum parcels supplementary, non-digital information is uploaded to Landonline to provide a representation of the lower and upper extents of the subject stratum parcels. The surveyor has provided the following 'plan graphic' plan (Figure 2.15) and sectional views (Figure 2.16 & Figure 2.17) to convey the necessary information.

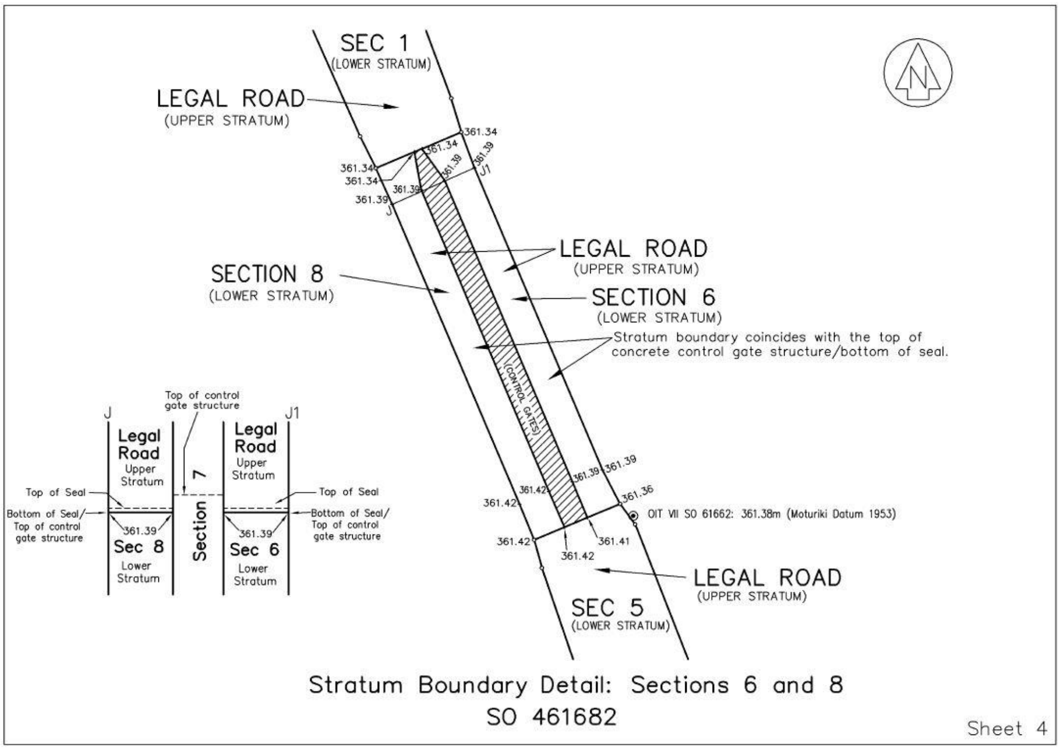

Figure 2.15: Paper-based plan with inset cross-section view

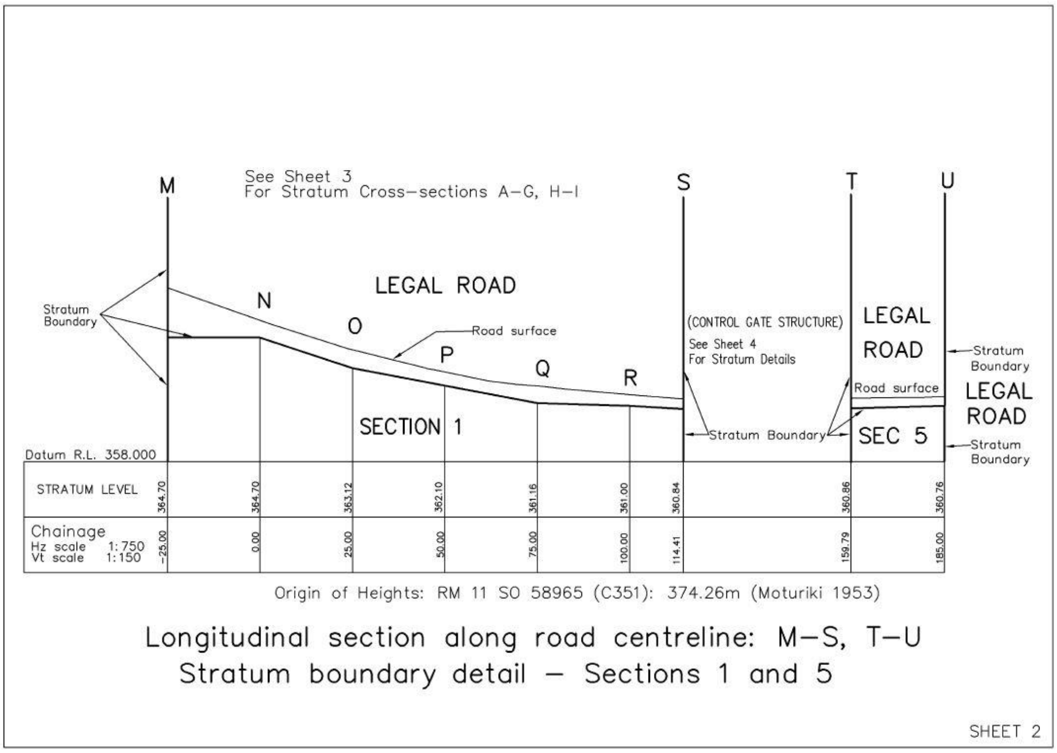

Figure 2.16: Paper-based longitudinal section view

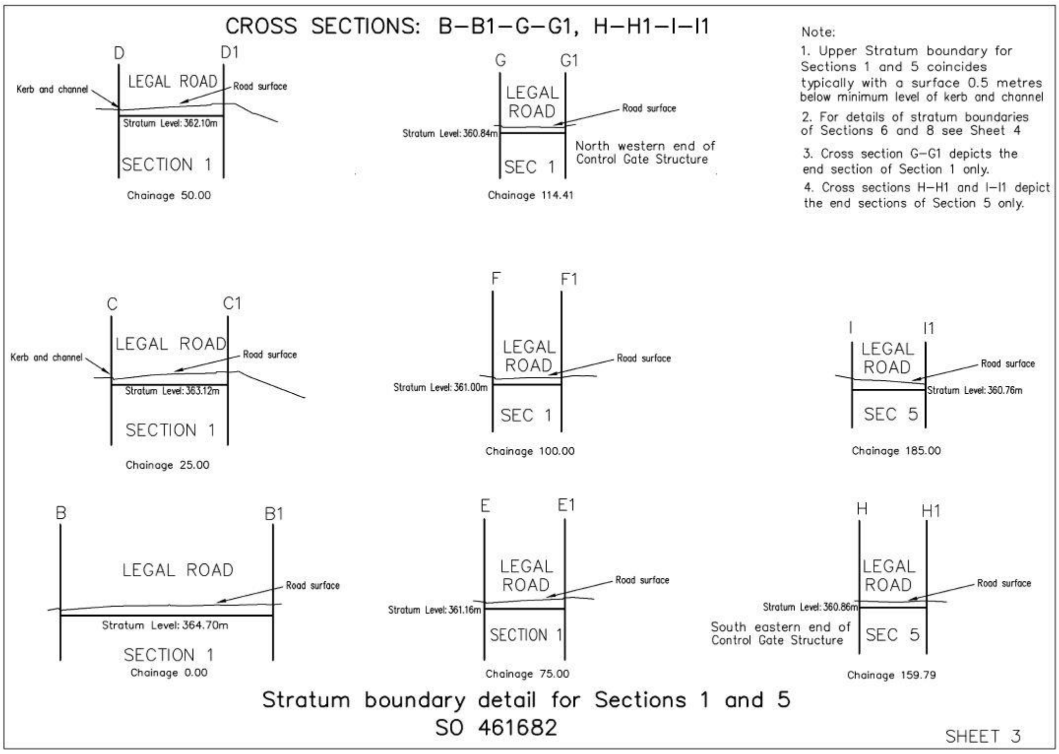

Figure 2.17: Paper-based cross section views

2.4 Motivation & Support for a 3D Digital Cadastral System

2.4.1 Evolving Society

New Zealand is experiencing an increase in multi-level multi-occupancy developments. Unit titles, which are governed by the Unit Titles Act 2010 (and previously the Unit Titles Act 1972), are the most widely used form of multi-unit property ownership in New Zealand (Ministry of Business Innovation & Employment, 2012). As of November 2014 there are 13,815 residential and commercial unit title developments comprising more than 140,000 principal units. An increasingly complex nature of land utilisation is also requiring the definition and management of other above surface (e.g., airspace, view shaft) and subsurface (e.g., utilities, natural resources) rights.

Changes to the way in which people live and work are being accompanied by rapid changes to the expectations of government, land professionals and the general public. Land Information New Zealand (2014c) identifies that society is increasingly demanding ready access to cadastral information. The general public increasingly expect to be well-informed of their rights and this is placing pressure on the cadastral system which is currently incapable of representing all rights, restrictions and responsibilities in land clearly and unambiguously. The case studies in section 2.3, above, highlight the difficulties users face when interpreting 3D situations from 2D representations.

2.4.2 Advancements in Technology

Today's surveyors and others (not necessarily spatial specialists) use equipment (including sensors) and methods which allow efficient collection and processing of 3D data. This information is used by surveyors, engineers, urban designers and architects for design and planning purposes which often precede cadastral work. The 'intelligent' information is then 'watered-down' in the course of capturing it into Landonline. A 3D digital cadastral survey system would promote the retention of all relevant location data determined by survey (i.e., survey accurate information) and align with current practice by land professionals.

In the fifteen years since the introduction of Landonline there have been major advances in measurement technology and also expertise in developing property rights applications. There have also been significant advances in the information technology readily available to the general public. Smartphones and tablets can provide immediate access to location information and enable visualisation of objects in 3D (Land Information New Zealand, 2014c). These advances are leading to increased public expectation that data will be readily accessible in this form.

2.4.3 Use of Cadastral Data

Cadastral data is no longer the sole domain of the property rights system. It is used extensively by government and private sectors for the provision of non-cadastral services. Land Information New Zealand (2014c, p. 13) states that the cadastre is a "…mechanism that supports the delivery of social, economic, and cultural benefits, and which relies on and contributes to the overall spatial data infrastructure and property rights system." Councils use cadastral information to underpin land valuation, rating, administration, planning, electoral and resource management roles. Private sector businesses and individuals use cadastral data when developing applications such as route optimisation and research and analysis for social, cultural, economic and environmental purposes.

2.4.4 A Single Authoritative Source

Land Information New Zealand (2014b) states that "Landonline is the online service for surveyors, lawyers and other land professionals, providing access to New Zealand's only authoritative database for land title and survey information." A Christchurch City Council developed system provides an example of a non-authoritative system which was used for public purposes for many years.

In the late 1970s, Christchurch City Council embarked on a project where teams of Drainage Board staff, apparently with limited survey knowledge, produced a digital land database by copying coordinates from traverse book records held by the Department of Lands and Survey (LINZ's predecessor), then plotting the points and joining the dots. This system was slightly ahead of the Department of Lands and Survey's own development of a Digital Cadastral Database. The result was a system that was rigid and required manual updating by council staff each time subdivision and council services data came in. The new data had to be fudged to fit the rigid map base. Despite the advent of Landonline and bulk data extracts of LINZ cadastral data, the Christchurch system, which was effectively a local, non-authoritative digital cadastre, was still in use up until the Canterbury Earthquakes. It was at that point when the deficiencies of the system, particularly alignment with other datasets, became obvious to all (K. Blue, retired Christchurch City Council Surveyor, personal communication, 2014).

2.4.5 Other 3D Digital Data Sources Relating to Property

The international concepts of 'Building Information Modelling' and 'Smart Cities' have reached New Zealand's shores. Whilst there is currently scant literature exploring the relationship of these 3D digital data concepts with cadastral survey data, there do appear to be opportunities for 3D digital cadastral survey data to add value to these concepts, and vice versa. For this reason, Building Information Modelling and Smart Cities are included under Motivation and Support for a 3D Digital Cadastral Survey System, and are discussed in more detail below.

2.4.5.1 Building Information Modelling (BIM)

BIM is the digital representation of the complete physical and functional characteristics of a built asset – everything from bridges to buildings. It involves creating a model with real life attributes within a computer and sharing that information to optimise the design, construction and operation of that asset. "Building a 'virtual building' in the computer makes it possible to iron out the bugs before trying to build it in real life" (Ministry of Business Innovation & Employment, 2014).

In July 2014 the Building and Construction Productivity Partnership, in collaboration with the Ministry of Business, Innovation and Employment, released the New Zealand BIM Handbook to help increase the use of Building Information Modelling by the construction industry. Accelerating the application of BIM in the construction process is a priority because it is seen as key to achieving a step change in sector productivity. The benefits of BIM are linked to an ability to provide "affordable, quality buildings and infrastructure for New Zealanders at a time of high construction demand" (Ministry of Business Innovation & Employment, 2014).

In June 2014 both the Office of the Surveyor-General and the New Zealand Institute of Surveyors (NZIS) provided feedback (separate) on the Draft BIM Handbook. This feedback commonly highlighted the significant role of cadastral surveyors to ensure confidence in the integrity of a BIM and the reliability of its spatial position, particularly in terms of legal property boundaries. The published BIM Handbook acknowledges the importance of digital 3D survey data (and indirectly, the feedback received from the Office of the Surveyor-General and NZIS) through the following introductory statement:

> *The geospatial data provided from survey tools is a key input into BIM. The production and formatting of 3D survey information for use in BIMs is outside the scope of this edition of the Handbook. Future editions will provide more details on BIM for Facilities Management, BIM for industrial/civil projects and integration with digital survey data.*
>
> (Building and Construction Productivity Partnership, 2014)

As noted in s. 2.2.6.1, above, surveyors typically refer to architectural and structural designs when establishing the boundaries of units. A process such as BIM is likely to assist surveyors to digitally determine and describe new 3D cadastral boundaries, particularly those associated with units. This observation is supported by the findings of a recent paper out of Sweden where the integration of 3D cadastral and BIM data is considered (El-Mekawy, Paasch, & Paulsson, 2014). Conversely, 3D digital cadastre data, such as the extents of property rights, could form a valuable layer of information within BIM, particularly in terms of facilities management.

2.4.5.2 Smart Cities

Worldwide cities are striving to become ‘smart’. Numerous definitions exist to describe the concept of ‘Smart City’. A common thread is the use of digital technologies and information to enhance performance and wellbeing, to reduce costs and resource consumption, and to engage more effectively with citizens. The following quotes provide further elaboration on what can make a city ‘smart’:

> *A city can be defined as ‘smart’ when investments in human and social capital and traditional (transport) and modern (Information and Communication Technologies - ICT) communication infrastructure fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory action and engagement. The smart city concept essentially means efficiency. But efficiency based on the intelligent management and integrated ICTs, and active citizen participation. Then implies a new kind of governance, genuine citizen involvement in public policy.*
>
> (Caragliu et al., 2011)

> *Smart cities are defined by their innovation and their ability to solve problems and use of ICTs to improve this capacity. The intelligence lies in the ability to solve problems of these communities is linked to technology transfer for when a problem is solved. In this sense, intelligence is an inner quality of any territory, any place, city or region where innovation processes are facilitated by information and communication technologies. What varies is the degree of intelligence, depending on the person, the system of cooperation, and digital infrastructure and tools that a community offers its residents.”*
>
> (Komninos, 2002)

In New Zealand cities including Auckland, Wellington and Christchurch are endeavouring to become ‘Smart Cities’. Auckland City is currently working on a city-wide digital strategy to increase its smart city priorities (Auckland Council, 2014); Wellington City Council has developed the strategy, Wellington Towards 2040: Smart Capital (Wellington City Council, 2012); and Christchurch is being touted internationally to become a model Smart City (Ashok, 2013).

It is clear that cadastral data from a 3D digital cadastre would be a significant and valuable feature of the digital infrastructure for a Smart City, particularly the intelligent management of the built environment.

2.4.6 Costs & Benefits of a 3D Digital Cadastre

At this stage it is considered inappropriate to assign a dollar-value for the development of the system. An estimate of the monetary cost to develop 3D capabilities is best left to vendors during their assessment of what can be delivered and for what cost. Despite this, a qualitative assessment can be made based on perceived costs and benefits for all users of the system. This assessment is summarised in Table 2.5, below.

Table 2.5: Cost versus benefit matrix

User Group	Increase understanding of 3D rights	Improve land information management	Decrease capture time	Reduce validation time (increased automation)	Increase business opportunities
Government as a whole	✓	✓			✓
Individual government agencies	✓	✓			✓
LINZ	✓	✓		✓	✓
Surveyors	✓	✓	?	✓	✓
Other location based data consumers	✓	✓			✓

There is an element of uncertainty around the benefit to surveyors in terms of time savings when capturing 3D information. As emphasised throughout this document, surveyors are routinely working with 3D digital data. The way and the extent to which an individual surveyor is working with 3D data, and the way the system is ultimately designed to receive 3D data, could mean reduced or increased capture times. That is, there is an expectation that some surveyors will experience an increase in time spent capturing 3D digital data while others might notice a decrease.

With regard to the validation of 3D digital survey data, LINZ currently has a small group of experienced staff responsible for approving Unit Title development cadastral survey datasets.

This is due to the often complex nature of these datasets (commonly 3D) and the very manual validation of non-digital plan graphics. The functionality to accept 3D digital data will promote automated validation and, in turn, permit dataset approval to be undertaken by staff outside the specialised group.

2.5 LINZ Strategic Initiatives

There are a series of interrelated initiatives underway at LINZ. Each initiative has involved and/or is continuing to involve consultation with government, land professionals and the general public. The ability to fully reflect all rights, restrictions and responsibilities is a common theme to the initiatives, which are briefly outlined below.

2.5.1 Integrated Property Services

'Integrated Property Services' was formerly referred to across government as 'Better Property Services'. Those wanting property information or property services currently need to interact with a number of central and local government agencies (including government agencies themselves). Property service information tends to be fragmented, and the information provided is often not easily integrated with information from other agencies or the private sector. This causes delays and costs for users.

LINZ is working with other government agencies to explore how to make it easier to find and use property information and services. A report assessing the economic value of a 'Better Property Services' future promotes the concept of interoperability and concludes that there would be significant benefits from such enhancements (ConsultingWhere Limited & ACIL Allen Consulting, 2013).

2.5.2 LINZ 10-year View – The Power of Where

LINZ has developed a view of its future direction for the next decade (Land Information New Zealand, 2014f). The 10-year View identifies areas where LINZ can best apply focus, funding and people to the greatest benefit for New Zealand. Location information is identified as central to LINZ's strategic direction with a key component being the concept of a 'location system'. The location system will enable diverse location-based datasets to be merged to gain new knowledge, provoke better decisions and inspire innovation.

Grant et al. (2014) identifies that New Zealand's property rights system will be a significant part of this location system "…by enabling New Zealanders to relate the intangible legal spaces (boundaries within which rights, restrictions and responsibilities apply) with the tangible 3-dimensional and dynamic world in which people make important decisions related to the use of land and real property."

2.5.3 Cadastre 2034

Cadastre 2034 (Land Information New Zealand, 2014c) is a comprehensive strategy for the development of the New Zealand cadastral system over the next 10 to 20 years (Grant et al., 2014). A primary objective of the strategy is to enable New Zealanders to understand where their rights in land are. The strategy proposes a number of substantial changes to the cadastral survey system. These include broadening the scope of the cadastral survey system to cover the boundaries and extents of all rights restrictions and responsibilities in land and real property. A significant component of the strategy is to make provision for 3D cadastral capabilities.

2.5.4 New Zealand Positioning Strategy

In 2014, the National Geodetic Office at LINZ released the New Zealand Positioning Strategy (Land Information New Zealand, 2014e). This document defines the strategic direction for the development of the geodetic system for the next ten years. The strategy includes a goal to "enable the efficient definition of three-dimensional property rights through an accessible geodetic system" (Land Information New Zealand, 2014e, p. 6). The strategy proposes the establishment of a network of control marks with heights determined in terms of the official national height model.

2.5.5 Advanced Survey and Title Services

As outlined in Chapter 1, LINZ is developing a business case to advance the current Landonline application. The programme is being promoted to "ensure that LINZ maintains the integrity of our world-leading property rights system" (Land Information New Zealand, 2014a) and will help realise strategic goals outlined in Integrated Property Services and also the LINZ 10-year View. A 3D digital cadastral system is seen as a crucial component of an enhanced system not only to ensure that New Zealand's property rights system continues to be world-class, but to fuel sustainable economic development and a high quality of life.

2.5.6 Canterbury SDI Programme – 3D Enabled Cities

The Canterbury Spatial Data Infrastructure (SDI) Programme is an initiative consisting of eight projects designed to accelerate and support the earthquake recovery in Canterbury. It is reasoned that this will be achieved by enabling improved sharing of location-based information between government agencies and the private sector and contribute to the development of a regional and national SDI (Land Information New Zealand, 2014d). One of these projects, 3D Enabled Cities, will help achieve the above purposes through the development of a system to allow government agencies, private sector companies and the general public to view and edit 3D models of greater Christchurch (Gulliver & Haanen, 2014).

