University of Southern Queensland

Faculty of Health, Engineering and Sciences

The application of visualisation techniques for stratum and strata boundaries within the New South Wales digital cadastre

A dissertation submitted by

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Abstract

Population growth and trends towards urban consolidation have lead to a change in cadastral definition within the Greater Sydney area as high-density mixed-use buildings becoming more prominent. This has lead to increased potential of conflicts between end-users regarding boundary locations and the associated rights, restrictions and responsibilities and the vertical subdivisions are used to alleviate potential sources of conflict within developments in the form of stratum subdivisions, Torrens title lots with vertical restrictions, and strata subdivisions, strata lots existing within a scheme. However due to the complexity of these plans, specifically stratum subdivisions, the usability for the end-user is limited without access to surveying knowledge and practices.

This dissertation sought to investigate the use of 3D visualisation within digital cadastral mapping to improve the end-users experience with understanding height limited boundaries and the relationship between lots within stratum subdivisions. Through the investigation of three case studies, each representing a different density of development with stratum subdivisions, and the modelling of the lots in Google Earth the research demonstrated how the use of 3D models improves the comprehension and ability to access spatial data through digital cadastral maps. The outcomes of this research suggest that the use of 3D models for height limited parcels can improve digital mapping and not to replace traditional surveying plans but provide a parallel format that is more user-friendly than the survey plan on its own.

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I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Glossary

AHD	The Australian Height Datum (AHD) based on an approximation of mean sea level adopted by National Mapping Council of Australia in May 1971 as defined by *Surveying and Spatial Information Act 2002* (NSW). This height datum is the accepted standard datum for surveying in Australia.
Building management scheme	A document outlining the rights, responsibilities and restrictions of all lots within a strata subdivision that share a common building and services.
Deposited plan	The registered survey plan defining the legal boundaries of Torrens title land parcels and easements in New South Wales.
Development application	The formal application process through the local government area to be considered for consent for a proposed development.
Georeferencing	Coordinating a drawing or model with geographic coordinates to enable positioning within a mapping program.
Greenfield subdivision	Subdivision of undeveloped land for residential purposes, typically land previously zoned as rural or agricultural and is commonly located on the fringe areas of cities.
Local Government Authority	The governing mechanism for cities, towns, suburbs, municipalities, shires and districts manage their own proceedings under the *Local Government Act 1993* (NSW). Also referred to as councils.

KML	Keyhole Markup Language (KML) is an file format for geographic data. Also can be in a KMZ format which is the archive version of a KML compatible with Google Earth.
Owners corporation	The management body comprised of all owners within a strata scheme that covers finances of the strata scheme and the maintenance of common property.
Stratum	A form of Torrens title subdivision that allows for vertical restrictions to be applied to land parcels and is registered as a Deposited Plan.
Strata plan	The registered survey plan defining the legal boundaries of strata title land parcels in New South Wales.
Urban consolidation	The process of urban densification which involves demolishing older dwellings and replacing with higher density dwellings.

Chapter 1 Introduction

1.1 Background

The representation of 3D data is a consistent challenge within cadastral surveying. The cadastral regulations in New South Wales allow for a system to represent vertical boundary definition of land parcels, including subdivision within one building as either a Torrens title lot or as part of a strata scheme, yet the plan formats used to present this data is industry specific and not necessarily convenient for the end-user.

Digital cadastres are being widely for a range of uses outside of cadastral surveying, such as planning, utilities mapping and data retrieval, and is accessed by government departments, local councils, private businesses and the general public. Current digital cadastre presentation lacks in its representation of 3D boundaries and, in the case of stratum subdivisions, boundary data is presented in a format that it complicated for those not trained in cadastral surveying.

Due to the significant growth in the construction industry in the Greater Sydney area the focus of many large scale developments is multi-use buildings containing a range of services and dwellings. This increases the trend towards stratum subdivisions to reduce potential conflict between users of the building upon completion with different usages being subdivided into their own lots and being able to be operated under individual strata schemes upon further subdivision.

1.2 Objectives

The objective of the project is to identify methods of which 3D boundary data could be integrated with digital cadastres currently utilised in New South Wales. The utilisation of Google Earth by Land and Property Information NSW for their digital cadastre, part of NSW Globe, creates an opportunity to investigate the application of 3D lot representation within a supportive software environment.

This research seeks to identify how the application of 3D visualisation can improve the end user functionality of 3D boundary parcels and improve the understanding of non-surveying end-users of spatial data in digital databases. It will also consider time and cost implications of the modelling of stratum lots and the potential benefits to both surveying and non-surveying end-users.

1.3 Justification

Cadastre 2034 is a cross-jurisdictional guideline aimed at developing spatial data and its use into modern technology. The objective of the guideline is to create 'a cadastral system that enables people to readily and confidently identify the location and extent of all rights, restrictions and responsibilities related to land and real property' (Intergovernmental Committee for Surveying and Mapping 2015). This research project seeks to investigate a component of research in relation to this topic and focus on the benefits and problems faces with the digital visualisation of multi-level boundary scenarios with a focus on stratum and strata plans within New South Wales.

In the Greater Sydney area increasing population numbers and consolidation of employment opportunities to the area have lead to an increase in demand for denser a denser living environment in the city and inner suburbs. Existing residences, whether single occupancy lots or low-rise apartments, are not meeting the current demand and the region is currently undergoing a surge in large scale development projects aimed to increase real estate stock in key areas. While some areas of Greater Sydney are greenfields subdivision, a larger proportion of the development is urban consolidation in existing suburbs close to the city or public transport hubs.

One of the growing concerns with urban consolidation is the lack of public amenity which is causing conflict with urban consolidation within Greater Sydney. The inclusion of facilities within developments, creating a mixed use building, can provide the facilities required by urban communities at the lower levels and allow for residential residences to be built above and is outlined in *State Environmental Planning Policy No 65 - Design Quality of Residential Apartment Development* (NSW). This can improve the liveability of a high-density urban community and help eliminate some of the pitfalls of apartment living. While the inclusion of mixed use developments can combat this issue yet has the potential to cause conflicts with the application of mixed use developments under one strata scheme and owners corporation. Conflicts between occupants of a building can be due to different priorities and expected outcomes from the building, for example balancing the rights, restrictions and responsibilities of both residential and commercial occupants.

Stratum subdivision offers an opportunity to alleviate the tensions that can arise in mixed use developments. But first subdividing the land into 3D lots, individual strata schemes and owners corporations can be established for each use of the building and areas of exclusive use defined and paid for by the users of the facility. This has the potential to reduce sources of conflict within building occupants and improve the value of the lots.

The problem that arises with stratum subdivision is the ease of use component for end-users not familiar with the intricacies of the plan format. As required in New South Wales, stratum subdivision plans are shown as a cross section per floor divided into components for the each variation in vertical restrictions. This can create a complicated plan that is not easy to use and limits the end-users understanding of where the location of land parcels fall.

With the increased use of digital databases for spatial data, land parcels subdivided by stratum are increasing difficult to present in a digital format the can benefit the end-user. AS software platforms increase in their capabilities there lies an opportunity to consider the presentation of 3D land parcels as part of the existing growing digital cadastre.

1.4 Limitations

The application of 3D boundary definition, being either stratum or strata subdivision, is primarily featured within the Greater Sydney area. This forms one of the primary limitations of this research as the work primarily relates to high density urban areas therefore is not relatable to the majority of boundary applications within New South Wales. However this limitation can be approached based on the impact on a population level, with the Greater Sydney region containing 4.92 million (Australian Bureau of Statistics 2016) of the total New South Wales population of 7.64 million (Australian Bureau of Statistics 2015). Therefore improvements to mapping methodology within the Greater Sydney region has the potential to improve the usability of spatial data in areas that contain a larger proportion of the population of the state.

Another major limitation to consider in the presentation of spatial data is the software capabilities. Consideration should be taken in regards to rendering capabilities and availability of software for end-users. Spatial professionals often utilise high capability 3D software to process data, including computer-aided design (CAD) packages such as AutoCAD or Civil CAD. However the end product of digital cadastres are usually accessed via web portals and these have major limitations in regards to data visualisation beyond a simple format. The SIX Maps Portal is the primary digital cadastre accessed by surveying professionals and has significant limitations regarding data presentation. This will be discussed further in Chapter 2. Due to this limitation, the decision was made to focus on the use of the NSW Globe database and its application of Google Earth as the software platform. Google Earth is a robust software platform with rendering capabilities and is an accessible software package for the majority of end-users

1.4.1 Implications of the Research

Digital cadastres and their use across multiple spatial data sources is a current topic within New South Wales. Cadastre 2034 is a concept aimed at guiding the evolution and development of jurisdictional systems in relation to presentation and standards of spatial data (Intergovernmental Committee for Surveying and Mapping 2015.). These guidelines and research are Australia-wide and cover a multitude of research topics regarding the use of spatial data.

This research is specifically targeting one small aspects of the developments within this field in the consideration of the benefits and problems in the use of 3D visualisation for height-defined boundary definition. The full implications will be explored and analysed in the literature review.

1.5 Conclusions

This chapter establishes the basis for the research project and identifies the situation that justifies the work to be undertaken. The area of stratum and strata boundary presentation in digital cadastres was identified as an area with potential for research and the real estate market and construction industry within the Greater Sydney area are a prime target for denser housing. This trend in housing density was investigated further in Chapter 2 and from this research this methodology was developed and outlined in Chapter 3.

Chapter 2 Literature Review

The following chapter investigates the following topics relevant to the research into 3D data visualisation for spatial data within New South Wales:

- urban growth in within metropolitan areas;
- current application of digital cadastral databases;
- limitations of current digital cadastral maps.
- the impact of 3D boundaries within the digital cadastre;
- the legislation and policies that govern boundary definition;
- the current plan formats for presenting boundary data for 3D lots.

The literature review will investigate these topics and explore the changing dynamics of the Greater Sydney area and the impact on the cadastral methodology used to subdivide high-density mixed-use developments. Having identified the shift in cadastral trends, digital cadastres and the mapping portals used in New South Wales will be investigated to identify how they currently display 3D land parcels and the failings of the current systems.

2.1 Urban Growth

Urban growth has two main components; population growth and urban consolidation. In the Greater Sydney area, a combination of the two components has lead to higher density suburbs and complex survey plans defining the legal relationship between land parcels. The following sections will investigate the changing demographics and development style within the region which is leading to the trend towards high density living in Sydney.

2.1.1 Population Growth

Population growth within Australian is a constant topic that requires changes to the current approaches to town planning and urban development. As of June 2015, New South Wales had an estimated resident population (ERP) of 7.62 million people and the Greater Sydney area had an ERP of 4.92 million people being an increase of 1.4% and 1.7% respectively from June 2014 (Australian Bureau of Statistics 2016). This population growth is aided by a combination of natural increase, being the difference between births and deaths, and immigrations, offsetting migration out of the state (NSW Department of Planning and Environment 2014b).

Immigration is a major factor of Sydney's growth with immigration growth contributing more than natural increase (Australian Bureau of Statistics 2013a). Australia's migrant population is relatively large compared to other western nations and consist of 26% of the Australian population in the 2011 Census yet 85% of immigrants settle within major urban areas compared to only 64% of Australian-born residents (Australian Bureau of Statistics 2014b). The three case study areas to be analysed for this research are Eastwood, Burwood and Wentworth Point. In Figure 2.1 both Eastwood and Burwood fall within the 50% or more category. Wentworth Point however is excluded due to lack of residents in 2011, reflected in the suburb was only established in 2009, but since this time significant development has occurred within the suburb and it is transitioning from industrial to high density residential and is beginning to reflect the neighbouring suburb of Rhodes which does fall into the high migrant population category.

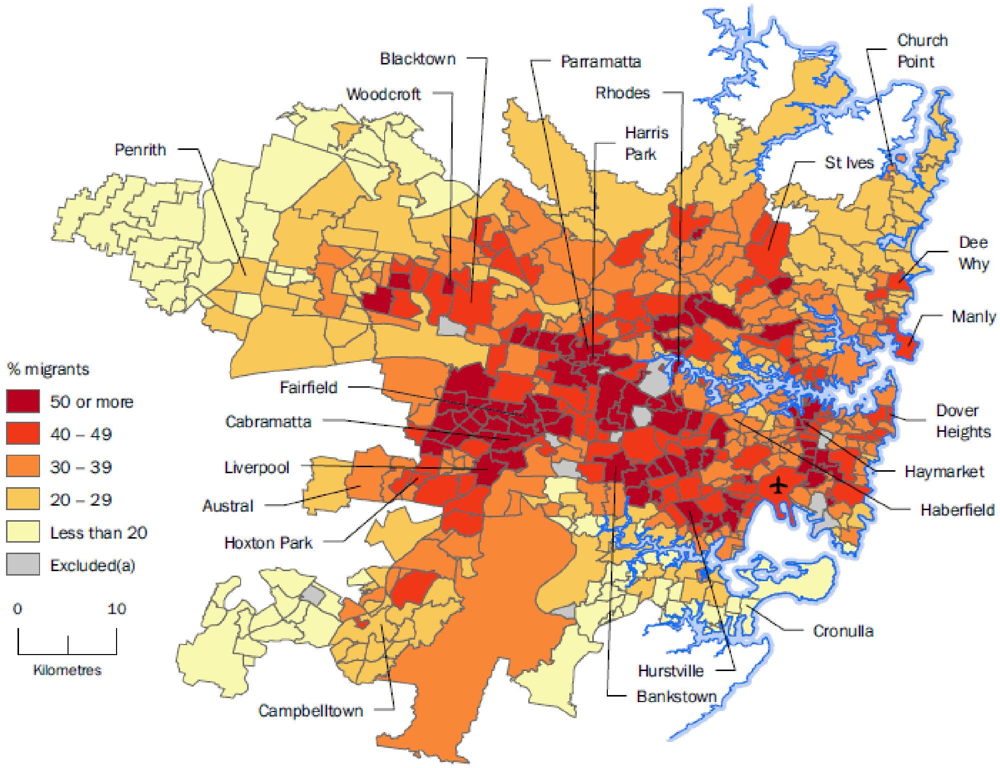

Figure 2.1 Percentage of migrants in Sydney by Suburb 2011 (Australian Bureau of Statistics 2014b).

Changing demographics within the Greater Sydney area are also impacting on the requirements and demands for housing models as residential setups and household composition is changing. Trends now show that couple-only families, with no dependent children, are beginning to form an equitable portion of Australian households a couples with children, and these couple-only households comprise of both younger adults and mature 'empty-nesters' (Australian Bureau of Statistics, cited in Qu & Weston 2013, pp. 5). Increased immigration has also seen a rise in multi-family households with Australian-born multi-family households at 2.3 percents and overseas-born households at 4.5 percent with a trend of non-English speaking households more likely to be in this arrangement (Australian Bureau of Statistics 2013b).

2.1.2 Urban Consolidation

Due to the population growth within New South Wales, especially that centred around the Greater Sydney area, the requirement for additional homes has been identified. The New South Wales government released the document A Plan for Growing Sydney (NSW Department of Planning and Environment 2014a) to identify the changes to the Sydney's growth and the requirements to meet housing and infrastructure requirements. They key feature identified was the requirement for an additional 664,000 residences by 2031 to meet population growth and in the last four years housing production has increased from around 13,300 dwellings per annum to around 22,800 dwelling per annum (NSW Department of Planning and Environment 2014a) however the report identifies that there will still be a shortfall in housing stock. Western Sydney has been identified as the central focus for this growth. Currently housing 47 percent of the Sydney population it is predicted that by 2031 there will be an additional one million residents west of Homebush (NSW Department of Planning and Environment 2014a). This growth in the western region highlights issues with the reliance on cars, lack of public transport infrastructure, lack of public amenity and high commuting requirements to reach employment opportunities.