2.6 Summary

This chapter began with a statement that New Zealand's cadastral survey system is a key component in a property rights system that is considered to be Accurate, Authoritative and Assured. Analysis of data produced annually over a twenty-year period about the strength and security of property rights provided statistical evidence that New Zealand has maintained a world-class system over that time. This discussion was followed by an investigation into New Zealand's institutional framework of laws, regulations, standards and procedures, where it was found that current institutional framework supports a 3D cadastral survey system.

The institutional framework provided a platform from which to investigate the development of survey regulation in New Zealand. This look at the past sets the scene for the consideration of the current state of technical and operational processes, and the role of the survey and title recording and delivery system, Landonline, in supporting these processes. At this point in the discussion it became clear the limitation of the cadastral survey system resides at the technical and operational levels which are based on a 2D digital cadastre with aspatial scaled diagrams used to depict situations where property rights are limited in 3D. Case studies emphasise this limitation through a demonstration on how surveys involving 3D boundaries are currently handled by the system.

Advancements in technology and an evolving society (where it is fast becoming the norm to provide and consume 3D information digitally) were shown to be key drivers for developing a fully digital cadastral survey system. Land development professionals and society generally are intuitively thinking and seeing in 3D while management of the built environment is increasingly expecting and requiring 3D digital information. The motivation to develop a cadastral survey system that is in-keeping with the demands of its users is reflected by a series of LINZ initiatives that either promote or would benefit from a 3D digital cadastral system.

Overall, this chapter established the status of 3D cadastral system in New Zealand and, in doing so, presented the context for developing 3D digital capabilities. A sound base is provided to now progress the development of a 3D digital cadastral system for New Zealand in the following chapters.

3 Review of the Literature

In the previous chapter the current status of 3D in New Zealand's cadastral survey system was determined and presented, thus establishing the premise of this research. In this chapter, the discussion progresses into the realm of international literature supporting research and development of 3D cadastral survey systems and associated cadastre. The review commences with a historical overview of the cadastre while key characteristics of cadastres and cadastral survey systems are set into the context of land administration. This flows on to an introduction to the concept of 3D cadastre followed by consideration for the development of 3D cadastres on a global scale. Discussion on the international status of 3D cadastres leads into the identification of issues and opportunities of 3D cadastres. The review of literature is rounded out with discussion summarising the current state of the literature.

3.1 The Cadastre and Cadastral System

Cadastres and cadastral systems support economic and social objectives for individual jurisdictions (Grant et al., 2014). These concepts are central to this research so it is important to develop an understanding of their role in the domain of land administration.

3.1.1 Defining an Evolving Cadastre

Cadastres have existed for as long as land has been able to be privately held or owned. The literature supports three main classes of cadastre, being: fiscal; juridical; and multipurpose (e.g., Effenberg, 2001; Karki, 2013; Williamson, 1985). Fiscal cadastres support a system of land valuation and land tax, and can be traced back to Egyptian times (Dale & McLaughlin, 1988). Juridical cadastres are a relatively more recent development to support ownership and interests in land (Effenberg, 2001). The fiscal and juridical systems have evolved over time beyond their initial purpose to provide the basis for general land administration systems (Effenberg, 2001; Williamson & Ting, 2001). This evolution has seen the establishment of the third and most recent type of cadastre, multipurpose.

Multipurpose cadastres were developed when additional registers or information were added to the base fiscal and/or legal components within a cadastre (Williamson, 1985). The term 'multipurpose cadastre' appears to have been first published in a 1980 paper by the US-based National Research Council. In that paper the need for a multipurpose cadastre was founded on the view that the parcel of property ownership should be the fundamental building block for an integrated system of land information to support a wide range of decision-making (National Research Council, 1980).

Williamson (1985) argues that it is difficult to give an absolute, general definition of a cadastre because systems vary between countries throughout the world due to historical development, jurisdictional differences in legislation, customs and traditions, and land administration processes. This statement resonates with an early conclusion by Dowson and Sheppard (1956) in which it is maintained that a concise and comprehensive definition of cadastre is impossible. While a precise definition of cadastre is difficult, Dowson and Sheppard (1956) go on to contend that the distinctive nature of any cadastre is readily recognised and may be expressed as the marriage of:

> *(a) a technical record of the parcellation of the land through any given territory, usually represented on plans of suitable scale, and*
> *(b) an authoritative documentary record, whether of a fiscal or proprietary nature or of the two combined, usually embodied in appropriate associated registers.*
>
> (Dowson & Sheppard, 1956, p. 47)

More recently the International Federation of Surveyors (FIG - Fèdèration Internationale des Gèometres) described cadastre through the following statement:

> *A Cadastre is normally parcel based and up-to-date land information system containing a record of interests in land (e.g. rights, restrictions and responsibilities), which 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.*
>
> (International Federation of Surveyors, 1995)

The general characteristics of a cadastre described by Dowson & Sheppard and FIG commonly infer a cadastre as being the product of two separate systems. The geometric description of land parcels is provided by a cadastral survey system while the authoritative record of interests in land is provided by a tenure system. Williamson (1985) emphasises that it is these components which are central to a cadastre because they provide the basic data for the maintenance of the legal records. Any other records such as valuation and multipurpose cadastre-type data such as service or utility details and land use information are considered secondary components of a cadastre. This viewpoint is also expressed in the document, Cadastre 2014 (Kaufmann & Steudler, 1998), which set out a strategic vision for developing the cadastre.

The commonly used term, land parcel, is the spatial unit of the cadastre and is interpreted by Effenberg (2001) to be complex geometric features with connections to geographic, historical and legal objects. Effenberg also stresses that the process of maintaining the cadastre must ensure the integrity of spatial cadastral data. Zevenbergen (2004) highlights that a land parcel is an institutional creation rather than a physical reality. This statement, while correct in the strictest sense, does not account for the fact that some parcel boundaries may coincide with physical features, such as a boundary that has been established to follow the bank of a stream or the external face of a building, for example.

The spatial aspect of the cadastre is normally under the governance of a jurisdiction's survey and mapping organisation (Effenberg, 2001) and is maintained by cadastral surveyors (government or private) operating within legal guidelines (Williamson, 1985). The main purpose of a cadastral survey is to delineate on the ground and on a plan the spatial extents of a land parcel. These data about the land parcel is ultimately incorporated into the cadastre, either digitally or through hardcopy plans (or a combination both).

Discussion in the literature associated with traditional cadastres, including the characteristics of a cadastre outlined by Dowson and Sheppard (1956) and International Federation of Surveyors (1995), commonly refers to 'land' or 'land parcels'. The New Zealand Cadastral Survey Act 2002, Part 4, interprets land to include "subsoil, airspace, and water and marine areas". This legislative definition of land to include subsoil, airspace and water and marine areas is recognition that interests in land are not confined to ground level and are 3D in reality. Despite the actual 3D nature of interests in land, cadastral data is represented in 2D.

3.1.2 Cadastre and the Cadastral System

The terms cadastre and cadastral system are used interchangeably in literature. While cadastre and cadastral system are closely related they each have particular meanings and distinguishing features. Effenberg (2001) describes the relationship between the terms by stating that a:

> *cadastre tends to refer to the actual cadastral data, whereas the cadastral system is additionally the collection of organisations (people) and procedures that are associated with that data.*
>
> (Effenberg, 2001, p. 2)

Effenberg's generalised differentiation is in harmony with a more detailed offering by Land Information New Zealand (2014c) where the:

> *system includes more than the repository of information about the current and historical extents of rights* [i.e., the cadastre]. *It* [i.e., the cadastral survey system] *also includes the physical boundary and survey marks, regulations, rules and standards, required competencies, and occupational regulation.*
>
> (Land Information New Zealand, 2014c, p. 7)

3.2 Introducing 3D Cadastre

The concept of 3D cadastre as a specific research topic can be traced back to an inaugural workshop held by FIG in November 2001. Second and third international workshops followed in 2011 and 2012 with a fourth workshop held during November 2014. These workshops are supported by a substantial volume of international research from a broad variety of countries, particularly out of the Netherlands (e.g., Stoter, Ploeger, & van Oosterom, 2013; van der Molen, 2003; van Oosterom et al., 2006) and also Australia (e.g., Karki, Thompson, & McDougall, 2013), China (e.g., Guo et al., 2012), Israel (e.g., Benhamu, 2006), Greece (e.g., Dimopoulou & Elia, 2012), Denmark (e.g., Sørensen, 2011), Malaysia (e.g., Tan & Hussin, 2012), Sweden (e.g., Astrand, 2008), Turkey (e.g., Doner & Biyik, 2013) and Russia (e.g., Vandysheva et al., 2012).

Despite a reputation for having a world-class cadastral survey system (Land Information New Zealand, 2014c), New Zealand's literary contribution to the research of 3D cadastres is both indirect and brief. During a three-year period from 1998 through 2000 Hoogsteden and Robertson (1998), Robertson, Benwell, and Hoogsteden (1999), Bevin (1999), Grant (1999) and Knight (2000) gave consideration to the concept of a marine cadastre for which a 3D component was deemed necessary, although not further explored.

Current cadastres throughout the world are 2D with geometric and descriptive information based on 2D land parcels even if real property has three dimensions. Stoter (2004) and van Oosterom (2013) contend that these 2D systems have been adequate for dealing with simple, low-density parcels with single ownership. However, a primary driver for a truly 3D cadastre is the intensification of land use particularly in major urban centres. As a result building constructions and infrastructure are increasingly being positioned under and above each other which is, according to Stoter and Salzmann (2003) "putting the practicality of the 2D cadastre to the limit". Land Information New Zealand (2014c) identifies other drivers including rapid changes to society, particularly in terms of access to information, the uses to which information is put and advancements in technology.

A 3D cadastre is defined by Stoter (2004, p. 4) as being a "cadastre which registers and gives insight into rights and restrictions not (only) on parcels but on 3D property units. A 3D property unit… is that (bounded) amount of space to which a person is entitled by means of real rights." Stoter (2004) argues that in a legal sense, cadastral registration has always been 3D. While parcels are represented in 2D those with a right to a land parcel have always been entitled to the 3D space. In addition to parcels with unlimited height and depth, four types of parcel with a 3D component are distinguished:

- *building parcels, which are parcels that are generally defined by floors, walls and ceilings;*
- *restricted parcels, which are parcels restricted in height and depth by a defined distance above or below the surface or be a defined plane (restricted easements can also be restricted in height and depth). The* [horizontal] *boundaries of the restricted parcels must coincide with the boundaries of the surface parcel;*
- *volumetric parcels, which are parcels that are fully bounded by surfaces and are therefore independent of the 2D boundaries of the surface parcels;*
- *remainder parcels, which are parcels that remain after a volumetric or building parcel have been subdivided out of it.*

(Stoter, 2004, p. 71)

3.3 Development of 3D Cadastres Abroad

Countries throughout the world are confronted with the complexity associated with the cadastral registration of 3D property rights. The way in which jurisdictions handle this complexity is dependent on the requirements of their legal and cadastral systems (Stoter, 2004). Stoter (2004) investigated 3D cadastral issues in the jurisdictions of Denmark, Norway, Sweden, Queensland (Australia), British Columbia (Canada), Israel and the Netherlands. The research found that the registration of 3D property rights was possible in each jurisdiction. Despite this, and irrespective of jurisdictional differences, no system offered a complete solution for the registration of 3D rights for two primary reasons. Firstly, 3D property rights were not digitally incorporated into the system and subsequently maintained. This means that 3D property rights cannot be viewed interactively and the geometry of 3D parcels cannot be validated. Secondly, 3D parcels are not represented in the digital cadastre, therefore, it is not possible to query a 3D situation. These findings remain applicable to the New Zealand context today.

In the decade that has followed the work by Stoter (2004), interest in 3D cadastres has steadily grown as evidenced by the volume of literature coming out of an increasing diverse number of counties. In 2010, FIG initiated a questionnaire sent to jurisdictions internationally to document a world-wide inventory of the status of 3D cadastre development and also to gauge future expectations. After analysis of the 2010 results, for which there were 35 respondents, a main conclusion was that:

> *Despite all research and progress in practice, 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.*
>
> (Van Oosterom, Stoter, Ploeger, Thompson, & Karki, 2011, p. 2).

A second FIG questionnaire was sent out in 2014. The preliminary results of this follow-up questionnaire indicate that China has made the most progress and reached a point where it has developed an operational 3D cadastral database (Van Oosterom et al., 2014). However, further investigation by this research indicates that there are caveats to China's progress. China's advanced status appears restricted to the city of Shenzhen in Guangdong Province (Guo et al., 2014; Guo et al., 2011) and is subject to limitations. Guo et al. (2014, p. 310) report that while the 3D cadastre in Shenzhen displays some advances, "the 3D cadastral administrative still faces many difficulties and challenges, such as the supported laws and regulations, [and] the complete 3D data organisation." Based on this assertion it would seem that there is still no country in the world that has a fully functioning 3D cadastre.

The lack of fully functioning 3D cadastre highlights the complexity of the subject and could also be a reflection of the complexity of a country's underlying cadastral system and the ability to change that system. Karki (2013) for example, considers Australia's multiple jurisdictions, each with their own legislation, systems and practices, as an impediment to the implementation of a national 3D cadastre. New Zealand's centralised and national land administration system can be seen as being advantageous in this regard.

3.4 Identifying and Understanding Issues of 3D Cadastre

It is important to understand the general complexities of a 3D cadastre as well as particular 3D related needs within each cadastral jurisdiction. There are institutional issues such as 3D specific legislation, policies, standards and technical guidelines; operational issues such as the registration of 3D properties and their interaction with current 2D properties; and technical issues such as 3D parcel construction, 3D validation, 3D data capture and storage and 3D data representation.

3.4.1 Interoperability and Standardisation

Interoperability is defined as being "…a property of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, without any restricted access or implementation." (AFUL, 2015). The increasingly broad and diverse range of people and applications for which cadastral data is being used is likely to increase significantly after the implementation of a 3D digital cadastre. Interoperability frameworks incorporating standardisation will be the key to unlocking the opportunities of 3D digital cadastral data.

A lack of standards in the cadastral domain was raised in an early and comprehensive paper, entitled, 3D Cadastre (Stoter, 2004), where it was argued that international discussion was complicated by the unique problems concerning 3D registration and also due to specific legal and cadastral requirements. Another factor complicating international sharing of knowledge is the fact that countries use similar terms with slightly different meanings. This variation continued to be noted in research that followed Stoter's 2004 paper. Karki (2013, p. 22), for example, states that the lack of a shared set of concepts and terminology is a "significant problem in the cadastral domain". This problem continues to be evident today. The use of the terms parcel (e.g., Stoter, 2004), land parcel (e.g., International Federation of Surveyors, 1995), property unit (e.g., Stoter, 2004) and spatial unit (AS/NZS ISO 19152, 2012) have all been used synonymously to describe the spatial unit of a cadastre, for example.

Issues associated with a lack of standardisation are particularly apparent in Australia where there are several independent cadastral jurisdictions. Effenberg (2001) and Williamson and Enemark (1996) concur that for any jurisdiction, the cadastral system is a unique product that has evolved from its initial design function relevant to the cultural and social history of the jurisdiction within which it has evolved. Evolutionary differences of cadastral systems can also extend to specific jurisdiction levels within a country. A 1996 workshop for digital cadastral databases (DCDBs) for New Zealand and the Australian states found that:

> *The considerable diversity between different DCDBs came as a surprise to some and reinforced that jurisdictions have different cadastral systems, different title registrations systems and different methods of maintaining and updating their DCDBs.*
>
> (as cited in Effenberg, 2001)

McDougall (2006) outlines the need for national standard to achieve a coordinated approach to land administration in Australia while Kalantari et al. (2006) proclaim that a common approach is needed to address legal and semantic interoperability issues. Australia's multi-jurisdiction issues with interoperability and standardisation, which are also documented by Karki (2013), are not in common with the New Zealand context. While New Zealand's nationalised cadastral system eliminates issues of internal differences, any ambition to develop 3D digital capability by sharing knowledge and processes would benefit from international standardisation.

The geometrical representation of 3D spatial data is a particular issue that needs a collaborative effort from the international community to solve. Thompson (2007, p. 327) concludes that if the standardisation effort is to allow spatial data to be interchanged without expensive, manual intervention, "a well defined logic is needed to underpin the standards and support the definition of validity of that data. This would also ensure that inferences drawn from the digital model remain consistent and do not lead to logical fallacies."

3.4.2 3D Geometrical Representation

3D geometrical representation is a key component of a 3D cadastre as the geometric description of land parcels provides the building block of a jurisdiction-wide map of all parcels. Karki (2013) reports that 3D properties have been complex to deal with due to the multiple ways in which to represent, store and visualise these objects as they may or may not be independent of the surface parcel. In addition to these complexities, validation and topology is difficult as it is dependent on the 3D geometry chosen, network and crossing objects are not easily stored in the database, and spatial querying of 3D objects depends on the spatial location, storage and topology in the database.

In a 2D digital cadastre, the most common means of representing a parcel is by bounding polygons (Karki, McDougall, & Thompson, 2010). However, in a 3D digital cadastre there are numerous ways of storing the 3D geometry. The Land Administration Domain Model (AS/NZS ISO 19152, 2012), for example, outlines the following five ways of defining a 2D/3D parcel (referred to as a spatial unit): point spatial unit; text spatial unit; line spatial unit; polygon spatial unit and topological spatial unit. The Land Administration Domain Model is discussed further in s. 3.4.3, below. There are also various methods of representing 3D objects. Examples of methods finding favour with researchers include: tetrahedrons (Penninga, van Oosterom, & Kazar, 2006) simpler solids (Kolbe, 2009) regular polytope (Thompson & van Oosterom, 2006) and extruding (Ledoux & Meijers, 2009, 2011).

3.4.3 3D Data Modelling

Prominent researchers agree that data modelling is one of the most important elements of a successful 3D digital cadastre (e.g., Aien, Kalantari, Rajabifard, Williamson, & Bennett, 2013; van Oosterom et al., 2006). In the same way that architectural models of building design help users to visualise a creation, a 3D cadastre data model allows 3D digital cadastre users to understand the structure and behaviour of the system and provides a template to guide construction and implementation. This is because models are a generalisation of reality to make that reality more comprehensible. A data model is a representation of the data structures that are required by a database with a focus on what data is required and how that data should be organised (Vossen 1991). It is clear that a 3D data model has two important functions in the development of a 3D digital cadastral system. Firstly, it provides a framework and template to define a 3D digital cadastre and, secondly, to facilitate its implementation through the construction of a 3D digital cadastral database.

There have been a number of attempts by researchers to develop a cadastral data model based on various jurisdiction requirements around the world. Aien et al. (2013) note that cadastral data models are primarily based on the definition of a 2D land parcel, neglecting the third dimension. Examples of these models include: The core cadastral data model (Henssen, 1995); ArcGIS Parcel Data Model (Von Meyer, 2004); Swiss Cadastral Core Data Model, DM.01. (Steudler, 2006); and ePlan (ePlan, 2010). There are examples of data models where researchers have considered 3D capabilities, including: the South Korean 3D Cadastre (J. Lee & Koh, 2007); and the 3D cadastral data model (3DCDM) (Aien et al., 2013). It is also apparent from the literature that the Intergovernmental Committee on Surveying and Mapping (ICSM) is investigating extending the 2D ePlan data model to include 3D functionality (ePlan, 2010, 2015). Additionally, the Open Geospatial Consortium (OGC) have initiated the research and development of 'LandInfra', a conceptual model standard that is to include a cadastral survey component in 3D (Open Geospatial Consortium, 2015b).

Local nuances exist within each of the above mentioned data models due to their given land administration jurisdiction and also in the language used to describe them (it is noted that Aien et al. (2013) aspires to enhance the 3DCDM to be more in terms of international standards). Despite these differences the various data models were all found to be based on a land administration system that maintains information about land parcel, person (i.e., owner) and associated rights, restrictions and responsibilities. This 'people–land' relationship commonality is described by Kalantari et al. (2006) as being the core model. Figure 3.1 shows how the core model links ownership rights to the parcel and owner.

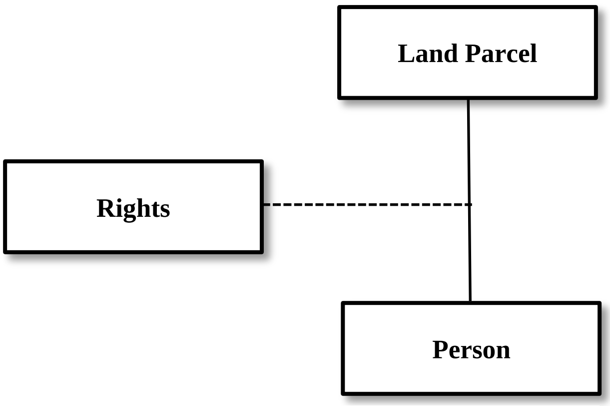

Figure 3.1: Core model
(Kalantari, Rajabifard, Wallace, & Williamson, 2006)

The value in the development and refinement of efficient and effective land administration systems (incorporating cadastral survey and tenure systems) at national and international levels is seen as a catalyst for an internationally standardised approach to modelling of land administration systems. This approach comes in the form of the Land Administration Domain Model (LADM).