The provision of amenity can allow residents access to alternative facilities that cater for a void in facilities within their private property and maintained green space combined with facilities can assist when there are limits on the usage of private open space and this can improve the desirability of locations as reflected in sales prices but requires maintained areas as the research established that unmaintained national parks facilities did not have the same impact (Mahmoudi et al 2012). The research by Mahmoudi et al 2012 focuses on the limitations on private yards due to reduced water availability it was also noted that other limitation in private open space, such as small courtyards or balconies, lead to heavier use of public open space. Research suggests that there is an additional economic imperative in providing and maintaining usable open space within communities.

2.1.3 Conflicts Arising from Urban Consolidation

With the changes in population growth and the need for denser urban dwelling, high density developments are popular with developers due to the higher yield and with government departments to reduce urban sprawl (Blandy et al, 2006, p. 2365). However while high density living may be the way forward of approaching required housing growth within Australian cities and begin to mirror countries where this form of living is the norm, issues such as proximity and shared facilities are flashpoint for conflict between residents and managers (Easthope & Judd 2010). This form of living is not the standard for Australian society and as a result the move towards urban living sees a community in close living conditions forged from a multitude of sub-markets within conflicting interests and desired from the facilities of their dwellings and community property. Therefore it becomes imperative that planners and developers work closely to create suitable living environments that will sustain a population more commonly used to detached suburban living and provide strong communities in the areas undergoing urban consolidation. Factors such as building design, amenity and construction quality are key factors in improving the quality of high density living and are required to bring Australian development to the level of international countries with established urban dwelling as a norm (Easthope & Judd 2010).

This rise of high density living has formed sub-markets with the two critical ones low-income suburban families forced into small living spaces and middle-income, child-free occupants consisting of owner occupiers and renters with the other submarkets being mature downsizers, students and high-income which represent a lower portion of those living in strata schemes (Easthope & Rudolph 2009). The two primary categories of occupiers are driven towards high density living for different reasons and the conflicts that arise in the management of both interests can be from this clash of living requirements. The lower income portion of occupants are primarily suburban families driven to apartment living due to cost factors and the majority fall into the category of renters which leave them with little power within owners corporations while the second market of medium-income, child-free occupants trend towards high-density for the provision of facilities and the lifestyle impact (Easthope & Rudolph 2009).

The application of strata legislation in New South Wales establishes the owners corporation as a legal entity that has emerged a fourth tier of urban governance that sites below local governments (Tornai, cited in Easthope & Rudolph 2009, pp. 248) and with it binds the legal relationship between the shareholders in a strata scheme. Unit entitlements are allocated to within a strata scheme and determine the voting power and levies required from each unit owner. The schedule of unit entitlements is part of the administration sheets as part of the plans prepared by a registered surveyor in accordance with clause 6 in the Strata Schemes (Freehold Development) Regulation 2012. The market value at the time of registration of the strata plan is used to calculate the unit entitlements (NSW Land & Property Information 2015, pp. 7) and as a result owners area reliant on their market share of the strata scheme to determine their representation in matters of voting and levies (Easthope & Rudolph 2009, pp. 252). The voting power allocated to owners however has been shown to be manipulated by developers through a variety of methods. Proxy votes being allocated to developers as part of sales contracts (Thompson, cited in Easthope & Rudolph 2009, pp. 253) and developers retaining ownership on a majority share of dwellings, consequently rented out, can lead to management contracts and maintenance issues being sought in favour of the developers and leaving owners with high costs and poorly maintained shared facilities. Renters form a significant portion of the low-income sub-market in high density residential yet have no voting capabilities within the strata scheme and area limited in their influence which lessons their role in participating in the framework that governs their homes and neighbourly relations (Easthope & Rudolph 2009, pp. 253).

As can be seen from the research the conflict of multiple shareholders arises due to the different expectations of occupants regarding the facilities and usage on residential strata schemes and becomes more complex in mixed-use development that attempt to include commercial, retail and council interests in the owners corporation alongside the residents. The trend towards mixed-use developments is rapidly becoming common within the Greater Sydney area and are growing in complexity and leave 'the commercially hard-headed able to prosper at the expense of new owners' collective' (Andreone, cited Thompson 2007). Case Study 1 in this research project looks at Wentworth Point and the development of a master plan community by the developer Billbergia. Covering approximately 9 hectares this sites included multiple apartment dwelling towers, roads with public access and amenities including a school, shops and a library and is covered by a community plan further subdivided into strata plans and features as an example of the level of complexity that exists within high density developments within Sydney. Other examples of mixed-use developments include Rhodes Waterside in Rhodes, Jacksons Landing in Pyrmont and Breakfast Point at Cabarita (Thompson 2007)/. With these developments spanning multiple usages the legislation for simple strata schemes falls short in aiding communities to operate and mitigate conflict. This is where stratum subdivision can aid developers in creating mixed-use communities.

The application of stratum subdivision of buildings allows this tension to be reduced through the subdivision of the developments into suitable lots and then each lot manages by its own strata scheme that addresses the issues of the shareholders. The method of subdivision allows for facilities specific to a strata scheme to be managed and paid for by those that use the facility, such as a lift that only services the residential areas of a building or external gardens that provide exclusive use space for retails in their strata scheme, and this separation of facilities allows for contributions and unit entitlements to be addressed in a suitable manner and improve the affordability of dwellings within mixed-use developments. It also would improve value of the buying into the strata scheme as it limits the shareholders involved and requires fewer negotiations for action to be taken by the owners corporation.

2.2 Subdivision and the ePlan Protocol

For the focus of this research project, the Greater Sydney area is the primary location undergoing analysis. As a result of increased development within the area, as discussed earlier, the cadastral requirements for subdivision are more complex than low density areas. Due to the density issues with urban consolidation in Sydney multi-storey developments with mixed-use functions or development over infrastructure including transport tunnels and services are common. These style development require specialised subdivisions that recognise the vertical relationship between the land parcels. The two methods used in New South Wales are stratum and strata.

The relationships between land parcels are important to understand in order to reduce the potential for conflict and dispute and establish the impact on land owners and tenants. Within land use there is the concept of rights, restrictions and responsibilities and how they affect or benefit a land parcel and the landowner's use of their property and are founded through legislation and policy. Rights, restrictions and responsibilities that can affect a land parcel include mining rights, water frontage access, water and fishing licenses, maintenance of services and features, land development control, working under environmental protection acts and registrable interests in the land ownership and use (Intergovernmental Committee on Surveying and Mapping 2015).

2.2.1 Digital Cadastre

There are two primary digital portals used by surveying professionals in New South Wales. The first to be discussed digital cadastre map is SIX Maps. This cadastre is run and maintained by NSW Land & Property Information and is accessed via http://six.nsw.gov.au/. There are two versions of this mapping portal. There is an open access version for the general public which allows search options to identify plan and title numbers and in this portal approximate boundary line work and survey marks can be viewer over aerial imagery. The SIX Maps portal also has a professional log-in version which allows the user to access more search options and download coordinates for survey marks. In regards to boundary data shown, however, the two portals are comparable.

The second digital cadastral map to be investigated is NSW Globe and is access through the Google Earth software. It is run and maintained by Land & Property Information, same as SIX Maps, but is a KML file that is accessed locally off the individuals computer. The KML file contains the same boundary data as SIX Maps and has metadata attached to all objects. It also expands it data layers to include items such as land sales prices, council areas, transport and

Australian Bureau of Statistics data. Due to the utilisation of the 3D controls in the software platform with an orbit view function Google Earth has the capabilities of displaying 3D data.

Figure 2.2, Figure 2.3 and *Figure 2.4* demonstrate the current methods of presenting stratum data in the format options available. Lot 2 from Deposited Plan 1177634 is used for the comparison study and is the retail lot within a mixed use complex with basement parking, two levels of retail units and access corridors in the form of elevators and stairs. Above this is Lot 1 in Deposited Plan 1177634 which is the residential lot of three levels situated above the retail lot. For the details of Deposited Plan 1177634 refer to *Appendix B*.

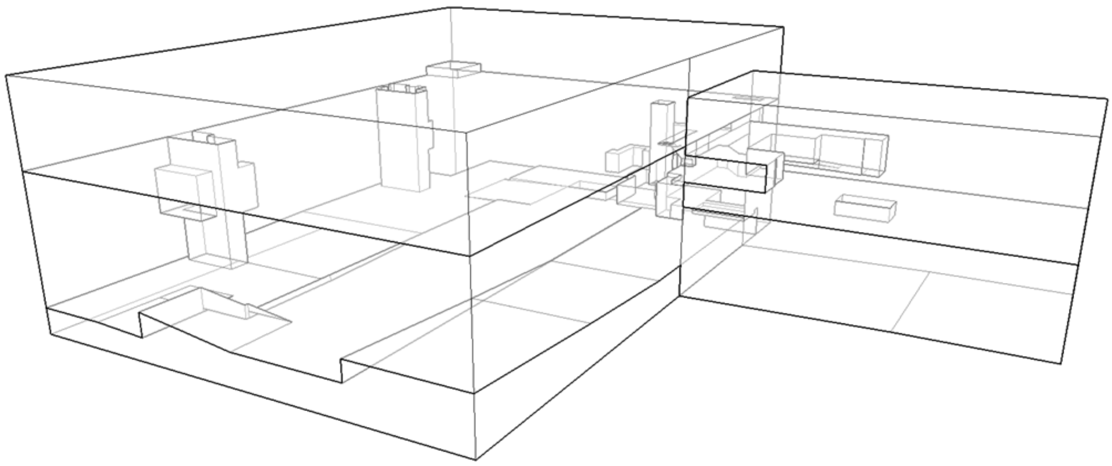

Figure 2.2 Model of the three lots in Deposited Plan 1177634.

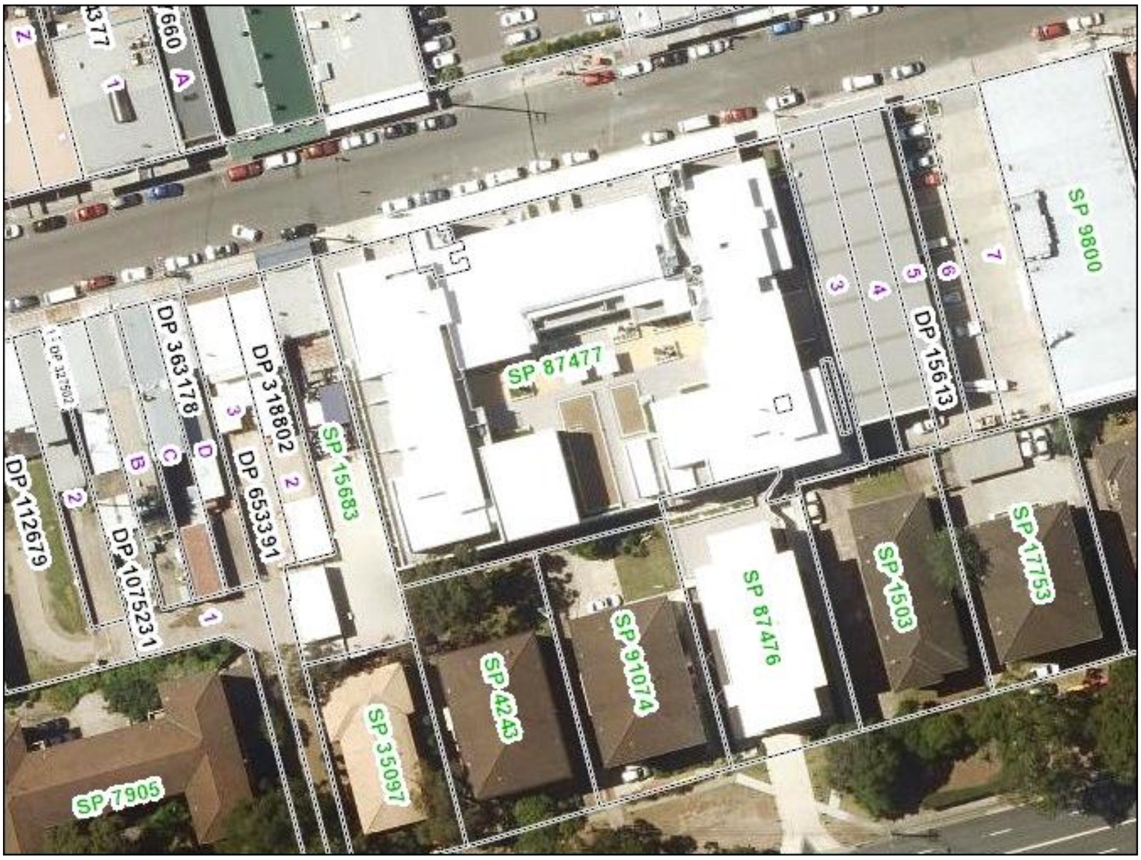

Figure 2.3 Deposited Plan 1177634 as shown in SIX Maps (NSW Land & Property Information 2014).

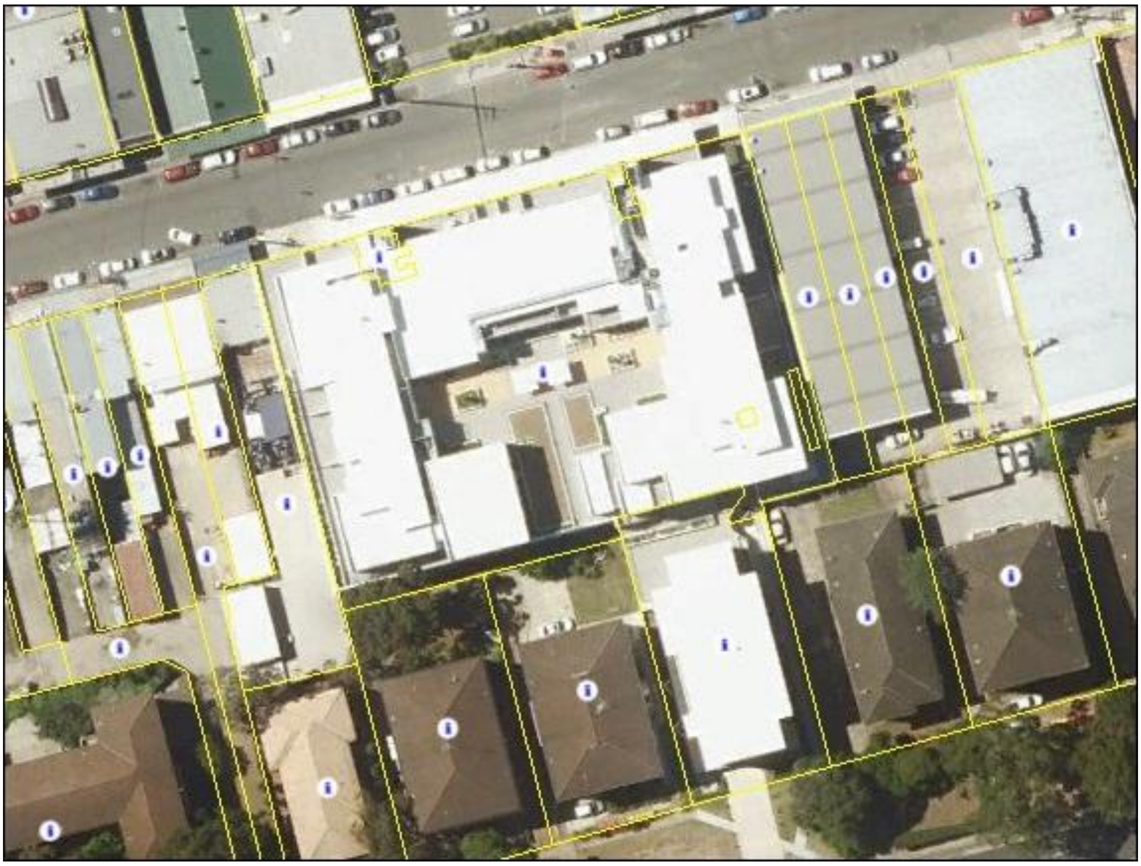

Figure 2.4 Deposited Plan 1177634 as shown in NSW Globe (NSW Land & Property Information 2013).