The idea for a land administration standard is traced back to van Oosterom and Lemmen (2002) in a paper presented at the FIG Congress in Washington DC during 2002. This was followed by the development and standardisation at an international level in collaboration with organisations such as OGC, Infrastructure for Spatial Information in the European Community (INSPIRE), UN-Habitat and International Organisation for Standardisation (ISO). On 1 December 2012, almost a decade after the idea was first conceived, ISO 19152, Geographic information – Land Administration Domain Model (LADM), was officially published. The ISO standard was subsequently adopted verbatim and republished as a joint Australian and New Zealand Standard, AS/NZS ISO 19152:2012.

Since the LADM was published it has been the focus of substantial research attention, with a particular focus on the development of country profiles to promote the modernisation of cadastres. The following examples show the sudden breadth of international LADM research attention: Poland (Bydlosz 2013), Republic of Korea (Kim et al 2013), Republic of Croatia (Vucic et al 2013), Malaysia (Zulkifli et al 2013), China (Zhuo 2013), Israel (Felus et al 2014) and Czech Republic (Janecka & Rak et al 2014).

3.4.4 3D Data Validation

Validation is the process of checking for errors in data through a series of pre-defined automated business rules and normally occurs before data is processed or entered into the system. The objective of validation in a 3D environment is to form a rigorous definition of what is a valid object (Karki, 2013; Karki, Thompson, & McDougall, 2010). Karki, Thompson, et al. (2010) note that the validation of generic 3D geospatial objects has been the focus of substantial work (e.g., Kazar, Kothuri, van Oosterom, & Ravada, 2008). While that research and development is beneficial, the validation requirements of cadastral 3D parcels add a new level of complexity (e.g., some 3D parcels may be required to be within base 2D parcels). Karki, Thompson, et al. (2010) report that, ultimately, the technical aspects of storing, retrieving and manipulating 3D cadastral data is yet to be developed at par with 2D cadastral data.

Much of the problem lies in defining a data model for 3D cadastre, the interactions with the existing database and data capture methods, and the range of possible shapes and combinations of 3D objects in existence at present and those likely to be in the future. Additionally, support for the subdivision or consolidation of these 3D objects, validation rules for checking the data before, during and after entry into the system, and the optimal validation rules for entry of the data into the system must be considered. Karki (2013) and Karki, Thompson, et al. (2010) outline 3D cadastral situations that may require validation, including:

- *Internal validity of 3D parcels – geometrical validations;*
- *Surface or base parcel – validation of objects on or below the surface parcel;*
- *Relationships to other parcels – validation of inter-parcel relationships;*
- *Unique geometrical situations – network and multi-strata objects;*
- *Further processing on the geometry – subdivision, consolidation, easements; and*
- *Entry level validations – includes spatio-temporal aspects, continuity.*

(Karki, 2013, pp. 22-23; Karki, Thompson, et al., 2010, p. 9)

3.4.5 3D Cadastre and Elevation

In a 3D digital cadastre, elevation details about the spatial extents of property rights are as important as information about horizontal position. This is because of the positional certainty required for property rights located above and below each other. In a study by Stoter and Gorte (2003) it is argued that a 3D cadastral system should be capable of showing the absolute position of 3D parcels, with respect to their topographical surface (i.e., the ground profile). Stoter and Gorte also contend that Triangulated Irregular Network (TIN) computations should be performed within a 3D cadastral database management system to allow 3D parcels to be assessed against the surface model (sometimes referred to as a Digital Terrain Model or DTM).

The research by Stoter and Gorte has both merits and limitations. A surface model would make for more meaningful visualisation of the cadastre by allowing 3D parcels to be set into the context of its surrounds. Without a surface model 3D parcels would appear to be ‘floating in the air’, particularly in hilly parts of a city, for example. However, currency issues with the surface model may arise as the land contour and built environment is altered through any subsequent development activities. With this in mind it would seem that a surface model should be considered as being no more than an indicative tool to aid visualisation of the cadastre. It should not be used as an authoritative means to establish the heights of parcels, which is the very concept promoted by Doner and Biyik (2007).

A noteworthy omission from the literature is a lack of emphasis on the importance of vertical datums, which provide the basis for height measurements to 3D cadastres. A suitable vertical datum across a jurisdiction (nationally in terms of New Zealand) is paramount to enable 3D parcels to be incorporated into the digital cadastre and subsequently maintained. This observation could be a reflection of the level of maturity (advanced) of the New Zealand cadastral system (Land Information New Zealand, 2014c) which is founded on a robust national survey control system (Land Information New Zealand, 2014e). Similarly, the magnitude of land deformation (through earthquakes) and displacement (through continental drift) experienced by New Zealand is a factor that must be accounted for in the on-going maintenance of the digital cadastre.

3.5 Opportunities of 3D Digital Cadastre

A 3D cadastre provides an opportunity for a series of improvements to a cadastral survey system with flow-on effects also benefiting tenure systems which rely on the accurate definition of legal boundaries for the purpose of registration. Stoter (2004) describes three primary opportunities resulting from the implementation a 3D digital cadastral survey system:

- *3D registration provides information on the 3D extents of rights, limited rights and legal notification and allow integration of 3D information in the current cadastral geographic data set…*
- *A 3D cadastre will incorporate digital information on 3D situations…*
- *When enabling 3D registration, the parties involved have a tool to register 3D situations…*

(Stoter, 2004, p. 91)

A digital 3D cadastre will allow 3D parcels to be queried in a 3D environment in the same way parcels are queried in current 2D digital cadastres with an added benefit of more interactive visualisation of 3D situations. A vector representation of 3D parcels in the cadastre will offer better registration possibilities and provide an overview of the whole 3D situation. Digital information will also promote better possibilities for the electronic exchange of data and automation of quality checks through data validation.

The opportunities of 3D digital cadastre are not limited to the registration of property rights. This is because cadastral data is now being used extensively by government and private sectors for the provision of non-cadastral services (Gulliver & Haanen, 2014). LINZ (2014, p. 13) states that the cadastre is a "…mechanism that supports the delivery of social, economic, and cultural benefits, and which relies on and contributes to the overall spatial data infrastructure and property rights system." Councils use cadastral information to underpin land valuation, rating, administration, planning, electoral and resource management roles. Private sector businesses and individuals use cadastral data when developing applications such as route optimisation and research and analysis for social, cultural, economic and environmental purposes.

BIM (Building Information Modelling), and the potential reciprocal relationship it may have with 3D digital cadastral data, is identified as a specific opportunity worthy of further consideration. The relationship between BIM and 3D digital cadastral data is a recent and emerging area of research. Although BIM is evolving in the construction domain and 3D cadastre is evolving in the legal cadastral domain, El-Mekawy et al. (2014) argue that the two domains can interact due to their often shared relationship to the built environment. BIM is the digital representation of the complete physical and functional characteristics of a built asset. It involves creating a model with real life attributes within a computer and sharing that information to optimise the design, construction and operation of that asset (Issa & Suermann, 2009). BIM is considered as an object-oriented process which describes buildings in respect to their geometric and semantic properties. It therefore involves the generation as well as management of spatial digital representations of physical and functional characteristics of building spaces and their surrounding environment (Isikdag & Zlatanova, 2009a). Through this definition, it can be understood that BIM is characterised by a clear and logical structure of spatial objects of a building enabling spatial analyses rather than only visualisation of a building and its spatial elements (El-Mekawy et al., 2014).

The advent of BIM presents an opportunity to consider how detailed spatial representations of buildings and other structures might contribute to the determination of the spatial extents of 3D property rights and also visualisation of those rights in the context of the physical world. In addition to any known or perceived (such as BIM) opportunities of 3D digital cadastral data, there are likely to be unknown and unexpected opportunities and benefits borne out of readily accessible 3D data.

3.6 Summary

In this chapter the discussion explored the literature supporting research and development of 3D cadastral survey systems and associated cadastre. The review commenced with an historical overview of cadastres while key characteristics of cadastres and cadastral survey systems were presented in the context of land administration. It was identified that cadastres have evolved to a point where their value to society now extends beyond their core function within the domain of land administration. They have become a mechanism to support the delivery of social, economic and environmental benefits to jurisdictions and countries.

Following the detailing of the background to cadastral survey systems and cadastres, the concept of 3D cadastre was introduced. The subsequent consideration for the development of 3D cadastres on a global scale facilitated the identification of issues and opportunities. It was established that variances between cadastral survey systems in countries around the world means that no two systems are the same. This is impeding discussion and the sharing of knowledge between jurisdictions at national (in the case of multiple jurisdictions within one country) and international levels. This observation is particularly well evidenced through the inability of the literature to succinctly and comprehensively define the term, cadastre. Research promoting the merits of standardisation also adds support to this finding.

In addition to jurisdiction-based issues, the geometrical representation, validation and modelling of 3D cadastral data are a common focus of the research and development. However, an apparent gap in the literature was identified in relation to a cadastral survey system providing the basis for elevation data in a 3D cadastre. This is an interesting finding given the importance of accurate height information to the determination of 3D property rights.

The opportunities associated with a 3D digital cadastre are confirmed to be wide-ranging and likely to positively benefit every level of society in many ways. In addition to detailing a series of applications of 3D digital cadastral data, BIM was given specific consideration due to its status as an emerging area of research. The potential relationship between BIM and 3D digital cadastral survey data is yet to be explored in the literature.

The review of the background literature confirms and highlights that while there is a substantive volume of research in the area of 3D cadastres, there is a distinct absence of a contribution from New Zealand. This finding is of concern given the challenges emphasised through the literature associated with the development of 3D cadastres. The overall complexity of 3D cadastres within the topic area of 3D cadastral survey systems is further and ultimately accentuated through the fact that no country in the world has a fully developed and functioning 3D digital cadastre. It is through these findings in this chapter that this research is substantiated.

4 Developing a 3D Digital Cadastral System for New Zealand

This chapter presents a proposal for the development of a 3D digital cadastral survey system for New Zealand based on knowledge obtained and documented in the preceding chapters. In Chapter 2, the status of 3D in New Zealand's cadastral survey system set the context for developing 3D digital capabilities. The review of international literature in Chapter 3 then provided a platform from which to consider and assess developmental progress against the New Zealand context. The information in these chapters combines to ensure that the development of 3D digital capabilities for New Zealand is informed, relevant and purposeful.

Discussion on developing a 3D digital cadastral system commences with the definition of the term '3D digital cadastre' for the New Zealand context. The definition of 3D digital cadastre leads into documenting the generic requirements of a 3D digital cadastral survey system. These requirements are followed by the identification and examination of approaches to enable a 3D digital solution. Following consideration of the merits associated with each approach a preferred option is selected and subsequently developed through the elaboration of detailed requirements. The detailed requirements of a 3D digital system then allow specific components or impacts of the system to be identified and discussed. From this point the focus of the discussion evolves into developing the preferred approach to enhance the system.

Data modelling principles are applied to advance the concepts associated with the preferred approach to developing the cadastral survey system. An existing land administration data model, the LADM (first discussed in Chapter 3), is initially evaluated with regard to its applicability to New Zealand. A completely new data model to account for the New Zealand context is then presented and documented at a conceptual level. This data model provides the structure from which a case study demonstrates how analogue processes might be transformed to enable a fully digital 3D system. The chapter is concluded with a summary on developing a 3D digital cadastral system for New Zealand.

4.1 New Zealand 3D Digital Cadastre Defined

A definition of the term '3D digital cadastre' is considered to be a necessary starting point given the varying nature of definitions of cadastre throughout the world (refer to s. 3.1.1). The author has also observed that a level of confusion exists around what a 3D digital cadastre is and, conversely, what it is not, especially in this age of emerging 3D digital spatial information. This variety and confusion emphasises a need to ensure a definition tailored for the New Zealand context is derived to provide certainty for a term that is pivotal to this research.

4.1.1 What a 3D Digital Cadastre *is*

A 3D digital cadastre would be the product of a 3D digital cadastral system and would make 3D property rights related data available to anyone for subsequent reuse. It would provide the most tangible component to many users of the system. However, the review of international literature in Chapter 3 highlighted that there is no single, concise definition for the term, 'cadastre', in the generic sense let alone the specific term, '3D digital cadastre'. This is likely because of differences (including level of maturity) in land administration systems between jurisdictions, together with varying expectations of what is required from cadastral survey systems. Due to this, it would seem most appropriate to base a New Zealand specific definition for 3D digital cadastre on a modified definition for cadastre provided by the published LINZ cadastral strategy, Cadastre 2034 (refer to s. 2.5.3). A 3D digital cadastre is thus defined in this research as being:

> *the repository of digital cadastral survey datasets, including those with defined 3D data, and lodged with LINZ and integrated into its database.*

A 3D digital cadastre would permit data associated with the real world extents of property rights (Figure 4.1) to be digitally captured, automatically checked against requirements, combined with existing data (and subsequently maintained), and exported for reuse in other software or systems. A 3D digital cadastre would also allow the spatial extents of the existing 3D property rights system to be represented (visualised) digitally in 3D.

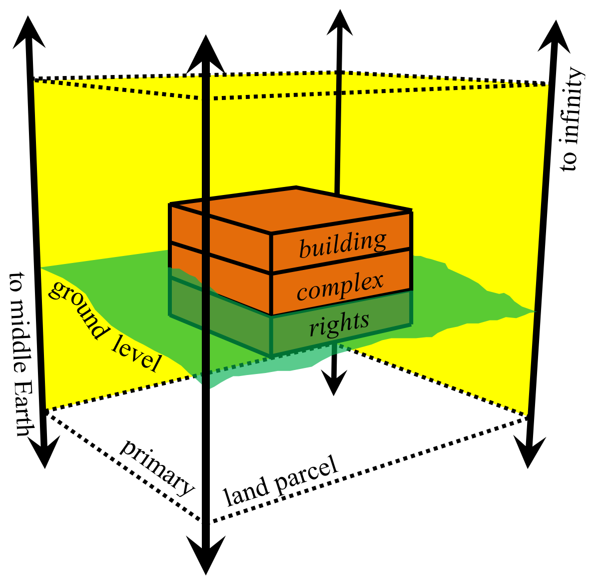

Figure 4.1: Extents of property rights

4.1.2 What a 3D Digital Cadastre *is not*

The world is a place where 3D digital information is becoming common place. This is particularly true in the development and administration of the built environment. Councils and developers are turning to BIM (Building Information Modelling) and 3D City Modelling to assist with design, build and management operations (refer to s. 2.4.5.1 & s. 2.4.5.2). It is important to not confuse these concepts with 3D digital cadastre. It is also important to appreciate that opportunities arise from the ability to combine 3D digital cadastre data and other 3D data, such as BIM and 3D city models.

A 3D digital cadastre is not BIM. BIM is the digital representation of the complete physical and functional characteristics of a built asset (e.g., Figure 4.2). While a 3D digital cadastre is not BIM and vice versa, 3D digital cadastre data, such as the extents of property rights, could form a valuable layer of information within BIM, particularly in terms of facilities management. BIM data could also be used to help define the extents of 3D property rights for the cadastre, in the same way that cadastral surveyors currently use architectural and engineering drawings and plans for this purpose (refer to s. 2.2.6.1).

Figure 4.2: BIM models
(Source: AecMag, 2014)

A 3D digital cadastre is also not 3D City Modelling. 3D city models are digital models of urban areas that represent terrains surfaces, sites, buildings, vegetation, infrastructure and landscape elements (Stadler & Kolbe, 2007). 3D city modelling is finding favour with councils as a way to communicate design ideas and impacts through 3D visualisations (e.g., part city model - Figure 4.3). 3D city model data could, however, be combined with 3D digital cadastre data by users. For example, 3D boundaries could overlay 3D city models allowing the relationship between the built environment and ownership rights to be visualised.

Figure 4.3: 3D City Model
(Source: ZNO, 2014)

4.2 Developing a Solution

4.2.1 Requirements

Solutions need to consider how 3D property rights are legally defined in a digital environment and also how the related digital data is incorporated into and managed within the system. The current regime supporting the defining and recording of the spatial extents of property rights is presented in Chapter 2. It was found that New Zealand's legislative framework already supports the definition of property rights in 3D. Additionally, existing legislation does not inhibit the development of the cadastral survey system to cater for 3D digital data. However, technical and operational changes are required for the cadastre to handle 3D information digitally. The specific requirements are identified and defined in Table 4.1, below.

Table 4.1: Requirements of a 3D digital cadastral survey system

Requirement	Description
Search	Users will need to be able to visualise, interrogate and extract digital 3D property rights related information.
Capture/Lodgement	Cadastral surveyors will need the ability to digitally capture/lodge 3D property rights related information.
Validation	Automated business rules will be necessary check the validity of incoming data.
Presentation	Diagrams portraying 3D property rights will be required for title purposes.
Integration	3D data should be integrated into the cadastre.
Maintenance	The spatial accuracy of the cadastre will require horizontal and vertical network maintenance.

4.2.2 Approaches

In Chapter 3, a review of literature relating to the development of cadastral survey systems and cadastres internationally was undertaken. During that review it was identified that Stoter (2004) is a comprehensive piece of research on the topic, 3D cadastre. Although Stoter's work is ultimately tied to the Netherlands' cadastral survey system, it contains generic ideas and theories that might be applicable to other jurisdictions. Particularly noteworthy is Stoter's three fundamental interpretations of 3D cadastre: full 3D cadastre, hybrid solution and 3D tags. These interpretations and variations thereof, form the basis from which options to develop the New Zealand system are considered below.

Fully 3D Digital Cadastre – a fully 3D digital cadastre follows the notion of 'full 3D cadastre' by Stoter (2004). It is a national and complete representation of all rights, restrictions and responsibilities as they currently are in the real world (i.e., 3D legal cadastre). This approach would require parcels that are currently spatially depicted in 2D to be digitally represented as 3D volumes (with an obvious need to set limits on the concept of ownership down to the centre of the Earth and to infinity above). A fully 3D digital cadastre would also require the back-capture of existing rights defined in 3D.

3D-Capable Digital Cadastre **–** a 3D-capable digital cadastre is a variation on the concept of 'hybrid cadastre' by Stoter (2004). 3D property rights can be integrated into the cadastre and subsequently maintained. In situations where the upper and lower height limits of property rights are defined, a full 3D spatial depiction would be used otherwise '2D' parcels would be maintained as a default.

2D Digital Cadastre + 3D Objects **–** like a 3D-capable digital cadastre, defined above, a 2D Digital Cadastre + 3D Objects is a variation of 'hybrid cadastre' by Stoter (2004). The concept of a 2D digital cadastre + 3D objects is to link rights defined in 3D (being 3D objects) to the existing 2D digital cadastre. 3D objects are not integrated into the cadastre and, therefore, cannot be maintained in terms of the underlying 2D digital cadastre.

2D Digital Cadastre + Tags **–** this approach is in line with '3D tags' presented by Stoter (2004) and would see the preservation of the present 2D digital cadastre with digital tags to aspatial representations of 3D situations. That is, plan references can be electronically selected to provide direct access to plan graphics (as opposed to the current user-actioned search process).

Status Quo **–** is the preservation of the current 2D digital cadastre with annotated, non-intelligent reference to aspatial representations of 3D situations. The inclusion of the status quo in the series of approaches reflects that New Zealand's existing cadastral survey system is in fact 3D.

4.2.3 Identifying the Recommended Approach

The development of a 3D-capable digital cadastre in terms with the approach outlined under 4.2.2, above, is deemed to be the most appropriate solution to enhance New Zealand's cadastral survey system. This approach builds on the existing world-class 2D digital cadastre by allowing 3D data to be digitally captured, validated, maintained and made available for reuse as and where necessary. It represents a fit for purpose approach that is a step back to realising a fully 3D digital cadastre. While a fully 3D digital cadastre could be deemed to be the ultimate solution, it would require the complete replacement of the existing digital cadastre. Although not quantified by this research, the cost to achieve a fully 3D digital cadastre is likely to far exceed that of a 3D-capable solution while any benefits might be negligible or even non-existent for now and in the foreseeable future.

A 3D-capable digital cadastre would deal with all 3D situations. A further step back to the 2D digital cadastre + 3D objects approach would mean that the spatial extents of property rights defined in 3D could not be integrated into the cadastre and subsequently maintained. This limitation would be a severe constraint on the value of the digital cadastre. Anything less than this approach would mean a continued reliance on aspatial, non-digital plan graphic representations of 3D situations. The 3D-capable digital cadastre is, therefore, confirmed as being the recommended approach to enhance New Zealand's cadastral survey system.

4.2.4 Detailed Requirements of 3D-Capable Digital Cadastre

In Chapter 2 it was identified that there are two generic methods of defining the boundaries of property rights in three dimensions - those defined as stratum boundaries, and those relating to a permanent structure. Currently both of these methods are handled by the cadastral survey system through the use of aspatial processes. It is proposed to continue with these conventions to define property rights digitally in 3D. Accordingly, the detailed requirements of a 3D-capable digital cadastre will be separately considered in terms of stratum boundaries and permanent structure boundaries.

4.2.4.1 Stratum Boundaries

This method defines the boundaries by dimensions related to reference marks in the ground (which are in turn related to the geodetic network horizontal and vertical datums, from which

X, Y & Z coordinates may be computed). These boundaries are not usually marked (they may be underground or in the air), but they can be located at any time by using the reference marks or/and the survey control network.

Search **–** users will be able to visualise, interrogate and extract digital stratum boundary information. More specifically, users of the system will have the ability to:

a. see 3D defined parcels as 2D birds-eye view against 2D cadastral network (e.g., show as overlapping in current Landonline spatial view)
b. see 3D defined parcels in 3D against a 3D projection of the 2D cadastral fabric, including the bed of water body where the bed is a boundary
c. interrogate 3D defined parcels by visualising them in 3D
d. retrieve all boundary bearings, distances, and reduced levels as provided by the surveyor
e. retrieve all data relating to 3D defined parcels as provided by the surveyor
f. retrieve 3D coordinates of all points (for a given cadastral survey dataset).

Capture/Lodgement **–** surveyors will have the ability to digitally capture/lodge stratum boundary information. The system will provide a digital record of 'mathematically' defined boundaries (mostly bearings & distances, and reduced levels) connected to the primary parcels network (usually underlying land parcel). All peripheral horizontal boundaries will be defined by nodes (points) and bearings & distances, unless they are water boundaries. Peripheral nodes (3D) will be connected to surrounding nodes (whether 2D or 3D) and new nodes will be inserted into primary parcel network topology. Boundaries that cannot be defined by bearings & distances and reduced levels (e.g., water and other irregular boundaries) can be defined by a '3D Spatial Object' (being similar in concept to an Esri shapefile). Data originally submitted by the surveyor will be preserved for audit purposes.

Validation **–** automated business rules will check that:

a. all points are defined by sufficient bearings & distances, and reduced levels or other means
b. horizontal dimensions of new 3D defined parcels 'fit' with each other (e.g., least squares test for internal consistency)
c. horizontal dimensions of 3D defined parcels fit existing parcels (e.g., least squares test for external consistency)

d. defined 3D defined parcels do not illegitimately overlap each other
e. defined 3D defined parcels do not overlap primary parcel boundaries (primary land parcels recorded in 2D may need to be projected as a column)
f. existing volume completely replaced by new 3D defined parcels (including to infinity, possibly using arbitrary maximum height & depth)
g. reduced levels are in terms of reference marks connected to the official New Zealand vertical datum.
h. plus usual checks as for 2D parcels (e.g., witness marks, permanent reference marks, adoptions, etc.).

The ability to visualise parcel boundaries is required for users to consider the overall spatial context and also manually assess compliance with rules.

Presentation **–** a Title Visualisation, consisting primarily of a diagram(s) of 3D defined parcels and their underlying land parcel(s) is required.

a. The diagram(s) could be based on 'screen grabs' of 3D visualisations rather than traditional plan, longitudinal section and cross section views.

Diagrams must:

b. be automatically produced from digitally captured survey data
c. show all 3D defined parcels in relation to each other and to the abutting/underlying 3D defined parcels and underlying land parcels.

A plan of the cadastral survey, similar to that required for a '2D' survey is not required. All information would instead be available via the digital dataset.

Integration **–** the following requirements will be necessary to enable the integration of stratum parcels into the cadastre:

a. assume peripheral nodes (3D) already connected at capture to surrounding nodes (whether 2D or 3D)
b. adjust horizontal coordinates defined by bearings & distances into the cadastral network, as per 2D.
c. 3D defined parcels must also be capable of integration into the cadastral network.
d. reduced levels assumed to be correct following capture and validation.

Maintenance **–** the spatial accuracy of the cadastre will require horizontal and vertical network maintenance.

a. Update horizontal coordinates as part of network maintenance.
b. Update reduced levels when reduced level of reference marks change.
c. Nodes that are vertically above each other must retain the same X, Y coordinates (thus ensuring the relationship between linked 3D defined parcels and underlying land parcels is maintained).

4.2.4.2 Permanent Structure Boundaries

The other generic method defines the boundaries by their relationship to their permanent structure. These boundaries are either 'marked' by elements of the building itself (e.g., the outer face of a wall), or in relation to it (e.g., the middle of a floor slab, or two metres above the roof parapet). These boundaries can be located at any time by using the relationship to the elements of the building as defined in the cadastral survey dataset.

Search **–** users will have to be able to visualise and interrogate boundaries related to permanent structures. More specifically, users of the system will have the ability to:

a. see 3D defined parcels as 2D birds-eye view against 2D cadastral network (e.g., show as overlapping in current Landonline spatial view)
b. see 3D defined parcel in 3D against a 3D projection of the 2D cadastral fabric.
c. interrogate the 3D defined parcels by visualising them in 3D
d. retrieve all data relating to permanent structure boundaries as provided by the surveyor
e. retrieve 3D coordinates of all points (for a given cadastral survey dataset).

Capture/Lodgement **–** surveyors will have the ability to digitally capture/lodge permanent structure boundary information. The system will provide a digital record of the 3D defined parcels and their defined relationship to the permanent structure. Permanent structure boundaries must be connected to the underlying lands parcels network (underlying land parcel must be survey-accurate). Permanent structure boundaries must be connected to horizontal and vertical datums (via reference point) to enable adjustment. Data originally submitted by the surveyor will be preserved for audit purposes.

Validation – automated business rules will check that:

a. 3D defined parcels do not illegitimately overlap each other
b. 3D defined parcels do not overlap primary parcel boundaries (underlying land parcels recorded in 2D may need to be projected as a column)
c. reduced levels are in terms of the official New Zealand vertical datum.

The ability to visualise parcel boundaries is required for users to consider the overall spatial context and also manually assess compliance with rules.

Presentation – Title Visualisation, consisting primarily of a diagram(s) of 3D defined parcels is required.

a. The diagram could be based on 'screen grabs' of 3D visualisations rather than traditional plan, longitudinal section and cross section views.

The diagram must:

b. be automatically produced from digitally captured survey data
c. show all 3D defined parcels in relation to each other and to the abutting/underlying 3D defined parcels and underlying land parcels.

A plan of the cadastral survey similar to that required for a '2D' survey is not required. All information would instead be available via the digital dataset.

Integration – the following requirements will be necessary to enable the integration of permanent structure boundaries into the cadastre:

a. 3D defined parcels are spatially adjusted to align with their underlying parcel
b. reduced levels are assumed to be correct as captured at that time.

Maintenance – the spatial accuracy of the cadastre will require horizontal and vertical maintenance:

a. maintain horizontal spatial alignment with underlying parcel whenever its coordinates change
b. update vertical spatial alignment when reduced level of reference point changes.

4.3 Considerations Arising from 3D-Capable Digital Cadastre

The detailed requirements of a 3D-capable digital cadastre established in the previous section provide the opportunity to identify specific components or impacts where further consideration is needed. This may be due to limitations of the current system or due to a radically new way of doing things. These considerations are highlighted and discussed below.

4.3.1 An Improved National Vertical Datum

Datums formed part of the discussion about New Zealand's existing cadastral survey system in Chapter 2. A 3D-capable digital cadastre requires national horizontal and vertical control datums suitable for cadastral survey purposes. While New Zealand's current horizontal datum, NZGD2000, is sufficient the current vertical datum, NZVD2009, requires improving.

NZVD2009 allows the separate regional levelling datums to be linked and enables GNSS to be used to determine heights. However, NZVD2009 was established using historical gravity data that was not collected with the intent of being used for height system definition (Land Information New Zealand, 2012). This has resulted in a number of problems including levels of accuracy, uncertainty of how datum accuracies have been maintained and an inability to provide heights reliable enough to meet cadastral requirements.

In 2012, LINZ commenced a project to acquire a national airborne gravity dataset. This will allow a more accurate definition of the NZVD2009 reference geoid shape and, in turn, support more accurate elevation determinations across the country. The completion of this project will help achieve the primary goal of the New Zealand Positioning Strategy, to "enable the efficient definition of three-dimensional property rights through an accessible geodetic system" (Land Information New Zealand, 2014e, p. 6).

4.3.2 Back-capture of Historic 3D Data

During consideration of the various approaches to achieve a 3D digital cadastre (refer to s. 4.2.2) the most advanced approach, being a fully 3D digital cadastre, is associated with a requirement to back-capture all historic 3D data. While back-capture is not a requirement of the 3D-capable approach, the advantages of having a fully populated 3D digital system should not be overlooked.

The benefit of back-capture is the immediate realisation of the full potential of a 3D-capable digital cadastre. To limit the implementation of a 3D system to the forward capture of new work would mean that it could take many years and even generations before the benefits of a completely digital system are realised. A query of Landonline data as of November 2014 shows there are 13,815 Unit Title datasets (comprising 140,220 Principal Units and 153,350 Accessory Units) and 1,139 datasets involving stratum boundaries. The number of existing 3D situations and the benefits of a complete 3D digital cadastre from initial implementation may mean that back-capture is feasible.

4.3.3 3D Defined Parcels & 3D Spatial Objects

A 3D defined parcel represents the spatial extents of 3D property rights. The survey definition of a 3D defined parcel will be possible through traditional bearing, distance and reduced level techniques and also through a new format, referred to as a '3D Spatial Object'. A 3D Spatial Object is a coordinate-based technique to capture and subsequently visualise 3D data. It will comprise a 3D vector data format, not unlike an Esri shapefile, to store information about the location, shape and attributes of the 3D defined parcel being represented by the 3D Spatial Object.

The use of 3D Spatial Objects to represent the spatial extents of a 3D defined parcel through its inherent coordinates would be a significant change to the New Zealand cadastral system which is founded on marks and observations. However, such a change is necessary for the 3D-capable digital cadastre to become a reality.

4.3.4 Digital Data versus Plans

In the present system the authoritative (and legal) source of data is that contained on the 2D plan and supporting dataset certified by licensed cadastral surveyors. In the 3D-capable digital cadastre the digital information held in the database would be the authoritative data. Plans produced by surveyors to present the structure and geometry of a cadastral survey would no longer be a mandatory requirement of the system. Instead, diagrams automatically generated by the system would be used to depict the extents of property rights for tenure system purposes. Diagrams of survey to assist user-interpretation of the cadastral survey data would also be generated by the system from data held in the system.

4.4 Developing a Data Model

In Chapter 3, it was found that data modelling is one of the most important elements of a successful 3D cadastre. A data model allows users to understand the proposed structure and behaviour of a system and provides a template to guide construction and assist implementation. Of the data models identified during the review of background literature, ISO 19152 Land Administration Domain Model stands out as being the most significant and worthy of further consideration.

4.4.1 ISO 19152 Land Administration Domain Model

4.4.1.1 Land Administration Domain Model Described

The ISO 19152 Land Administration Domain Model (LADM) specification proposes a reference model to formalise common aspects of land administration systems and, in particular, their cadastral survey components (AS/NZS ISO 19152, 2012). This formalisation is achieved through standardised graphical representation of features and concepts using the Unified Modelling Language standard (UML). LADM promotes a conceptual model that organises the concepts and the relationships pertaining to rights, responsibilities and restrictions governing ownership of land and the geometrical components associated with its spatial representation. The LADM data model consists of four packages: *Party*, *Administrative*, *Spatial Unit* and *Surveying and Representation*, as depicted in the UML diagram of Figure 4.4.

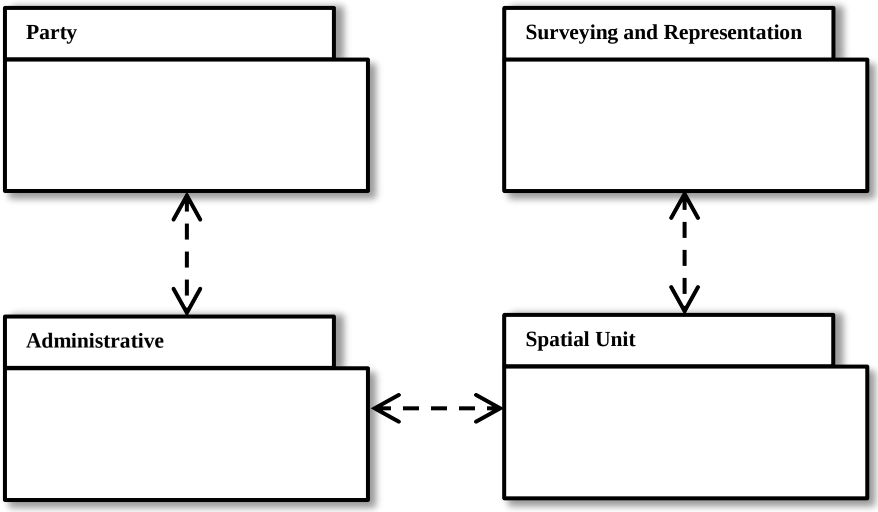

Figure 4.4: Overview of LADM packages

The *Party Package*, depicted in Figure 4.5, comprises classes applying to parties and their composition. The package has a main class of *LA_Party* with its specialisation *LA_GroupParty* and optional association *LA_Party-Member*. A Party is a person or an organisation that is connected to a land parcel, referred to as Spatial Unit. A Group Party is made up of any number of registered party members holding specified shares in rights.

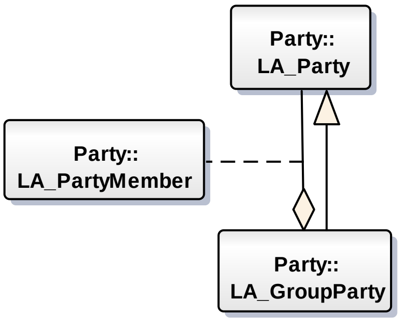

Figure 4.5: Classes of the LADM Party Package
(AS/NZS ISO 19152, 2012)

The *Administrative Package*, depicted in Figure 4.6, includes classes concerning spatial units and corresponding rights, restrictions and responsibilities. The package contains an abstract class of *LA_RRR* with three subclasses *LA_Right*, *LA_Restriction* and *LA_Responsibility*, and also *LA_BAUnit*. *BAUnit* is an abbreviation for Basic Administration Unit, an entity consisting of zero or more spatial units and associated with rights, restrictions or responsibilities. An example of a *BAUnit* in the New Zealand context is an apartment (Principal Unit) and its car park (Accessary Unit) under the Unit Titles Act 2010.

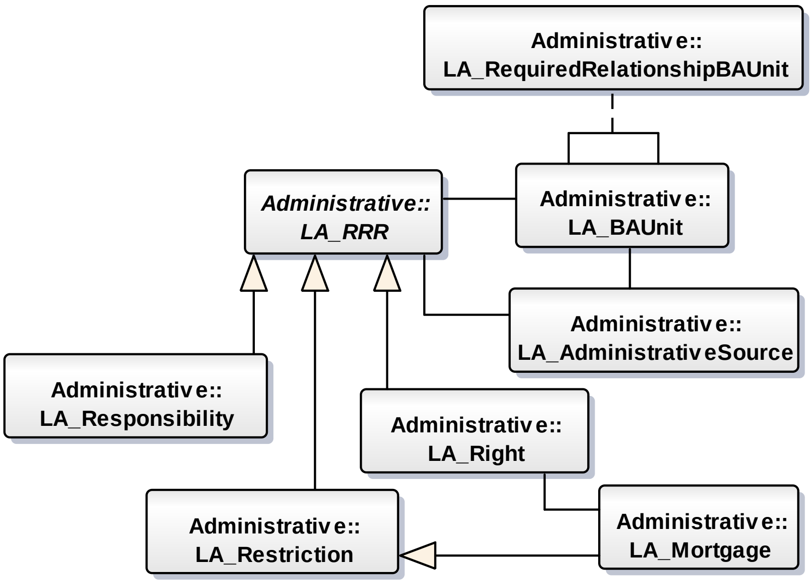

Figure 4.6: Classes of LADM Administrative Package
(AS/NZS ISO 19152, 2012)

The *Spatial Unit Package*, depicted in Figure 4.7, consists of classes relating to spatial elements such as land parcel, building, utility networks and associated descriptive elements. The package contains the classes: *LA_SpatialUnit*, *LA_SpatialUnitGroup*, *LA_Level*, *LA_LegalSpaceNetwork*, *LA_LegalSpace-BuildingUnit* and LA_Required-RelationshipSpatialUnit. A Spatial Unit can be represented as text, points, lines, polygons and topology. The LADM supports 2D (land area) and 3D (property volume) objects. It is important to note that only 3D legal spaces are considered in the LADM (which may or may not be coincident with building structures).

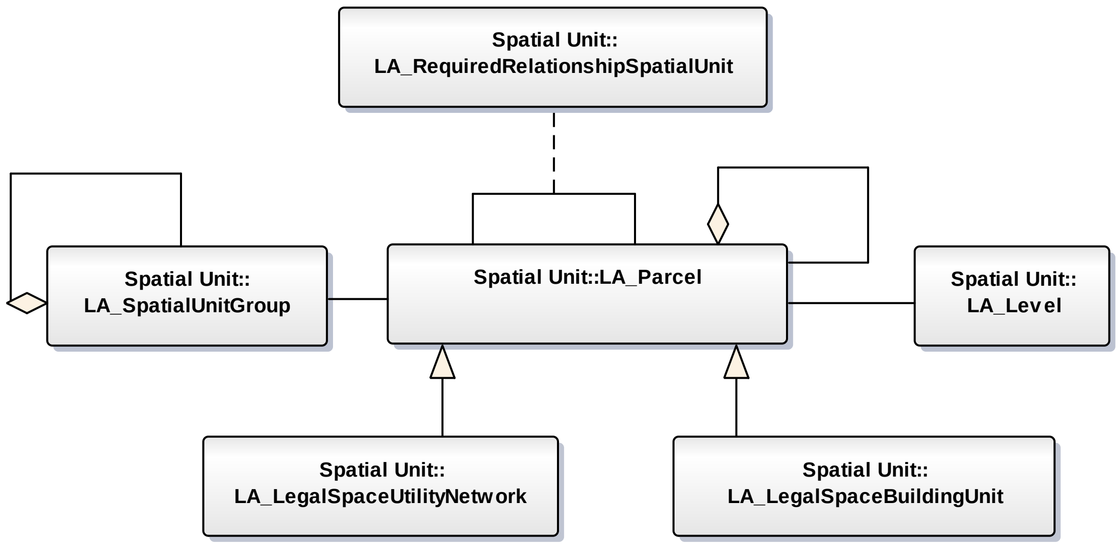

Figure 4.7: Classes of LADM Spatial Unit Package
(AS/NZS ISO 19152, 2012)

Spatial units are designed to support the creation and management of Basic Administrative Units. A Spatial Unit Group is a group of spatial units within an administrative zone, being a country in the case of New Zealand or within a planning area, such as a territorial authority. A Level is a collection of spatial units with geometric/topologic and/or thematic consistency. The Spatial Unit Package contains the sub-package, Surveying and Spatial Representation.

The *Surveying and Spatial Representation Sub-package*, depicted in Figure 4.8, below, has classes: *LA_SpatialSource*, *LA_Point*, *LA_BoundaryFaceString* and *LA_BoundaryFace*. A survey is documented with spatial sources and vector observations of points as an attribute of *LA_SpatialSource*. The individual points are instances of *LA_Point*. Both 2D and 3D representations of spatial units use ‘boundary face strings’ where 2D boundaries indicate vertical faces which form part of the outside of a spatial unit. ‘Boundary faces’ are used in the 3D representation of a boundary of a spatial unit.

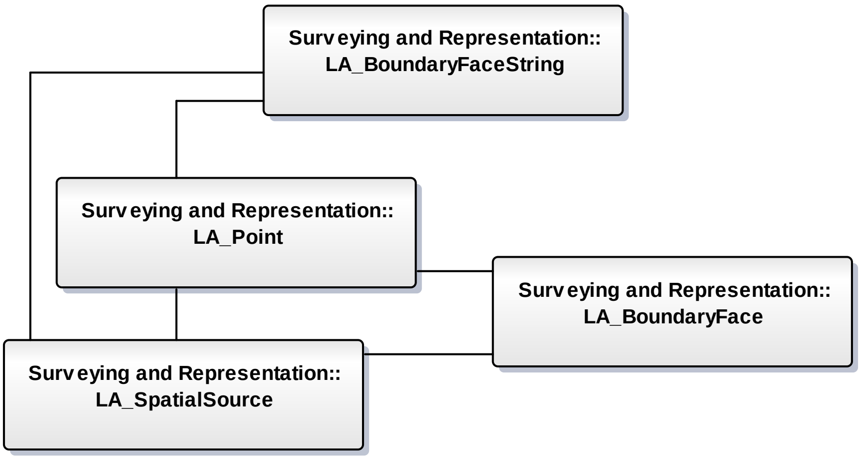

Figure 4.8: Classes of LADM Surveying and Representation Subpackage
(AS/NZS ISO 19152, 2012)

With the exception of *LA_Source*, depicted in Figure 4.9, all classes inherit from *VersionedObject*, which contains quality labels and attributes for history management. Both administrative and spatial sources are modelled commencing with an abstract class, *LA_Source*. *LA_Source* has two subclasses, *LA_AdministrativeSource* and *LA_SpatialSource*.