As can be seen by *Figure 2.3* and *Figure 2.4*, the visualisation of Lot 2 has been superseded by Strata Plan 87477 that further subdivides Lot 2 however this does not completely eliminate the original land parcel as the base plan is still relevant in regards to demonstrating the extent of the lot despite the strata subdivision. Unlike a Torrens Title subdivision, strata subdivisions do not void the original definition but act in addition to the base plan (NSW Land & Property Information 2015). In the case of a stratum subdivision, agreements and bindings between the stratum lots will affect the owners corporation as they act within the original stratum subdivision. The second strata plan fronting onto Rowe Street is Strata Plan 87478 which represents the residential above the retail component. This is the subdivision of Lot 1 in Deposited Plan 1177634 and is not seen on either digital cadastre due to the overlap of plans.

It can be seen from the examples the current digital cadastral maps available in New South Wales do not allow for the end-user to understand the relationship between the lots. Currently further investigation of the survey plans is required to understand the vertical components of the subdivision and there is no digital representation of the lots to allow for a easy view options for the end-user.

2.2.2 Legislation and Policies

Under the New South Wales surveying titling system there are three types of titled land being Torrens title, Old System title and Crown title. For the purpose of stratum and strata subdivision only the Torrens title is relevant as neither subdivision can be applied to Old System title and Crown Title. Similarly. strata subdivisions can only occur on a Torrens title that meets the currently requirements for a cadastral subdivision and plan. This covered requirements such as plan format, MGA connections and a suitable boundary definition. A lot that does not meet the requirements will first need to undergo a plan of redefinition and similarly an Old System title land parcel would require conversion prior to a development and strata scheme.

The relevant legislation for cadastral surveying in New South Wales in outlined in *Table 2.1* below.

Name of act (s)	**Subsequent documents**
Community Land Development Act 1989	Community Land Development Regulation 2007
Community Land Management Act 1989	
Conveyancing Act 1919	Conveyancing (General) Regulation 2013
Crown Lands Act 1989	
Crown Lands (Continued Tenures) Act 1989	

Real Property Act 1900	Real Property Regulation 2008
Roads Act 1993	
Strata Schemes (Freehold Development) Act 1973	Strata Schemes (Freehold Development) Regulation 2012
Strata Schemes (Leasehold Development) Act 1986	Strata Schemes (Leasehold Development) Regulation 2012
Strata Schemes Management Act 1996	Strata Schemes Management Amendment Act 2004
	Strata Schemes Management Regulation 2010
Surveying and Spatial Information Act 2002	Surveying and Spatial Information Regulation 2012

Table 2.1 Relevant legislation for New South Wales subdivision plans (NSW Land & Property Information nd.b).

There are also a number of State Environmental Planning Policies that can apply to urban development including:

- *State Environmental Planning Policy No 1 - Development Standards* (NSW)
- *State Environmental Planning Policy No 65 - Design Quality of Residential Apartment Development* (NSW)
- *State Environmental Planning Policy No 70 - Affordable Housing (Revised Schemes)* (NSW)
- *State Environmental Planning Policy (Building Sustainability Index: BASIX) 2004* (NSW)
- *State Environmental Planning Policy (Sydney Region Growth Centres) 2006* (NSW)
- *State Environmental Planning Policy (Urban Renewal) 2010* (NSW)

In particular *State Environmental Planning Policy No 65 - Design Quality of Residential Apartment Development* (NSW) and is the most relevant to this discussion with the aims of the policy summarised below:

- sustainability in social and environmental terms;
- form long-term assets;
- improve build form and aesthetics of streetscapes;
- maximise amenity, safety and security for the occupants and community;
- meet population growth.

The policy outlines nine principles aimed at improving design quality in apartment developments. These include context and neighbourhood character, built form and scale, density, sustainability, landscape, amenity, housing delivery and social interaction, safety and aesthetics as shown in Schedule 1 of *State Environmental Planning Policy No 65 - Design Quality of Residential Apartment Development* (NSW). These principles for apartment development can be met with the increased construction of mixed-use developments to provide communities within high-density areas and thus increasing the complexity of the cadastral relationships within these developments.

2.2.3 Urban Subdivision

Due to the changes in urban landscapes within the Greater Sydney area, primarily driven by population growth as identified earlier, the New South Wales cadastral system require review to streamline the process of plan registration and enable effective representation of legal boundaries for both the use of surveying and non-surveying end-users. This has been addressed through the development of the ePlan Protocol and research into improving digital data validation and representation for spatial queries.

The most common form of subdivision in New South Wales is a non-stratum Torrent title lot. this is a land parcel defined from reference marks with bearings and distances with no vertical limitations applied to the land. Land parcels have no height restriction and are defined as 'from the centre of the earth, through the earth's surface to infinity' (NSW Land & Property Information nd.f) however more practical applications see the definition of land vertical restrictions as to 'ordinary use & enjoyment' as demonstrated in *Bernstein of Leigh v Skyviews & General Ltd* (1978). This form of subdivision is known as a Deposited Plan using the acronym DP.

See *Figure 2.5* for an example of a non-stratum subdivision. It can be noted that it is a single page document and contains no vertical restrictions on the land.

Stratum subdivisions are a subset of Torrens title and are utilised when lots are required to be limited in height or depth. Examples of developments that may have this requirement include rail and road tunnels, services easements under buildings and mixed-use building requiring separate lot ownership (NSW Land & Property Information nd.e). For this research project the focus is on mixed-used developments where individual lots will be either sold individually, further subdivided into strata schemes or returned to the local government authority or Roads and Maritime Services as part of Development Application requirements. Typically a development may include multiple parking levels, retail or commercial on lower accessible levels and residential apartments above. In a stratum subdivision individual components can be isolated an allocated to their own lot, typically defined as entire floors of the building, specific areas or individual car spaces in parking areas. A stratum plan is drafted using the same format as a non-stratum Torrens title plan and uses on bearings and distances with reference marks to provide the boundary definition (NSW Land & Property Information nd.c). The only additional aspect for the definition is the height component for each section of a lot. This type of subdivision is also known as a Deposited Plan using the acronym DP. Stratum subdivisions also can be lodged with a Building Management Scheme, which is a document outlining the management and maintenance of the building in its whole entity and dispute settlements as set out by the *Conveyancing Act 1919* (NSW).

See *Figure 2.6* for an example of a stratum subdivision. This shows the lot divided into stratum limits which each have their own vertical limitations. The vertical limitations can be a flat plane, inclined plane defined by two levels or a inclined plane with all corners defined by a level (NSW Land & Property Information nd.g).

Strata schemes are a different format to Torrens title. For Torrens title the ownership is of the land in its entirety however for strata title the ownership is a portion of the whole as shown through unit entitlements and a right to use the portion defined on the strata plan defined as a cubic space (NSW Land & Property Information nd.d). Land parcels are defined by the structures onsite, by either thick line boundaries being walls, floors and ceilings or thin line boundaries where no structure exists being dimensioned from an existing wall. All other parts of the building not defined in a lot are common property and maintenance falls to the Owners corporation. Unit entitlements are allocated to each lot to represent each lots share in the overall strata scheme and are calculated based on the valuation relative to all other lots at the establishment of the scheme. Strata schemes can be used for townhouse or villa complexes and multi-storey apartment buildings. Strata scheme subdivisions are known as Strata Plans using the acronym SP.

See *Figure 2.7* and *Figure 2.8* for an example of a strata subdivision location plan and floor plan. The location plane shows the extents of the site in relation to the cadastral boundaries and will include identifying features including building description and street number, a layout of the features including car spaces and units and offsets to the surround boundary for structures within two metres. The floor plan shows the boundary definition, based on structures, of the individual strata lots and the lot's area. For a multi-storey building, strata plans will typically contain a location plan and a floor plan for each level.