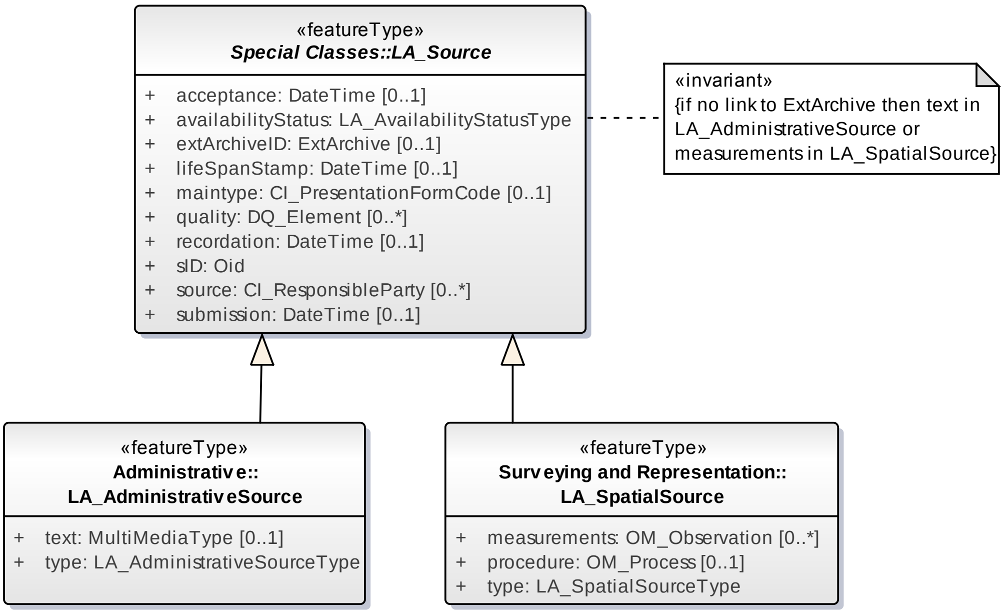

Figure 4.9: Classes and Attributes of LADM Source (with subclasses)
(AS/NZS ISO 19152, 2012)

4.4.1.2 Evaluation of LADM for Applicability to New Zealand

At face value the LADM would seem to be an invaluable tool for developing a country's cadastral survey system (and tenure system). The international standard constrains users to use a shared vocabulary and enables jurisdictions to more readily compare and contrast systems, a benefit demonstrated by Pouliot, Vasseur, and Boubehrezh (2013). However, there are downsides to international conformity for a mature cadastral survey system such as that of New Zealand. It is difficult if not impossible for a generic standard to exemplify a country's long standing terminologies, practices and societal expectations, which are often embodied in legislation and rules.

While there are benefits to international conformity, the elaboration of the LADM conceptual model in accordance with New Zealand's requirements is likely to cause conflict arising from local nuances. For example, in New Zealand the term 'parcel' is used to describe "an area or space that is a single contiguous portion of land separately identified in a CSD [Cadastral Survey Dataset] or integrated into the cadastre" (Rules for Cadastral Survey 2010, p. 11). Parcel is, therefore, affiliated with the practice of digitally capturing and integrating 2D digital data in Landonline. The LADM equivalent to parcel is 'spatial unit' which is defined to be a "…single area (or multiple areas) of land and/or water, or a single volume (or multiple volumes) of space..." (AS/NZS ISO 19152, 2012, p. 6).

Rather than adopt the LADM term, '3D defined parcel' is used in this research to describe volumes that are digitally captured and integrated into a 3D system. The retention of the term parcel ensures continued association with a term that is instantly recognisable and understood by surveyors and other land professional users of the system. Also, in New Zealand the term 'unit' is currently associated with the spatial extents of rights created under the Unit Titles Act 2010. That Act defines 'unit' as meaning "…part of the land consisting of a space of any shape situated below, on, or above the surface of the land, or partly in one such situation and partly in another or others, all the dimensions of which are limited, and that is designed for separate ownership" (Unit Titles Act 2010, s. 5). This definition of 'unit' is similar to that for 'spatial unit'. These similarities need to be managed to reduce the risk of confusion between the terms 'spatial unit' and 'unit'.

The generic nature of LADM means that it provides for a very broad range of techniques (encoding of geometry) to spatially define and describe the location and extents of property rights (i.e., parcels or spatial units). These techniques include: sketch, text, point, line, polygon and topological based units. This range of spatial definitions supports a fit-for-purpose approach to land administration, including the establishment of a system in a developing country where complete spatial certainty may not be initially necessary. However, for a country such as New Zealand where a topologically correct cadastre is of prime importance, the LADM contains a lot of superfluous information that results in a data model that is cumbersome and difficult to interpret.

Aien et al. (2013) and Pouliot et al. (2013) report on a specific limitation of LADM that is of particular concern. That is, an apparent inability of LADM to return information about the volume of a 3D object due to its use of surface geometry primitives in the data model. The ability to perform 3D volumetric computations is important for validation (e.g., to ensure 3D defined parcels are completely accounted for at time of subdivision). Volume information might also be an important attribute of a 3D defined parcel for title reasons and/or sale and purchase considerations. While both papers provide no further reasoning to support this conclusion, Khuan, Abdul-Rahman, and Zlatanova (2008) do emphasise that volumetric computations can be made through the representation of 3D spatial objects using solid geometry in a database management system. Despite this, the apparent limitation of LADM can only be categorically confirmed through a more detailed evaluation of its Surveying and Representation Subpackage.

Figure 4.10, below, shows the Surveying and Representation Subpackage, expanded to include class attributes and operations. As discussed under s. 4.4.1.1, the LADM class *LA_BoundaryFaceString* is used to represent 2D spatial units and *LA_BoundaryFace* to represent 3D spatial units. These two classes, together with their attributes, are emphasised by red boxes on Figure 4.10.

The geometry used to represent classes *LA_BoundaryFaceString* and *LA_BoundaryFace* is documented in their respective attributes (underlined in red). It can be seen that LADM refers to ISO 19107, Geographical information – Spatial schema, *GM_MultiCurve* and *GM_MultiSurface* to represent classes *LA_BoundaryFaceString* and *LA_BoundaryFace* respectively.

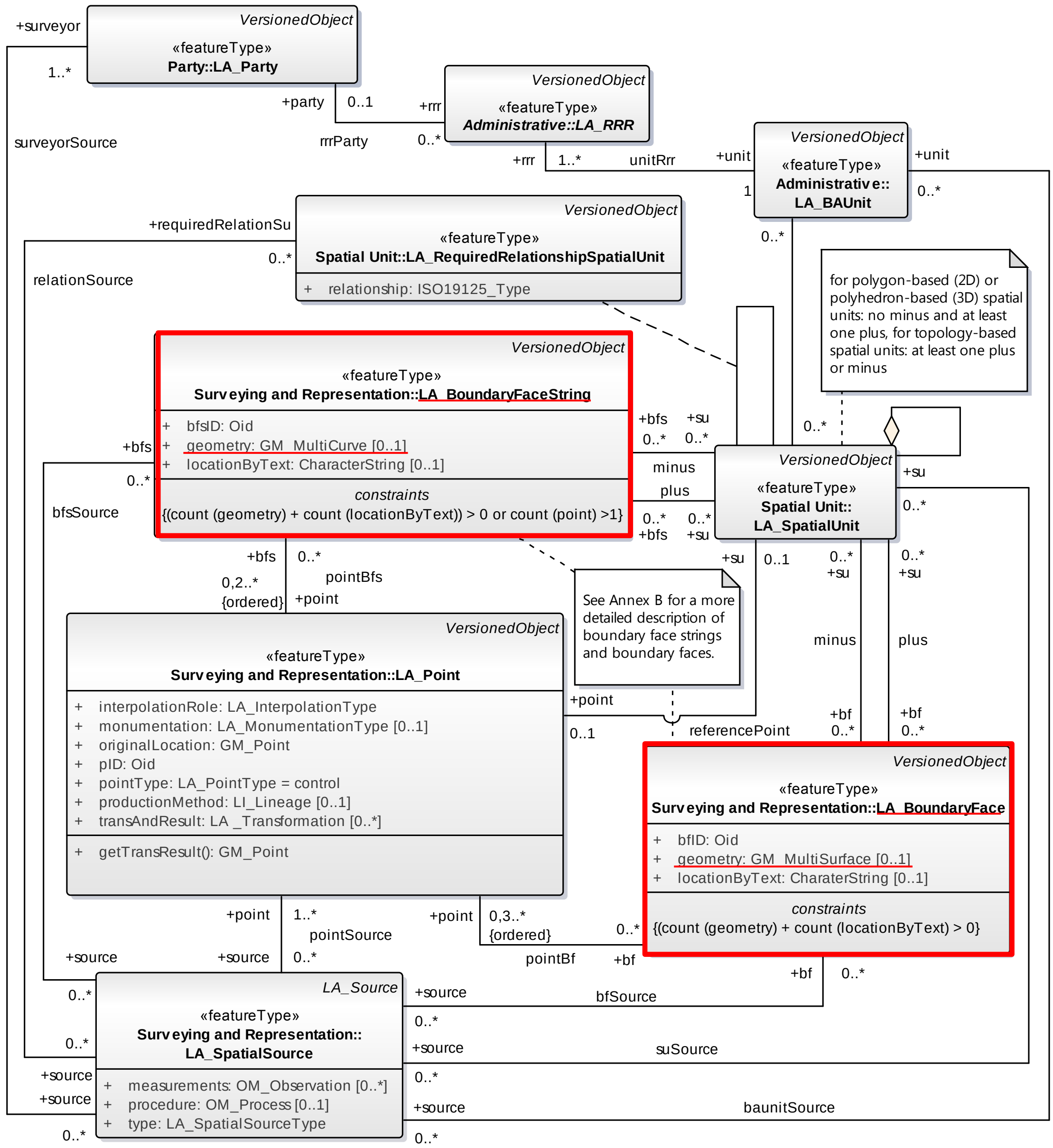

Figure 4.10: Surveying and Representation Subpackage (with class attributes & operations)
(AS/NZS ISO 19152, 2012)

With reference to Figure 4.11, below, a review of ISO 19107 shows that *GM_MultiCurve* returns information about 2D length, as expected. It can also be determined that while *GM_MultiSurface* returns information about the area of a surface, it indeed does not provide information on volume. This analysis confirms a limitation of LADM when it comes to 3D information. This shortcoming is made even more peculiar by the fact that ISO 19107 accounts for volumes through the class, *GM_MultiSolid*, but is disregarded by LADM.

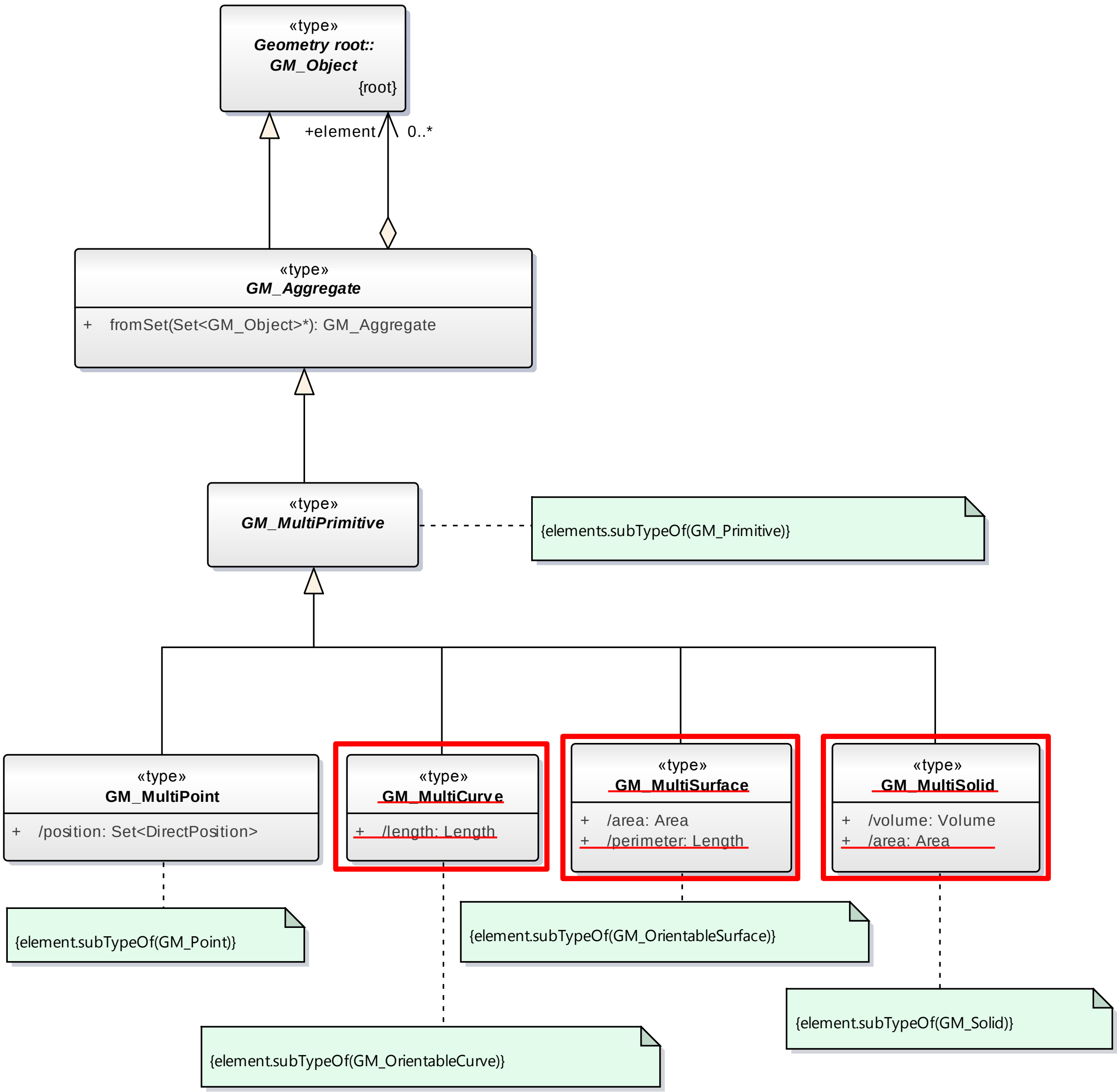

Figure 4.11: ISO 19107 Geometry classes
(AS/NZS ISO 19107, 2005)

The evaluation of the LADM data model and associated documentation additionally reveals that it does not provide for an explicit spatial ground parcel, an observation also noted by Pouliot et al. (2013). This finding is detrimental to the preferred 3D-capable digital cadastre approach identified above, which depends on an association between a 3D defined parcel and its underlying land parcel.

4.4.2 New Zealand 3D-Capable Digital Cadastral Data Model

The development of a 3D digital cadastral data model for New Zealand is deemed necessary to cater for intricacies unique to the local cadastral survey system. While the LADM was found to be inappropriate for New Zealand's requirements, the standardisation principles behind LADM are worth applying to a data model for New Zealand, where appropriate.

In the review of background literature (Chapter 3) the value of data modelling to document an abstraction of reality for a 3D digital cadastral system was emphasised. The literature distinguishes three phases to the data modelling process, each having their own data model associated with them: conceptual model; logical model; and physical model (e.g., Tsichritzis & Lochovsky, 1982; Vossen, 1991).

Data modelling typically commences with the conceptual phase where the concepts and their associations of reality are mapped to a conceptual model. This involves the identification of all major entities that need to be included in the data model, together with characteristics and relationships of those entities. Following the conceptual data model, the logical design phase involves the translation of the conceptual schema into the logical data model of a database management system. In the final phase of the data modelling process the physical design translates the logical model into hardware and software architecture. The physical data model is important to ensure the desired performance outcomes for various queries is achieved (Vossen, 1991). The data modelling development cycle is portrayed in Figure 4.12.

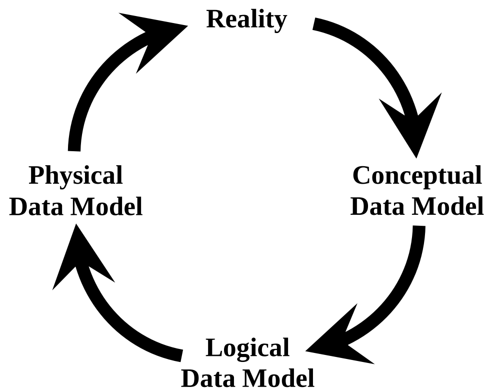

Figure 4.12: Data modelling design cycle

This research will focus on the development of a conceptual data model of the New Zealand 3D-Capable Digital Cadastral System.

4.4.2.1 Conceptual Data Model

The development of a conceptual data model requires knowledge of the real-world situation that is being emulated. This knowledge is acquired from consideration of the current New Zealand cadastral survey system and other systems related to the administration of land (Chapter 2), the review of international literature (Chapter 3) and finally through the detailing of requirements of a digital cadastral system for New Zealand (current chapter). This knowledge culminates in the first iteration of a New Zealand 3D-Capable Digital Cadastral System conceptual data model. The data model is developed around the concept of defining the spatial extents of 3D property rights through the linking of a 3D defined parcel to its underlying '2D' land parcel. This concept represents the 3D-capable digital cadastre described in s. 4.2.4. The accepted standard language for data modelling, UML, is used to depict and describe the conceptual data model.

Figure 4.13 represents the packages of the conceptual data model of the New Zealand 3D-Capable Digital Cadastral System. The model maintains a focus on the cadastral survey system's primary role in the land administration system to define and describe the spatial extents of property rights. The data model does not include the tenure system, however, there is a common connection point between the cadastral and tenure systems through the *Appellation Package*. This concept is a unique feature of the proposed system compared to other cadastral data models, including LADM, which adhere to the principles of the core model described by Kalantari et al. (2006) (refer to s. 3.4.3). The *Person*, *Rights*, *Parcel* components of the core model integrates the cadastral system with the tenure system.

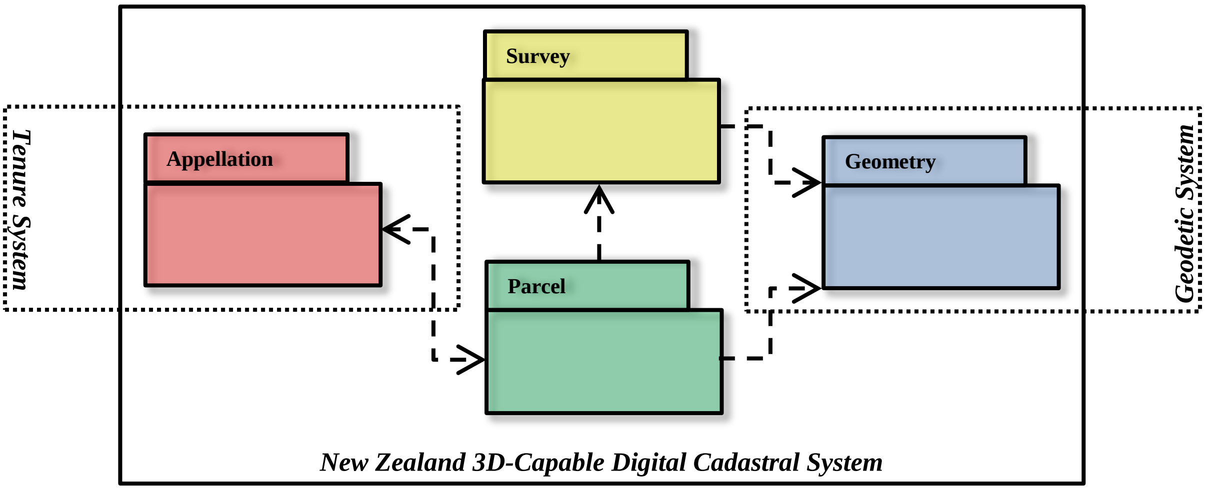

Figure 4.13: Overview of data model packages of the New Zealand 3D-Capable Digital Cadastral System

Similarly the data model of the New Zealand 3D-Capable Digital Cadastral System does not incorporate the geodetic system, although the *Geometry Package* provides a logical common connection point between the cadastral and geodetic systems. In this regard, the data model of the New Zealand 3D-Capable Digital Cadastral System represents a module in a modularised land administration system which would ultimately comprise a tenure system module and a geodetic system module.

The *Appellation* class contains the legal description of the *Parcel*. This information is a key component in the registration of rights, restrictions and responsibilities in the tenure system. It provides an important link between *Parcel* and its title, thus providing an essential point of entry into a tenure system, as noted above.

Parcel is the central class of the New Zealand 3D-Capable Digital Cadastral System. It contains information about the legally defined spatial extents of rights, restrictions and responsibilities of which are represented by a surveyed geometrical object, being the *Parcel*. *Parcel* may be represented by either 2D or 3D geometrical primitives, accounting for both 2D land parcel and 3D defined parcel situations.

The geometric representation of a *Parcel* class is depicted in Figure 4.14. The New Zealand 3D-Capable Digital Cadastral System data model conforms with AS/NZS ISO 19107 (2005) (Geographical information – Spatial schema). If *Parcel* is a 2D land parcel, it can be represented by 1D geometric primitives, such as *GM_Surface*. If *Parcel* is a 3D defined parcel, 3D geometric primitives, such as *GM_Solid*, are used. Incorporating solid geometry into the data model will facilitate 3D representation of parcels, volumetric computations, and 3D spatial queries.

As noted above, the *Geometry* package is the point of overlap with the geodetic system. The geodetic system would handle the integration of new survey data with existing survey data along with subsequent adjustment and maintenance processes.