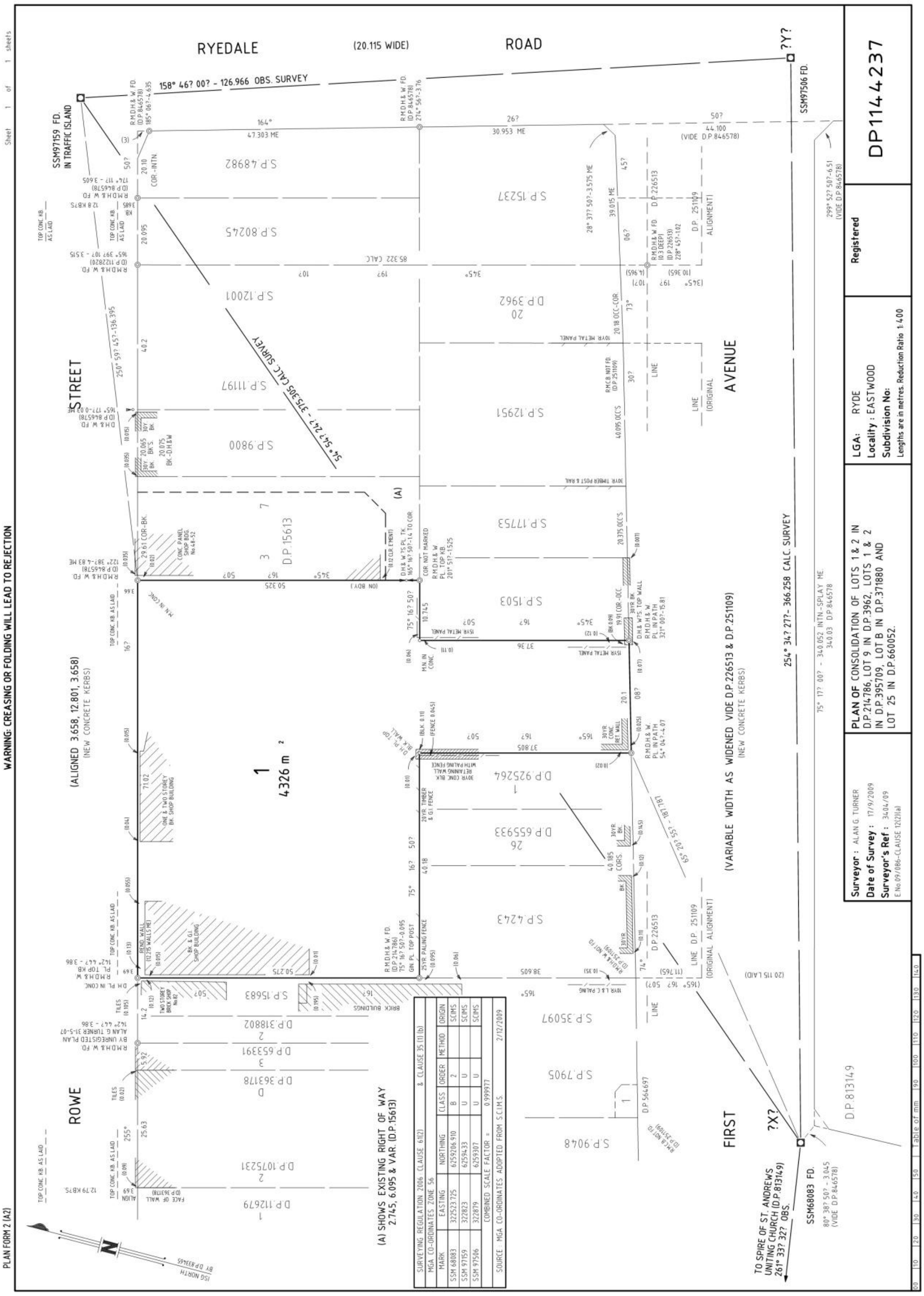

Figure 2.5 Original consolidation plan of Lot 1 in Deposited Plan 1144237, being the consolidation of Lots 1 & 2 in DP 214786, Lot 9 in DP 3962, Lots 1 & 2 in DP 395709, Lot B in DP 371880 and Lot 25 in DP 660052 (Turner 2012a).

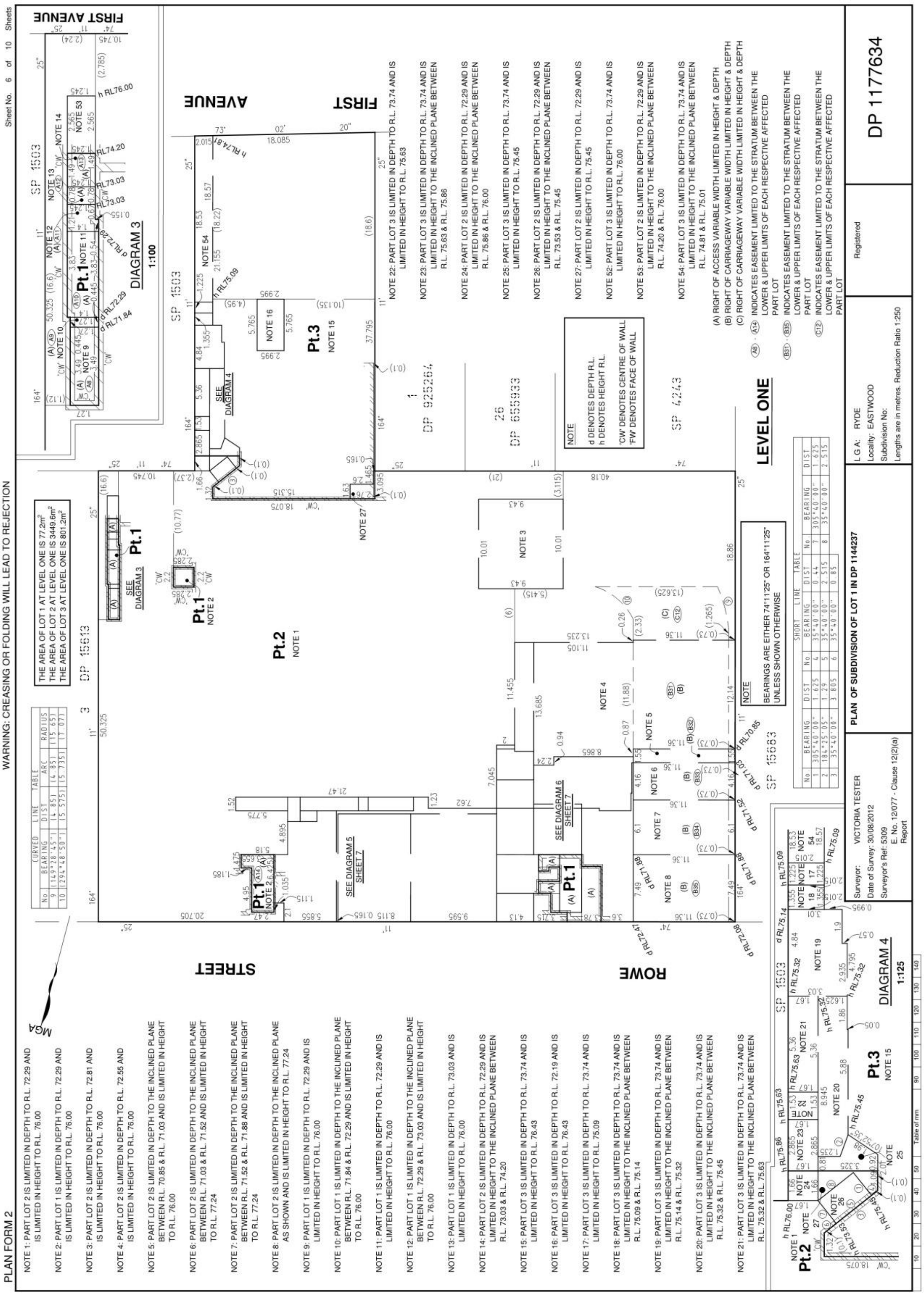

Figure 2.6 Section diagram of Level 1 from Deposited Plan 1177634, being the stratum subdivision of Lot 1 in Deposited Plan 1144237 showing the division of the lots into areas of the same height restriction (Tester 2012).