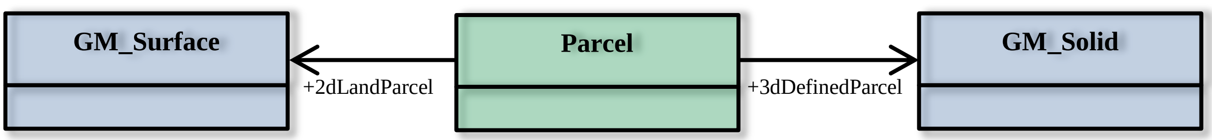

Figure 4.14: Parcel & geometry classes of the New Zealand 3D-Capable Digital Cadastral System

The *Survey* package contains the classes: *Survey*, *Surveyor*, *CoordinateSystem*, *SurveyPoint* and *SurveyObservation*, as depicted in Figure 4.15, below. These classes describe the administrative and technical information and are important elements of a cadastral survey from which *Parcel* is defined. *Survey* contains general metadata for the survey while *Surveyor* maintains details of the license cadastral surveyor responsible for the survey. The *CoordinateSystem* includes information about the horizontal and vertical datums used to define the *Parcel*. *SurveyPoint* contains elements related to the reference marks used in the survey and which can be reused in the future to relocate the spatial position and extents of a *Parcel* (whether 2D or 3D). *SurveyObservation* manages information about observations between survey marks and also calculated vectors between survey marks and 3D defined parcels and their underlying 2D land parcel.

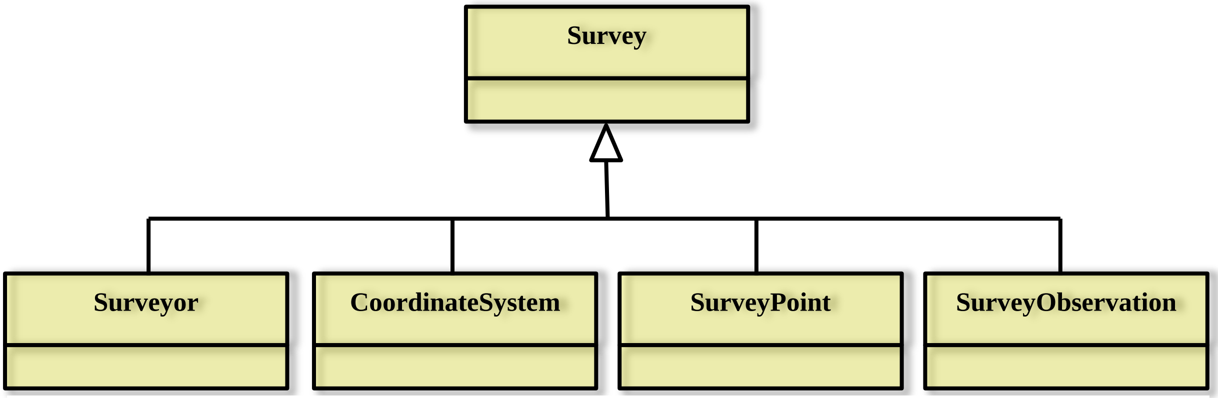

Figure 4.15: Survey classes of the New Zealand 3D-Capable Digital Cadastral System

4.5 Case Study: 3D Digital Cadastral Survey

In this case study a simple unit title development is used to demonstrate how the New Zealand 3D-Capable Digital Cadastral System data model might transform analogue processes to enable a fully digital 3D system. The case study also provides the opportunity to begin documenting the attributes of each of the classes of the data model described in the preceding section.

4.5.1 Background

The case study involves a real-life retail complex, known as Centamax, where six principal units and two accessory units were created over an underlying land parcel in Papamoa, Bay of Plenty, in the North Island of New Zealand (refer to Figure 4.16). The units have been defined through a combination of permanent structure and stratum boundary techniques. The horizontal boundaries of the units are referenced in relation to building structures while the lower and upper extents of the vertical boundaries are defined by reduced levels. The author has intimate knowledge of the development and the cadastral survey, being the certifying licensed cadastral surveyor of the associated dataset. The subject cadastral survey dataset, DP 424294, is contained in Appendix A.

Figure 4.16: Subject retail complex of Unit Title development
(Photo courtesy: Trevor Gulliver, 2015)

4.5.2 Plans of Cadastral Survey Dataset DP 424294

Figure 4.17, below, is a plan view taken from cadastral survey dataset DP 424294. This 'ground level' plan depicts units 1 through 6 in relation to the underlying land parcel boundaries (perimeter line work). The plan also shows common property and easement areas (DU, U, V, E, AI, AH, DAH, D), which provide legal protection for services, including the supply of water, electricity and telecommunications, and the drainage of stormwater and sewerage.

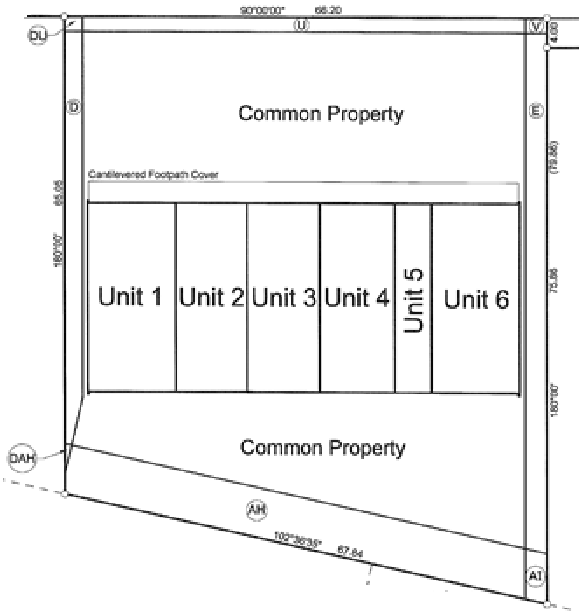

Figure 4.17: 'Ground-level' plan from DP 424294

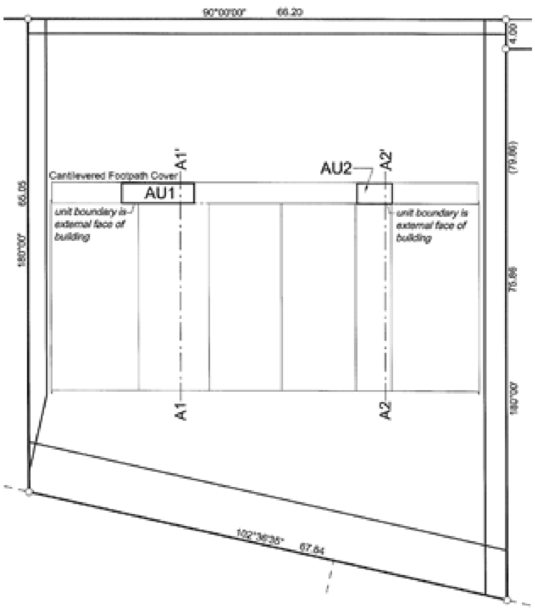

Figure 4.18: 'Upper level' plan from DP 424294

The horizontal extents of the two accessory units (AU1 & AU2) are depicted in relation to the principal units on the 'upper level' plan depicted in Figure 4.18, above. The vertical extents of AU1 and AU2, and their relationship to their principal units (Unit 2 and Unit 5 respectively), is shown on the elevation sections A1-A1' and A2-A2' depicted in Figure 4.19, adjacent. The purpose of the accessory units is to provide legal protection for advertising signage and related structures.

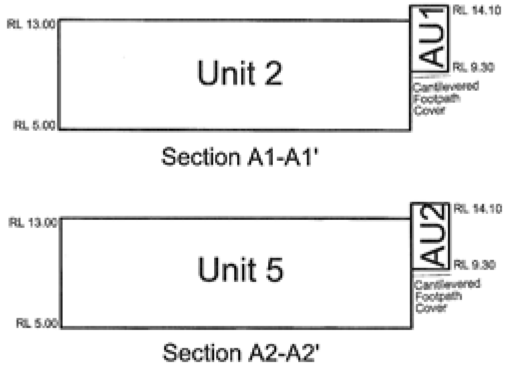

Figure 4.19: Elevation plan from DP 424294

4.5.3 2D Aspatial to 3D Digital

Figure 4.20 is an impression of how a digital system might spatially represent the aspatial information on DP 424294. The extents of the underlying land parcel is portrayed by thick, black line work at the perimeter with lower (centre of Earth) and upper (infinity) extents limited as necessary. These depth and height limitations are governed by user needs and also requirements of the system. The user needs to readily interpret the nature of any 3D defined parcel, such as the units in this case study, in relation to any other abutting parcel. Meanwhile the system is required to automatically check for conflicts, such as overlapping abutting parcels.

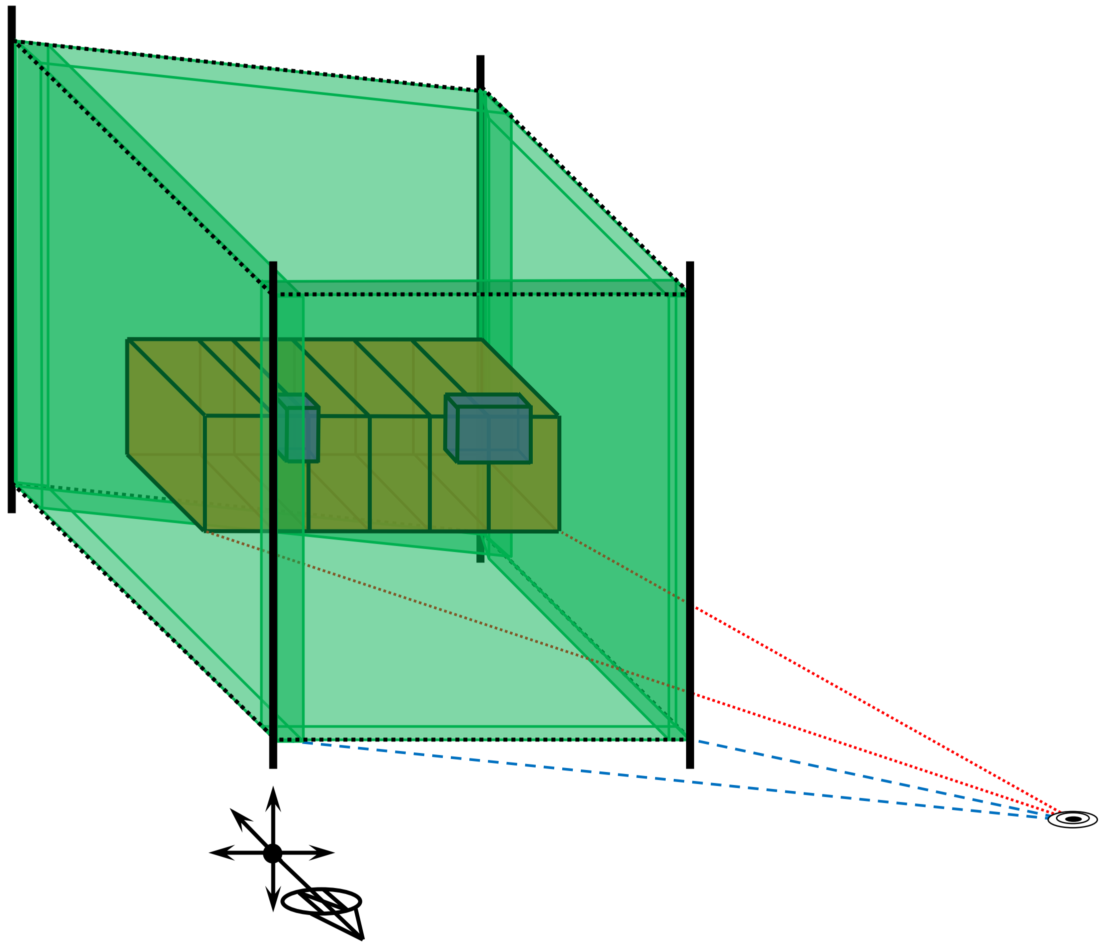

Figure 4.20: 3D Representation of 2D DP 424294

As for the underlying land parcel, the easements (depicted as green volumes) have no survey defined depth or height, thus have been subjected to the same vertical limitations. Transparency is used to assist interpretation of the land parcel and its 3D defined parcels, being the principal units (orange) and accessory units (purple). The user can also interact with the display through zoom and rotate functionality, while the ability to 'dissect' parcels would help with the understanding of more complex 3D situations.

The ability to turn off information further increases the ability of the user to focus attention on a specific parcel, parcels, or other features such as connections to survey control. Figure 4.21 shows how the 3D defined units are emphasised by removing the easement parcels. Through select and interrogate functionality the user obtains detailed information about a feature such as a survey mark, survey observation or parcel face or volume. The callouts show detailed information about a boundary face of a selected principal unit and also a vector connecting the 3D defined parcel to its underlying land parcel.

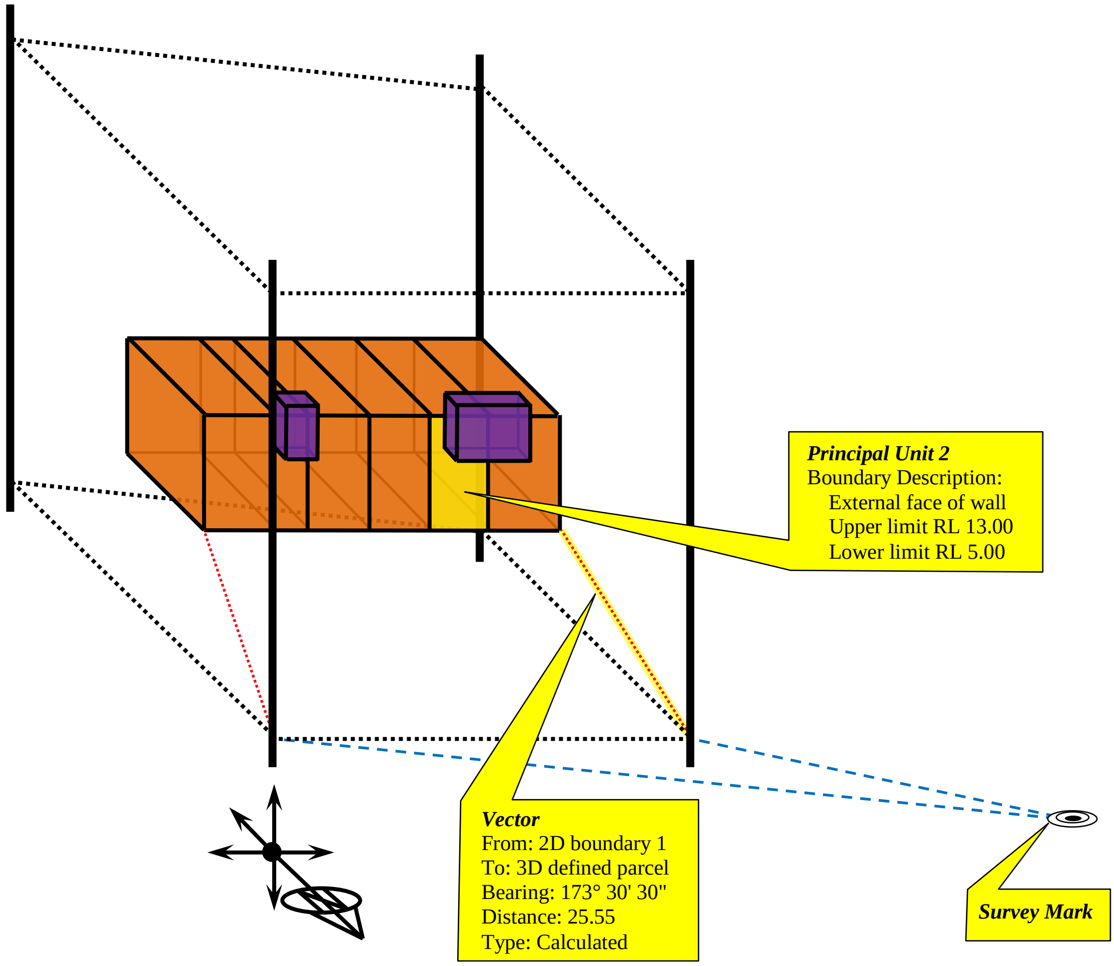

Figure 4.21: Interrogation of 3D digital survey data

Figure 4.22 presents a mock demonstration of a possible broader use of the 3D digital cadastral data from the survey. An application on a ‘smart device’ demonstrates how the 3D digital cadastral survey data may be taken by others and used to better understand how the 3D defined legal property boundaries relate to the physical environment.

Figure 4.22: ‘Value add’ using 3D digital cadastral data
(Photo courtesy: Trevor Gulliver, 2015; hands and ‘tablet frame’: Land Information New Zealand, 2014c)

4.5.4 Mapping DP 424294 to Data Model

For the purposes of this case study, the data model of the New Zealand 3D-Capable Digital Cadastral System will map the single instance of Unit 2 DP 424294. Accordingly the *Appellation* class (Figure 4.23, below) for Unit 2 DP 424294 is a unique legal description that will form the link between a certificate of title issued under the Land Transfer tenure system and its spatial depiction, as defined by the cadastral survey.

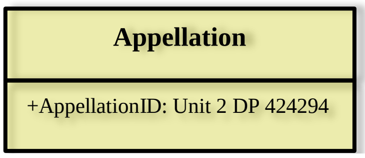

Figure 4.23: Appellation class with attribute

With reference to Figure 4.24, the *Parcel* class contains information for Unit 2, noting that it is a 3D volume with a specific area and volume. While area and volume information is not currently required by the tenure system for a development under the Unit Titles Act 2010 (i.e., a unit title does not include area and volume information), both attributes are required for automatic validation (such as future redevelopments where correlation between subdivided and underlying areas/volumes is required). Area and volume details might also be of use beyond the cadastral system, such as for building management, lease, sale and purchase etc.). The parcel geometry of Unit 2 is represented in 3D using *GM_Solid* primitives, thus facilitating volumetric computations and 3D spatial analyses. *GM_Solid* primitives are also used to enable the 3D defined parcel to be visualised in terms of its underlying 2D land parcel.

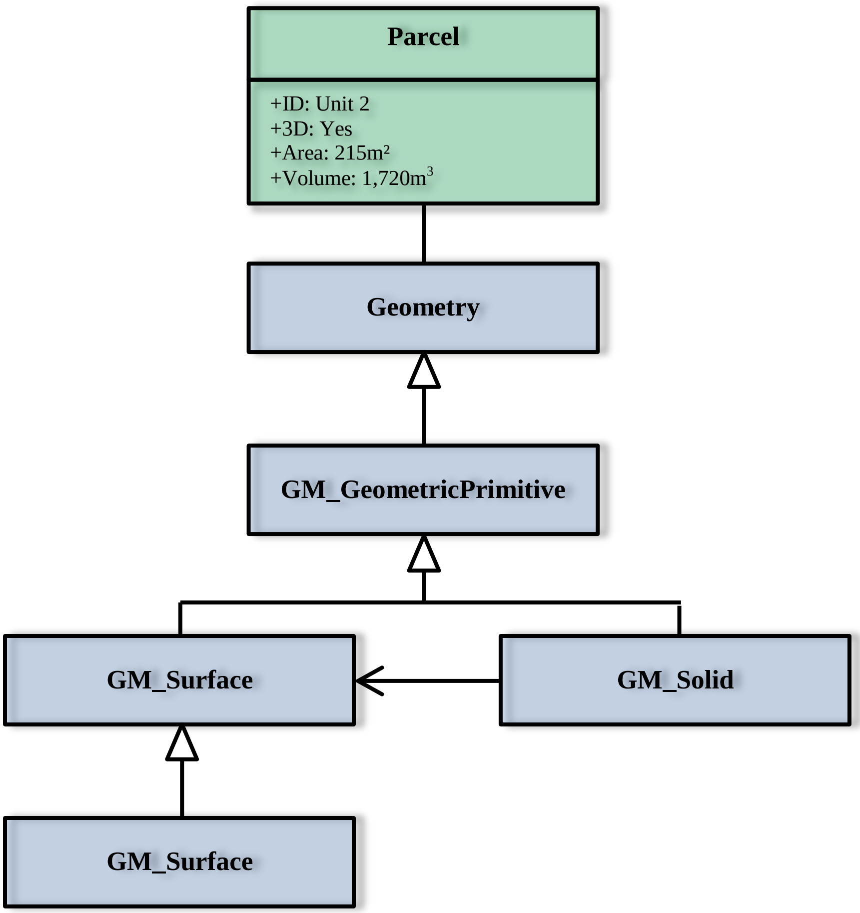

Figure 4.24: Parcel class with geometry subclasses

The way in which the common property shown on DP 424294 is handled is an interesting consideration. As discovered in Chapter 2, common property fills the space between principal and accessory units, including below (to the centre of the Earth) and above (infinity). In this case study, the common property is held in equal shares by Unit 2 together with Unit 1 and units 3 through 6. Rather than provide a unique spatial definition of the common property, which is seen as superfluous, it is defined as being the remaining volume within the underlying land parcel, that is not otherwise defined as a principal or accessory unit.

In addition to providing information relating to defining the 3D spatial extents of Unit 2 (*CoordinateSystem*, *SurveyPoint*, *SurveyObservation*), the Survey Package, depicted in Figure 4.25, below, includes metadata about the survey (*Survey*) and also the licensed cadastral surveyor responsible for the dataset (*LicensedSurveyor*). For the purposes of this case study, the vertical datum (*CoordinateSystem*), Moturiki 1953, was accepted from the original survey. However, in reality this regional datum will need to be replaced by the newly defined national datum, as discussed in s. 4.3.1, above.