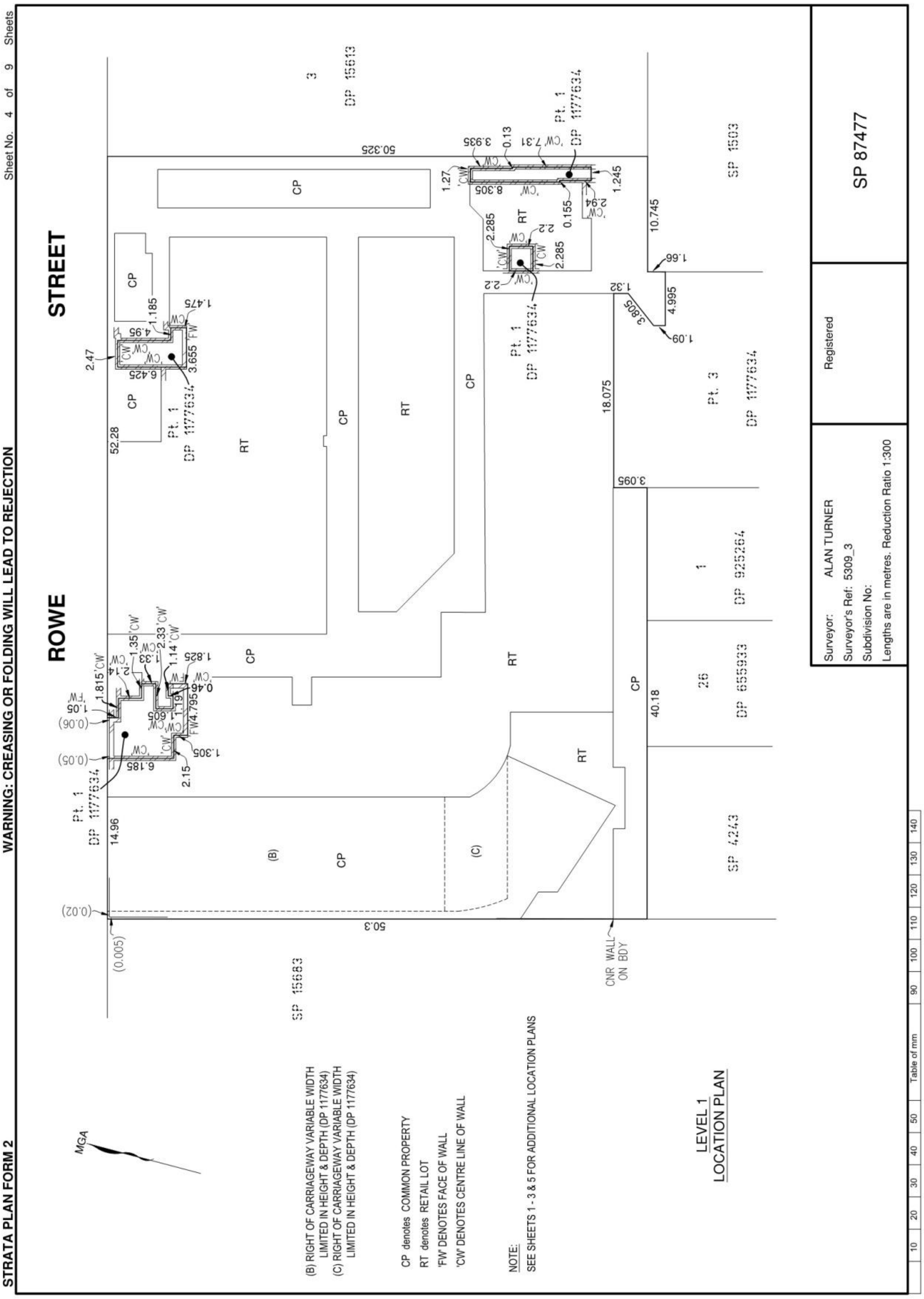

Figure 2.7 Location plan of Level 1 in Strata Plan 87477, being the subdivision of Lot 2 in Deposited Plan 1177634 (Turner 2012b).

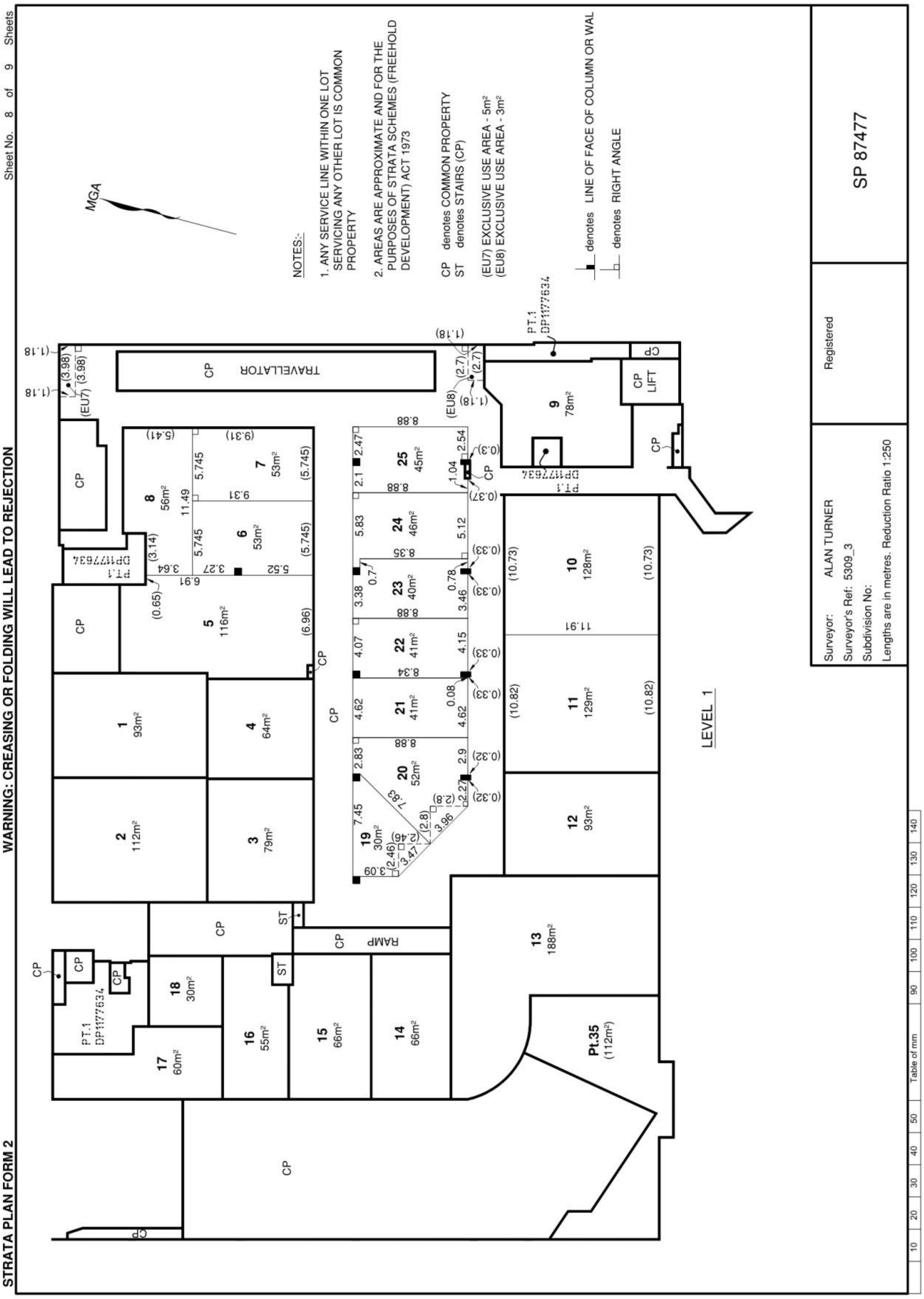

Figure 2.8 Floor plan showing definition and areas of Level 1 in Strata Plan 87477, being the subdivision of Lot 2 in Deposited Plan 1177634 (Turner 2012b).