Additionally to the original survey, the digital information captured in the data model includes a vector which provides a connection between the 3D defined parcel and its underlying land parcel. The *SurveyObservation* instance demonstrated in the model includes a single observation when, in practice, two vectors are required to each 3D defined parcel (or block of abutting parcels), as portrayed in Figure 4.20 and Figure 4.21. Two vectors are needed for definition and validation purposes to ensure that any mathematical misclosures (errors) between points can be calculated and assessed against required survey accuracy tolerances. Similarly, at least two vectors are required to connect the underlying land parcel to survey control. Thus the spatial positions of the land parcel and its 3D defined parcels can be maintained during post integration adjustment procedures. These integration and adjustment aspects would be a function of a Geodetic System.

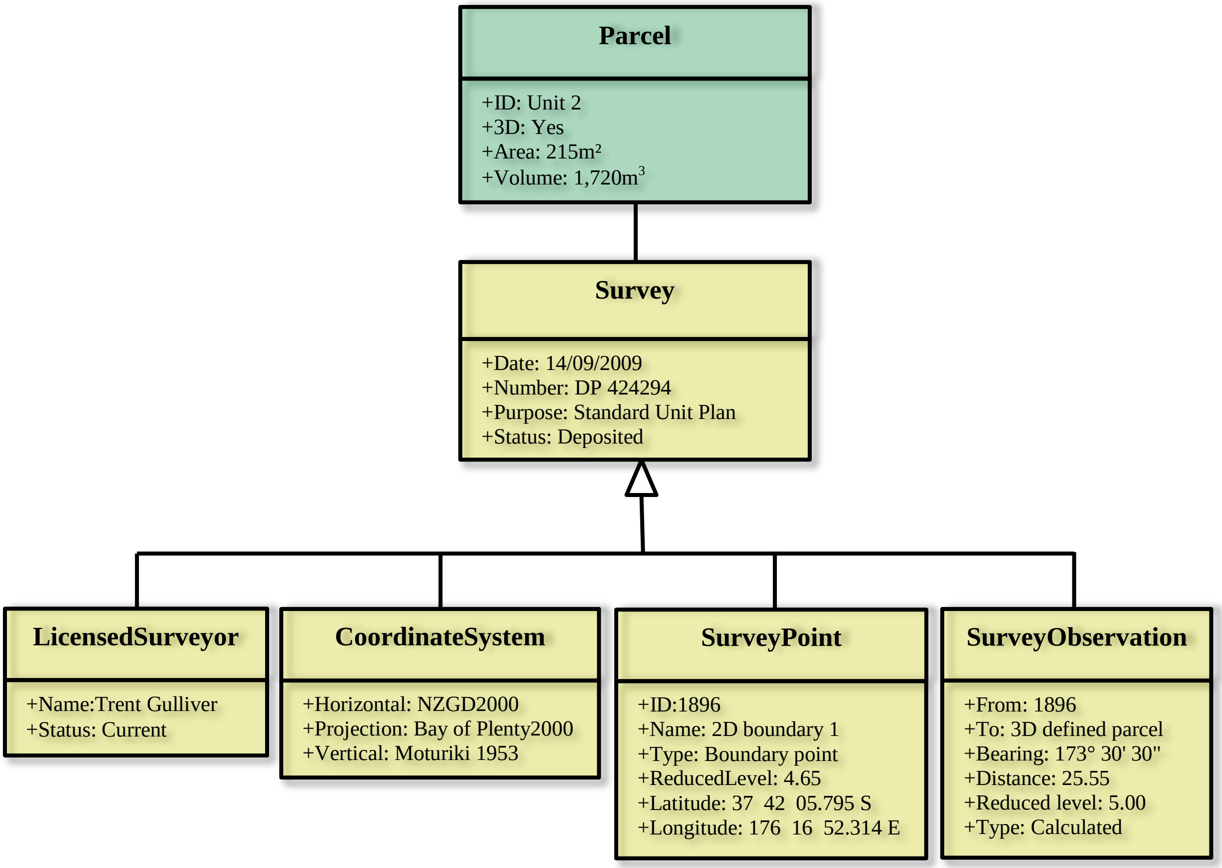

Figure 4.25: Survey classes with attributes

4.6 Summary

This chapter commenced with a definition of the term, '3D digital cadastre' tailored specifically for the New Zealand context. This definition provided the starting point from which to progressively advance the development of New Zealand's cadastral survey system. A need to respect the New Zealand situation is a common theme that continued to transpire in the discussion as the chapter progressed. The advanced level of maturity of New Zealand's land administration system cannot be ignored in favour of adhering to international standardised approaches. This need became particularly evident when evaluating whether the LADM could be used as the basis to enhance the New Zealand cadastral survey system. The determination that LADM is unsuitable for New Zealand is a key finding that ultimately triggered the first iteration of designing a data model for New Zealand's specific requirements.

5 Further Discussion, Final Conclusions & Future Research

As identified in Chapter 1, this research stems from the fact that New Zealand currently has a 2D digital cadastral system that is not representative of the 3D real-world situation. An initial review of the background literature revealed an apparent gap in the existing research that was subsequently verified by a more complete review of the literature during the course of this research. It was confirmed that while there is a substantial volume of international research on the subject of 3D cadastral systems and correlated 3D cadastre, there is limited local content to ensure due consideration in terms of the New Zealand context. This concern was reflected in the primary problem for this research:

> *New Zealand's appreciation for and understanding of 3D digital cadastral survey system characteristics, opportunities, issues and approaches is incomplete thus compromising the ability to determine appropriate solutions for developing a 3D digital cadastral survey system.*

The objective of this research was to facilitate an understanding of the opportunities and issues associated with the New Zealand context, and seek to identify and develop a specific solution to enhance New Zealand's digital cadastral survey system. The primary aim of the research was thus defined to:

> *Identify and consider the key characteristics, opportunities, issues and approaches to establishing a 3D digital cadastral survey system, and apply that knowledge to develop a solution to enhance the 3D capabilities of New Zealand's digital cadastral survey system.*

The primary aim of this research was progressively fulfilled through a series of chapters from which a base of knowledge was obtained, extended and ultimately applied to the development of an approach to enhance the 3D digital capabilities of New Zealand's digital cadastral survey system. In Chapter 2 the status of 3D in New Zealand's cadastral survey system was established and the context for developing 3D digital capabilities was presented. This set the scene for the research and provided a platform from which to explore developmental possibilities of a 3D digital cadastral survey system. The state of previous research was then undertaken in Chapter 3 through a review of the literature supporting the development of 3D cadastral survey systems at an international level. Chapter 4 leverages from the knowledge obtained and advanced in the preceding chapters to develop an approach to enhance New Zealand's cadastral survey system. In this fifth and final chapter, the key findings of the research, incorporated within each chapter, are revisited and discussed further. Findings are examined in the light of the previous research with final conclusions based on what has been learnt from this research.

5.1.1 Status of 3D Cadastral Survey System in New Zealand

New Zealand's cadastral survey system was identified as being a key component of a property rights system that is considered by its administrator (LINZ) to be 'Accurate, Authoritative and Assured'. Accuracy is founded on a cadastral survey system responsible for defining and depicting the spatial extents of property rights. Authoritativeness reflects the fact that the property rights system is the single source of legal information about property rights in New Zealand. Assuredness is connected to a guarantee of ownership provided by the Crown for freehold titles to land under the Land Transfer Act 1952.

LINZ's self-professed 'Triple A' rating is, to some extent, verified by this research. Firstly, the analysis of data produced annually over a twenty-year period about the strength and security of property rights (refer to Chapter 2 introduction) provides statistical evidence that New Zealand has maintained a world-class system over that time. Secondly, it argued that the few instances of serious incompetency or error by cadastral surveyors provides more tangible proof to support LINZ's high level of confidence in the quality of the current cadastral survey system (refer to s. 2.1.1). What is not yet reflected by the statistics or the professional record of cadastral surveyors, however, is that New Zealand's internationally revered property rights system is at risk of being undermined by a cadastral survey system that is beginning to fall out of step with the needs of a changing world.

While New Zealand's existing institutional framework supports a 3D cadastral survey system, current technical and operational processes require 3D data to be in analogue form. It is the digital cadastre, a product of the cadastral survey system, that does not permit 3D data to be digitally captured, automatically checked against requirements, combined with existing data (and subsequently maintained), and exported for reuse. Instead, 3D data is aspatially presented in the form of scaled diagrams that are referenced within a 2D digital depiction of the cadastre. Users are then required to manually search, interpret and, if necessary, recapture information shown on the diagrams into their computer software. This approach is converse with advancements in technology and an evolving society where it is fast becoming the norm to provide and consume 3D information digitally.

Land development professionals and society in general are intuitively thinking and seeing in 3D while management of the built environment is increasingly expecting and requiring 3D digital information, particularly in the age of BIM and Smart Cities. The cadastral survey system now needs to deal with an urban environment that is increasingly populated and structurally complex. A 3D digital cadastral survey system has a fundamental role in the creation of new opportunities and connections between the varying and growing needs of wider society. This is considered to be both necessary and crucial in terms of realising the visions of current LINZ strategies and to ensure that New Zealand's Accurate, Authoritative and Assured property rights system is preserved into the future.

A look into the development of survey regulation during the formative years provided more than just an interesting historical account of the cadastral survey system in New Zealand. It provides valuable lessons from past experiences. The issues arising from two competing cadastral survey systems (i.e., Government and the New Zealand Company) highlight the importance of having a single source of legal data. History could be deemed to have been repeated when Christchurch City Council developed a local digital land database alongside a nationwide database that was being developed by LINZ's predecessor. These historical lessons emphasise a risk that if LINZ is slow to respond to the changing needs and expectations of society, someone else may. Non-authoritative 3D systems might be established to fill the void, thus creating a competing system to undermine the national property rights system. The value of cadastral survey systems and cadastres to a nation's economy and wellbeing was a common point of emphasis in the review of literature.

5.1.2 Review of the Literature

The cadastre is more than a set of spatial data – it is a mechanism that supports the delivery of social, economic and environmental benefits to jurisdictions and countries. Since its conception, cadastres have been in a constant state of evolution that has seen their prominence and value to society extend beyond their core function within the domain of land administration. This rate of evolution and contribution to society is poised for a step-change through the advent of 3D digital cadastres and supporting 3D digital cadastral systems to reflect the 3D nature of the real world. However, according to the literature, the development and implementation of 3D digital capabilities is fraught with complications and challenges. These complications and challenges are emphasised through the substantial volume of research associated with the development of 3D cadastres over the relatively short period of time (thirteen years) since it became the focus of academics. The overall complexity of 3D cadastre as a topic is further and ultimately accentuated through the fact that no country in the world has a fully developed and functioning 3D digital cadastre.

An overarching issue hindering the development of 3D cadastre is the variances between cadastral systems in countries around the world. It is these local nuances that make it difficult, and perhaps even impossible, for one solution to be applied to jurisdictions around the world. To overcome these problems, solutions need to consider and implement interoperability and standardisation frameworks where possible. While this may not result in complete and universal solutions, at least the world can communicate using the same language, thus removing an immediate barrier to the successful development and implementation of 3D cadastres.

Aside from jurisdiction-based issues, it is the geometrical representation, validation and modelling of 3D cadastral data that is proving to be particularly complex and hence is a common focus of research. Of note, however, is an apparent gap in the research in relation to providing the vitally important elevation data in a 3D cadastre. This gap is particularly pronounced in the New Zealand context due to the country's high level of tectonic-based land movement, which needs to be accounted for by the digital cadastre.

The opportunities associated with a 3D digital cadastre are wide-ranging and will touch and benefit every level of society in many ways, well beyond its core function in the administration of land. In addition to detailing a series of applications of 3D digital cadastral data, BIM has been singled out for consideration due to its status as an emerging area of research. BIM may provide a significant contribution to a 3D digital cadastre and vice versa. This synergy will be enhanced if all data meets the same structure and standards. The key to realising the opportunities and benefits of 3D digital cadastral information is to overcome the complications and challenges to implementing a 3D digital cadastre and 3D digital cadastral survey system.

Ultimately the review of the background literature confirms and highlights that while there is a substantive volume of research in the area of 3D cadastres, there is a distinct absence of a contribution from New Zealand. This on its own may not cause alarm. However, the knowledge of how the international research community has struggled to overcome the problem due to local variances is a cause for concern. This emphasises the importance of considering and assessing developmental progress at the international level against the New Zealand context.

5.1.3 Developing a 3D Digital Cadastral Survey System for New Zealand

The status of 3D in New Zealand's cadastral survey system and the findings of international research combine to provide the basis from which the purposeful and informed development of a 3D digital cadastral survey system for New Zealand can proceed. The first step in the development process was to offer a definition of the term, '3D digital cadastre', tailored specifically for the New Zealand context. This definition provided the starting point from which to progressively advance the development of New Zealand's cadastral survey system. This starting point is deemed necessary in light of the various definitions of cadastre throughout the world. It is also considered important that the word 'digital' is included in the definition to distinguish the digital cadastre from the legal cadastre (refer to s. 2.1.2).

A need to respect the New Zealand situation is a theme that emerged throughout the discussion. It is found that the advanced level of maturity of New Zealand's land administration system cannot be disregarded in preference of stringent adherence to internationally standardised approaches. This need became obvious when evaluating whether the LADM could be used as the basis to enhance the New Zealand cadastral survey system. There was an initial expectation that the LADM would be suitable for New Zealand. This expectation was founded on the fact that LADM is an international standard and is the subject of substantial research interest promoting its applicability to a diverse range of countries. The determination that LADM is unsuitable for New Zealand is a key finding of this research that was not foreseen. This finding triggered the first iteration of designing a data model for New Zealand's specific requirements.

The New Zealand 3D-Capable Digital Cadastral System data model attempts to cater for the local nuances of New Zealand's cadastral survey system and also its relationship with tenure systems and the geodetic system. The conceptual model builds on what is considered to be a very sound platform, the existing 2D digital cadastre, by enabling data about property rights defined and depicted in 3D to be handled digitally for eventual incorporation into the cadastre. This approach is based on underlying principles established in previous research and then developed by this research for the New Zealand context. It is vital to bear in mind that this research presents the first iteration of the conceptual data model and that the author is by no means an expert in the field of data modelling. In light of this, it is expected that further iterations of the New Zealand 3D-Capable Digital Cadastral System data model would be needed before progressing to the logical model phase of the design process.

The New Zealand 3D-Capable Digital Cadastral System data model employs the principle to apply standardised approaches, where possible. This principle, inspired by the LADM, is most obvious through the incorporation of geometrical primitives from AS/NZS ISO 19107 (2005) (Geographical information – Spatial schema) to represent the spatial extents of 3D defined property rights. Another opportunity will present itself during the logical phase of the data modelling process when, preferably, an internationally accepted data transfer format will need to be incorporated. However, it was decided that the vocabulary used to describe features (notably parcel) could justifiably be based on terminology used at the New Zealand level. This is because of what is deemed to be a conflict between long-established terms that are entrenched in legislation, rules and guidance material and those defined by the LADM. Despite this, an awareness of differences to an international standard, such as this vocabulary example, would allow translation procedures to be introduced to promote understanding at the international level.

5.2 Final Conclusions

This research has finally launched New Zealand into an area of academic study that is very active and pertinent internationally. The development of a 3D digital cadastral survey system for New Zealand required an extremely broad scope of research that spanned the length, breadth and depth of not only the international literature, but also of New Zealand's current cadastral survey system. The non-existence of previous New Zealand-based research on the topic meant that the foundations upon which to build had not been formed. Future researchers can feel assured that the whole has now been accounted for allowing specific parts to be considered in a more focussed fashion.

New Zealand is currently well-positioned to benefit from and act upon this research as it is harmonious with LINZ strategies relating to property rights and a business case to enhance the current survey and title recording and delivery system. The timing of this research coincides with a tremendous opportunity to make a tangible contribution to developing the cadastral survey system for the benefit of New Zealand as a whole. Now that the conclusion of this research has been reached, the author believes that the broad scope of research was indeed justified.

In order to complete this thesis, responses to the research questions derived in Chapter 1 will now be provided:

What is the current status of 3D in New Zealand's digital cadastral survey system? The current status was presented in Chapter 2 and discussed further under s. 5.1.1, above. Ultimately it was established that the New Zealand cadastral survey system has always permitted property rights to be defined in 3D (through height and/or depth restrictions). Since the adoption of the common law principle of land ownership 'down to the centre of the Earth and up to the heavens above' legislation has never prevented the establishment of rights within the subsoil or airspace. However, it was discovered that legislation and case law have partially eroded the effect of the common law principle.

New Zealand's 3D cadastral survey system has two cadastres: a legal cadastre which is 3D and is represented by the data contained on survey plans and supporting cadastral survey datasets certified by licensed cadastral surveyors; and a digital cadastre, which is a representation of the legal cadastre, although this representation it currently limited to 2D. So, it is concluded that while New Zealand has a 3D cadastral survey system and a 3D legal cadastre, the status of its digital cadastre is 2D.

What are the characteristics, opportunities and issues of a 3D digital cadastral survey system for New Zealand? The characteristics of a 3D digital cadastral survey system for New Zealand were outlined in Chapter 4, with further discussion under s. 5.1.3, above. While a New Zealand system must be customised to account for the local situation, the opportunities and issues, presented in chapters 2 and 3, and discussed further under s. 5.1.1 & s. 5.1.2, above, are more generic and are applicable internationally.

The opportunities associated with a 3D digital cadastral system are both significant and varied. The ability to retain the intelligence and integrity of 3D data obtained by cadastral surveyors is a substantial step forward from current practice where 3D data is manually reduced to scaled 2D diagrams. The digital capture of that data into a system where it is then automatically validated, maintained, and made available for reuse, has advantages for all users of the system. The primary purpose of the cadastral survey system remains to spatially define and depict the legal extents of property rights for registration in a tenure system. However, the ever increasing other uses to which cadastral survey data is being applied means that the digital cadastre is exponentially increasing in value to New Zealand's economy and to society generally, far beyond its cadastral origins.

Overall the main issues associated with a 3D digital cadastral system are well-reported and generally well-evolved in the literature. The development of a conceptual data model by this research indicates that these issues would not impede further development and eventual implementation of a fully functioning 3D digital cadastral system for New Zealand. One issue that is not given consideration in the literature, however, is how users of the current system might react to change. The 3D-Capable Digital Cadastral System proposed by this research incorporates techniques that would amount to a significant change of practice that might require some users of the system, particularly cadastral surveyors, time to understand.

Should New Zealand develop the existing 2D digital cadastral system to allow 3D digital data? The answer to this question is a definitive yes. The value and benefits of 3D digital data in today's world are well-documented throughout this research. Any uncertainty about the cost of developing and implementing a 3D digital cadastral system should be considered in association with the risks of not enhancing the existing system. Past experiences where the development of competing, non-authoritative systems undermined the authoritative system provide a strong argument why New Zealand cannot afford to not develop the existing 2D digital cadastral system to allow 3D digital data.

What are the specific requirements of a 3D digital cadastral survey system for New Zealand? In this research it was found that enhancements are required to be made to the technical and operation processes associated with the digital cadastre. Accordingly, general requirements of a 3D digital cadastre were first developed (refer to s. 4.2.1) and then applied specifically to a particular approach (refer to s. 4.2.4). The implementation of these specific requirements of the digital cadastre would elevate New Zealand's cadastral survey system to 3D digital status.

Is there an approach to developing a 3D digital cadastral system that is best suited to the New Zealand situation? Yes there is. In Chapter 4 a 3D digital cadastral survey system for New Zealand was incrementally considered and developed. A 3D-capable digital cadastre is identified as being the recommended approach to enhance New Zealand's cadastral survey system. This approach is based on the integration of 3D defined parcels into the existing 2D digital cadastre of land parcels – a solution that is considered to be fit-for-purpose both for now and into the future.

5.3 Future Research

As noted in the preceding section, the broad nature of this research provides a good platform from which to base subsequent research. Future research may build on the holistic approach (in terms of the cadastral survey system) taken by this this research by continuing to advance the development of a 3D digital cadastral survey system for New Zealand. Alternatively, future research could be based on other leads established by this research. There is also an opportunity for the findings, concepts and directions of this research to be applied internationally. With this in mind future research options will now be considered beneath the subheadings below.

5.3.1 Advancing the New Zealand 3D-Capable Digital Cadastral Data Model

The data model derived in Chapter 4 (s. 4.4.2) is considered to be the first iteration at the conceptual design phase of the data modelling process. Further iterations and testing will be necessary to ensure that the data model achieves the desired outcomes. Progression to the logical design phase will require consideration of data transfer formats. While data transfer formats have not been directly considered by this research, it was noted that the OGC (Open Geospatial Consortium) is in the process of developing the international standard, LandInfra (refer to s. 3.4.3), which is to have 3D capabilities. The transfer format associated with the eventual LandInfra standard may be worth exploring. Also, as LandInfra is to include a cadastral survey component, the complete data model could be evaluated in terms of the New Zealand context.

5.3.2 3D Defined Parcels & 3D Spatial Objects

The New Zealand 3D-Capable Digital Cadastral System uses '3D Spatial Objects' as a means to represent 3D defined parcels. As noted in s. 4.3.3, a 3D Spatial Object is a coordinate-based technique to capture and subsequently visualise 3D data. The use of a 3D Spatial Object to represent the spatial extents of a 3D defined parcel through its inherent coordinates would be a significant change to the New Zealand cadastral survey system which is founded on marks and observations. While such a change is deemed necessary for the 3D-capable digital cadastre to become a reality, its magnitude requires a more full and thorough investigation.

5.3.3 Digital Data versus Plans

In the New Zealand 3D-Capable Digital Cadastral System it is proposed to abolish the current requirement of cadastral surveyors to prepare 2D plan diagrams of survey work and parcel boundaries. Instead the digital 3D data captured and held in the system would become the authoritative source of information. This proposal represents another significant change to New Zealand's cadastral survey system. Future research on the implications of such a change is warranted.

5.3.4 BIM (Building Information Modelling)

BIM was identified in both chapters 2 (s. 2.4.5.1) and 3 (s. 3.5) as being a particular avenue of research worthy of further exploration. 3D digital cadastral data about the spatial extents of property rights is likely to be a valuable additional layer of BIM. Equally, 3D BIM data is expected to be of value to cadastral surveyors for determining the positions of legal boundaries in terms of an as-constructed BIM.

5.3.5 Implications on other Systems

While this research considered the interactional relationships between the New Zealand cadastral survey system and other systems, particularly tenure and geodetic, the scope of this thesis limited the focus to the cadastral survey system specifically. However, in reality the impacts of any changes to the cadastral survey system on correlated systems will need to be tested and understood. With the modernisation of the cadastral survey system, the timing could be right to consider enhancing the Land Transfer tenure system, which has remained more or less unchanged since it was conceived in 1857 by Sir Robert Torrens. The aforementioned research opportunities would be beneficial to New Zealand's property rights system and also add value to the volume of literature.

5.3.6 Application of this Research Internationally

This research benefited enormously from the existing volume of international literature. Ideas conceived and developed for overseas jurisdictions have been evaluated, advanced and applied by this research to the New Zealand context. Despite a focus on the New Zealand environment, the findings, concepts, and above suggestions for further research, are likely to be beneficial in some form to other jurisdictions throughout the world. For this reason the author is confident that this thesis gives back to the international research community by making a tangible contribution to expanding the literature.

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Appendix A: Cadastral Survey Dataset – DP 424294

Landonline

Toitu te Land whenua Information New Zealand

Digital Survey Plan - DP 424294

Survey Number	DP 424294
Surveyor Reference	091942 - Gravatt Road
Surveyor	Trent Frederick Douglas Gulliver
Survey Firm	Lysaght Consultants Ltd
Surveyor Declaration	I Trent Frederick Douglas Gulliver, being a person entitled to practise as a licensed cadastral surveyor, certify that - (a) The surveys to which this dataset relates are accurate, and were undertaken by me or under my direction in accordance with the Cadastral Survey Act 2002 and the Surveyor-General's Rules for Cadastral Survey 2002/2; (b) This dataset is accurate, and has been created in accordance with that Act and those Rules. Declared on 07/12/2009.

Survey Details

Dataset Description	Units on Lots 10 & 11 DP 345994		
Purpose	Standard Unit Plan		
Status	Deposited	**Type**	Survey
Land District	South Auckland	**Survey Class**	Class I Cadastral Survey
Coordinate System	Bay of Plenty 2000		

Survey Dates

Surveyed Date	14/09/2009	**Certified Date**	07/12/2009
Submitted Date	07/12/2009 15:38:11	**Survey Approval Date**	16/12/2009
Deposit Date	09/12/2009		

Referenced Surveys

Survey Number	Land District	Bearing Correction
DP 345994	South Auckland	0°00'00"
DP 391941	South Auckland	0°00'00"

Territorial Authorities

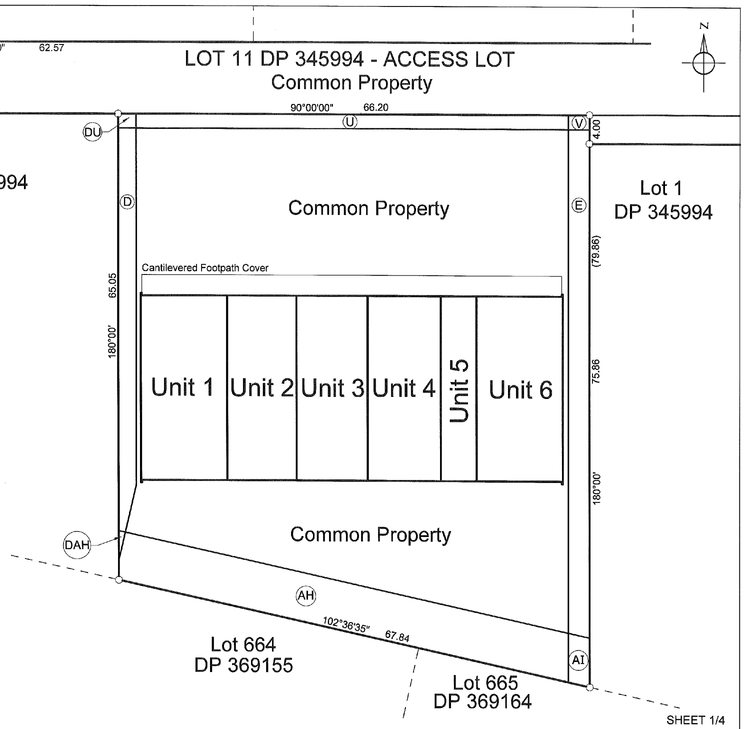
Tauranga City

Comprised In

CT 188562

Created Parcels

Parcels	Parcel Intent	Area	CT Reference
Unit 1 Deposited Plan 424294	Principal Unit		494434
Unit 2 Deposited Plan 424294	Principal Unit		494435
Unit 3 Deposited Plan 424294	Principal Unit		494436
Unit 4 Deposited Plan 424294	Principal Unit		494437
Unit 5 Deposited Plan 424294	Principal Unit		494438



New CT Allocated	Appellation	Unit Entitlements	Height Limits	
			Lower	Upper
494434	Unit 1	1,892	5.00	13.00
494435	Unit 2	1,703	5.00	13.00
494436	Unit 3	1,737	5.00	13.00
494437	Unit 4	1,791	5.00	13.00
494438	Unit 5	872	5.00	13.00
494439	Unit 6	1,903	5.00	13.00
	AU1	68	9.30	14.10
	AU2	34	9.30	14.10
Total Unit Entitlement		10,000		
Supplementary Record Sheet		494440		
Address of Body Corporate	Development Project Consulting Ltd, 112 Youngson Road, RD6, Omokoroa, Tauranga 3176			

I JAMES DOUGLAS BENNIE of TAURANGA Registered Valuer hereby certify that I have assessed the Unit Entitlements shown hereon in accordance with the Unit Titles Act 1972.

Dated this 27 day of OCTOBER 2007

Registered Valuer

Notes:
1) Principal Unit Boundaries are the External Face of Building and the Centreline of the walls between adjacent Principal Units, unless shown otherwise.

2) Accessory Unit Boundaries are the External Face of Signage Structure, unless shown otherwise.

3) All areas outside Principal and Accessory units are Common Property.

4) Common Property includes a 1/9 share interest in Lot 11 DP 345994.

GROUND LEVEL

SHEET 1/4

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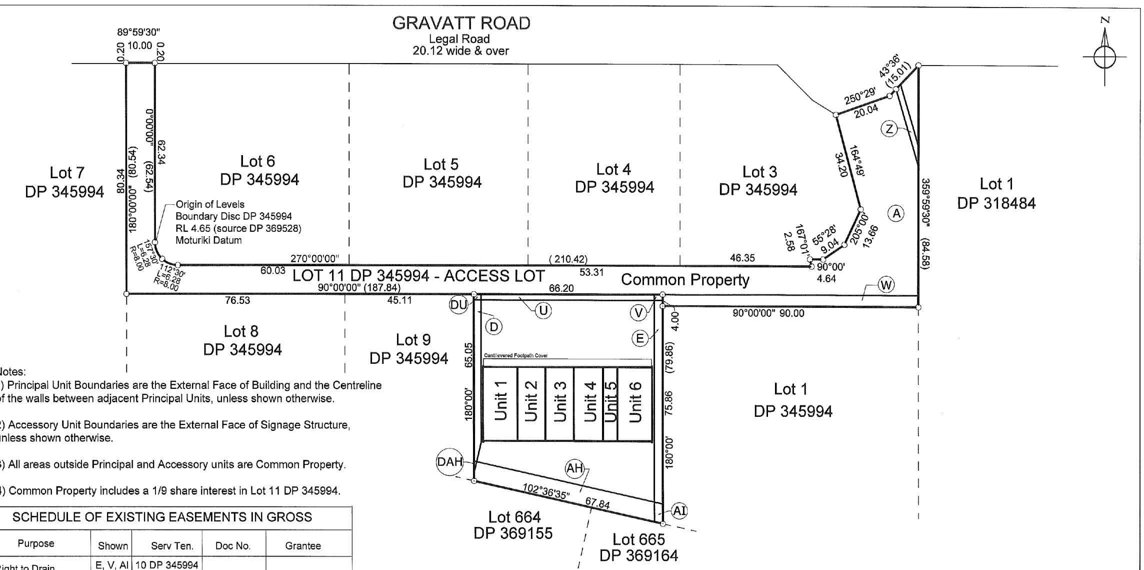
SURVEYING, ENGINEERING & LAND DEVELOPMENT Ph 07 578 8798 Fax 07 578 1222 E-mail admin@lysaght.net.nz

UNITS ON
LOTS 10 & 11 DP 345994

Plan Ref: DP 424294 Date: 7/09/2009
Territorial Authority: Tauranga City
Land District: South Auckland
LCL Ref: 091942 Scale 1:400 @A3



Notes:
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3) All areas outside Principal and Accessory units are Common Property.

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SCHEDULE OF EXISTING EASEMENTS IN GROSS

Purpose	Shown	Serv Ten.	Doc No.	Grantee
Right to Drain Stormwater	E, V, AI	10 DP 345994	EI6463666.12	Tauranga City Council
	A	11 DP 345994		
Right to Convey Water	A, W, Z			
	U, V, DU	10 DP 345994		
Right to Convey Electricity	A, W, Z	11 DP 345994	EI6463666.11	Power Co Ltd
	U, V, DU	10 DP 345994		
Right to Convey Telecommunications	A, W, Z	11 DP 345994	EI6463666.13	Telecom NZ Ltd
	U, V, DU	10 DP 345994		

SCHEDULE OF EXISTING EASEMENTS

Purpose	Shown	Serv Ten.	Doc No.
Right to Drain Stormwater	A, W	11 DP 345994	EI6463666.10
	V, E, AI	10 DP 345994	EI6463666.10
Right of Way	A, W	11 DP 345994	EI6463666.10
Right of Way	D, DU, DAH	10 DP 345994	EI7542232.5

EXISTING APPURTENANT EASEMENTS

Purpose	Created By
Right to drain Stormwater Right of Way	EI6463666.10
Right to drain Stormwater	EI6537531.1
Right of Way	EI7542232.3 & EI7542232.4

Existing Covenants

Purpose	Shown	Created By
Building Restriction	AI, AH, DAH	Doc No: 6463666.4

OVERALL LAYOUT

SHEET 2/4

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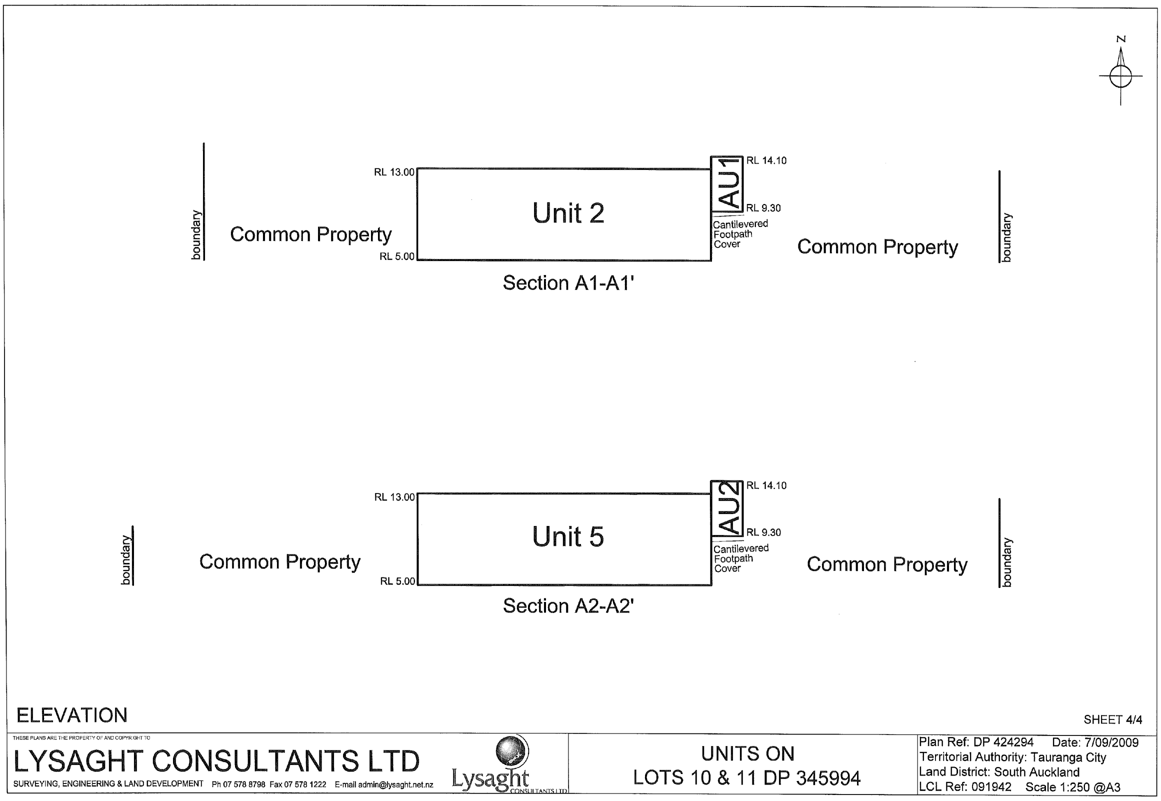
UNITS ON
LOTS 10 & 11 DP 345994

Plan Ref: DP 424294 Date: 7/09/2009
Territorial Authority: Tauranga City
Land District: South Auckland
LCL Ref: 091942 Scale 1:1000 @A3


Unit 2
RL 13.00
RL 5.00
AU1
RL 14.10
RL 9.30
Cantilevered Footpath Cover
boundary
Common Property
Common Property
boundary
Section A1-A1'
Unit 5
RL 13.00
RL 5.00
AU2
RL 14.10
RL 9.30
Cantilevered Footpath Cover
boundary
Common Property
Common Property
boundary
Section A2-A2'
N
ELEVATION
SHEET 4/4
LYSAGHT CONSULTANTS LTD
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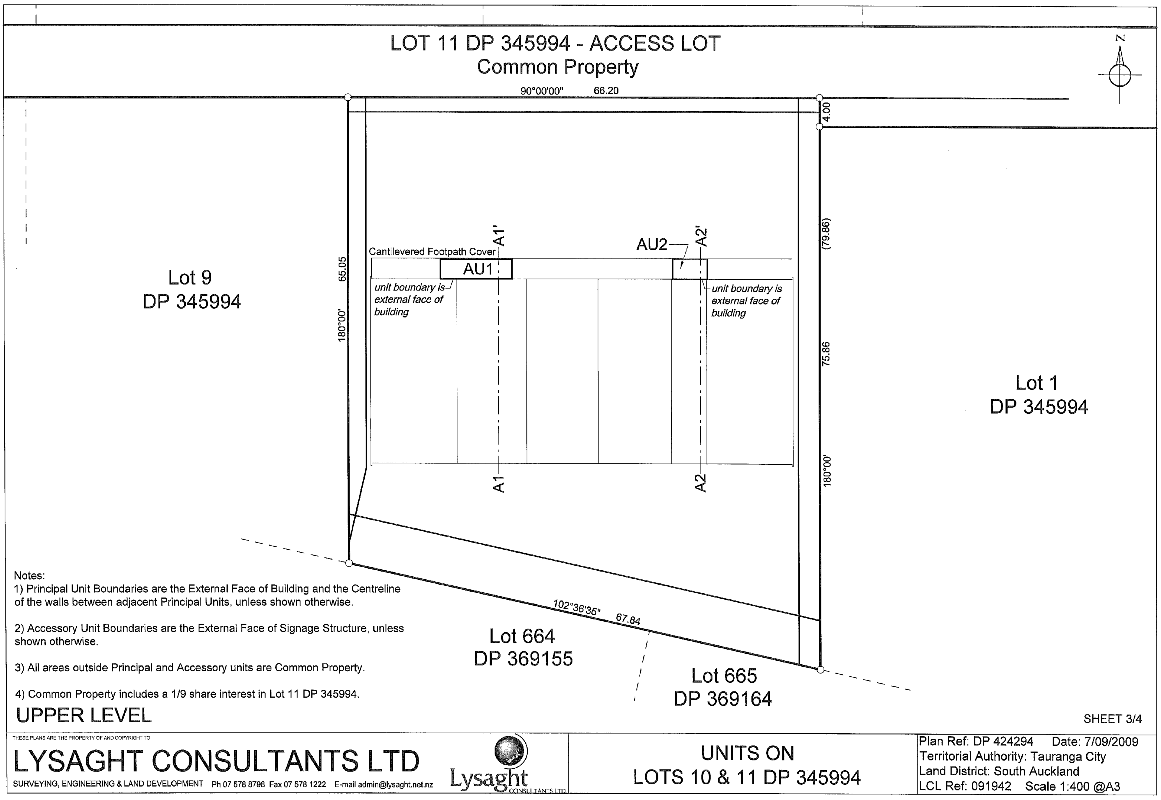
Lysaght
UNITS ON
LOTS 10 & 11 DP 345994
Plan Ref: DP 424294 Date: 7/09/2009
Territorial Authority: Tauranga City
Land District: South Auckland
LCL Ref: 091942 Scale 1:250 @A3


LOT 11 DP 345994 - ACCESS LOT
Common Property
N
90°00'00" 66.20
4.00
(79.86)
75.86
180°00'
65.05
180°00'
Lot 9
DP 345994
Lot 1
DP 345994
Cantilevered Footpath Cover
AU1
AU2
A1'
A2'
A1
A2
unit boundary is external face of building
unit boundary is external face of building
102°36'35" 67.84
Lot 664
DP 369155
Lot 665
DP 369164
Notes:
1) Principal Unit Boundaries are the External Face of Building and the Centreline of the walls between adjacent Principal Units, unless shown otherwise.
2) Accessory Unit Boundaries are the External Face of Signage Structure, unless shown otherwise.
3) All areas outside Principal and Accessory units are Common Property.
4) Common Property includes a 1/9 share interest in Lot 11 DP 345994.
UPPER LEVEL
SHEET 3/4
LYSAGHT CONSULTANTS LTD
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Lysaght
UNITS ON
LOTS 10 & 11 DP 345994
Plan Ref: DP 424294 Date: 7/09/2009
Territorial Authority: Tauranga City
Land District: South Auckland
LCL Ref: 091942 Scale 1:400 @A3

Lysaght CONSULTANTS LTD

7 December 2009

Senior Advisor to the Surveyor General
Land Information New Zealand
Private Bag 3028
HAMILTON

LCL Ref: 091942

1. Survey Description
Units on Lots 10 & 11 DP 345994.

Pre-allocated number – LT 424294.

2. Survey Purpose and Dataset
Land Transfer Survey – Unit Development.

This dataset type is Survey.

3. Dataset Components
The dataset contains the following items:

- Unit Plan (4 sheets)
- Survey Report (2 pages)
- Entitlement Assessment (1 page)

4. Class of Survey
Class I.

5. Equipment & Method used
NA.

6. Datum
Levels are in terms of Moturiki Datum
- Origin = Boundary Disc DP 345994, RL = 4.65
- Source = DP 369528

7. Origins: Marks, Bearings and Coordinates
NA.

8. Bearing Adjustment
NA.

9. Old Marks
NA.

10. Boundary Definition
New units are defined by a combination of existing title boundaries, the outside face of structures and the centreline of common walls.

The existing periphery boundaries have been adopted from DP 345994.

Lysaght Consultants Limited
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Tauranga
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www.lysaght.net.nz

11. Occupation
As depicted on the plan face.

12. Natural Boundaries
NA.

13. Accuracy Checks
NA.

14. Areas and Parcel Closures
NA.

15. Conflict with Cadastre

None.

16. Landonline Pre-Validation
NA.

17. Easements/Covenants
There are existing easements as shown on the plan face.

There are no easements to be surrendered or created.

18. Additional Information
None.

19. Survey System Maintenance
None.

20. Additional Notes
The address for the body corporate is shown on the plan face.

Lysaght Consultants Limited

Trent Gulliver
Licensed Cadastral Surveyor

X:\Documents\Trent\Job Folders\091942\CSD\LT 422164 SR.docx