In the case of typical Torrens title land parcels, the current methods of data representation in digital cadastres reflect the survey plan in a simple format and are suitable for the use of all end-users. Errors do exists within the cadastre regarding position; overlap between subdivisions and position of digital boundaries over aerial imagery and this will be address further in this chapter. These land parcels correspond well to a digital representation due to the lack of vertical restriction. Stratum and strata land parcels, however, consist of overlapping ownership rights and responsibilities connected to the legal boundaries of the land parcel. These are represented in a survey plan but do are not represented visually within the current digital cadastres. This method of survey plan, when accessed electronically, does not allow the end-user to effectively make spatial enquiries (Shojaei et al 2016).

Spatial enquiries currently within the current New South Wales digital cadastres, being Six Maps and NSW Globe through Google Earth, allow end-users to search for specific Torrent title lots by the metadata associated with the land parcel, typically the title reference, lot number and plan number or the street address. The end-user can then visually understand the location and relationship of the land to surrounding features or overlayed on aerial photography. As seen in *Figures 2.3* and *Figure 2.4* when stratum subdivisions are displayed the information is disjointed and overlapped with little indication of where lots exists within the area. Strata lots are not represent ted at all in the digital cadastres and the current spatial enquiries only allow for searches for the entire strata plan.

As discussed above, stratum subdivisions can be used to portion out elements of a development to be allocated to individual lots and as a result a lot could contain elements on different floor levels. Similarly, strata subdivisions will typically contain land parcels on different floor levels. As strata is commonly used for multi-storey complexes, both residential and commercial, the typical makeup of a strata lot would include an apartment along within a car space and storage cage at a lower level or basement. The ability to search for all components of a stratum or strata lot in a digital cadastre and visually understand the relationships, similar to the current method for non-stratum Torrens title lots, has the potential to improve the access of spatial data for the end-user.

While the New South Wales digital cadastres allow spatial enquiries and represent legal boundaries in a suitable format there are still discrepancies in the current cadastre. A solution to the problems of merging survey plans and geometry validation is the development of the ePlan Protocol developed by the Intergovernmental Committee on Surveying and Mapping (ICSM) in 2011 (Aien et al 2012). ICSM is an organisation comprising of all Australian states and territories and New Zealand to address common issue between jurisdictions and its core function is 'to coordinate and promote the development and maintenance of key national spatial data' (Intergovernmental Committee on Surveying and Mapping 2016).

The ePlan Protocol is currently being used for the submission of non-stratum Torrens title lots in New South Wales and consists of a LandXML electronic file that is lodged alongside a traditional survey plan. The system is designed to allow for a digital representation of the subdivision to be submitted. This file is comprised of a series of standard elements that the lodgement software can use to validate the data including road boundaries, lot boundaries, reference marks and MGA connections and check compliance to the ePlan Protocol (Cumerford 2010). The methodology developed is currently being applied to 2D land parcels but the ePlan Protocol is designed to support future ventures into 3D data representation. The use of LandXML lodgements on a standardised system facilitates the compilation of digital cadastres for portals such as SIX Maps.

Benefits of the ePlan system have been identified as including (NSW Land & Property Information nd.a):

- Ease of lodgement;
- Data validation prior to lodgement;
- Online system for requisitions;
- Quicker lodgement times;
- Easier to compile into digital cadastre.

At this stage, the ePlan Protocol is applied to non-stratum Torrens title subdivisions but the benefits already identified could have significant value if applied to more complex subdivisions. Currently, manual checking of stratum plans requires time and a suitable understanding of the development site and due to the nature of the vertical element it is simple to miss overlapping lots with encroachments or voids. Data validation could automate this process and identify problems with the boundary definition in significantly less time. The ability to compile the plan into digital cadastres allowing spatial enquiries would also be of significant value as discussed earlier in this chapter.

Shojaei et al (2016) investigate the application of 3D boundary representation in multiple formats including both Revit and Google Earth, but primarily focuses on the application to strata plans under the Victorian cadastral system. These plans are similar to strata plans in New South Wales but don't contain the full complexity of stratum subdivisions which will form the main focus of this research project. The research investigated the suitability of boundary representation by geometric faces under the ePlan Protocol and found the system is suitable for representing the required elements for 3D modelling (Shojaei et al 2016).

2.3 Requirements of Cadastral Systems

The primary requirement of a digital cadastre is the ability to make spatial enquiries based on metadata. The types of spatial queries required were found to include (Shojaei et al 2013):

- Identifying legal object within the cadastre with both the vertical and horizontal position;
- The ability to subdivide or consolidate volumetric parcels to facilitate registration;
- Identify utilities and infrastructure and their relationship to lots;
- The validation of spatial data to ensure no overlap or voids in the data.

The current system relies on 2D visualisation of land parcels and the survey plan, formed from cross sections and slice-based floor plans, to be used to fully analyse the relationship between lots. This method does not allow for any of the identified spatial queries to be undertaken with the cadastre. The application for the end-user, specifically those outside the surveying profession, when using the registered survey plan is complicated and requires a strong understanding of the development.

2.3.1 Uses and Applications

It was identified that surveying professionals are not the only industry that utilises the spatial data contained within digital cadastral maps. Professional industries related to construction and property development also require accurate and accessible spatial data and even the general public may use online portals to make spatial queries and the non-surveying end-users of the cadastral data are more likely to require suitable visualisation within the system to assists with understanding complex survey plans.

The end-users of digital cadastres are broken down into three categories:

- Surveying professionals;
- Non-surveying professionals;
- General public.

Table 2.2 below identifies specific users within the three categories and the tasks that are completed utilising digital cadastral data.

Category	**Description**	**Use of Digital Cadastres**
Surveying professionals	Surveyors (registered and technicians)	• File searches for new jobs and clients. • Finding plan and title numbers for identification of required survey plans for an area. • Comprehensive searches of what plans in the area affect their job site in the case of boundary redefinition. • Clarification of boundary and lot relationships when compiling survey plans for calculations.
	Admin staff	• File searches for new jobs and clients. • Finding plan and title numbers for identification of required survey plans.
Non-surveying professionals	Councils	• Digital cadastres used, based off the NSW Land & Property Information cadastre originally and typically updated internally. • Focus on the council area so forms a smaller cadastre than the full New South Wales wide database. • Access and update of council metadata relating to properties and ratepayers. • Insertion of new development designs prior to development application approval to check compatibility with adjoining land. • Search function for plan numbers for cadastral or reference work. • Identify densities and trends in housing to aid in the provision of services, community facilities and infrastructure.
	Owners corporations (strata) & building management schemes (stratum)	• Identify and understand relationships between lots within the development.

Category	**Description**	**Use of Digital Cadastres**
Non-surveying professionals	Civil engineers	• Identify affected land to areas undertaking works or upgrades. • Relate road designs back to cadastral boundaries. • Identify the location of existing services and structures affected work areas and the potential impact., specifically the location of underground services (see other spatial professionals below).
	Real estate agents (sales and rentals) and conveyancing professionals	• Source data on sites prior to site visits to streamline the onsite identification of land. • Identify plan numbers and title references. • Screenshots of cadastres used for marketing material. • Understand the context of the land they are selling
	Legal professionals	• Understand lot relationships for boundary disputes and establishment of rights and responsibilities within the development i.e. easements and covenants.
	Developers	• Evaluate the development potential of land and the trend of the surrounding suburb. • Identify impacts of adjoining properties. • Identity potential competition in the areas market share of off the plan developments. • Use the data above to establish the viability and potential profit.
	Town planners	• Access to lot positions and block layouts without requiring site visits. • Identify densities and trends in housing to aid in the provision of services, community facilities and infrastructure.

Category	**Description**	**Use of Digital Cadastres**
Non-surveying professionals	Other spatial professionals	• Category includes industries such as GIS, service providers, service locators • Used to place spatial data in an appropriate relationship to the boundary. • Services, such as communications, electricity, water, sewer and gas, are being located at installation through coordination methods to improve databases and availability of information.
General public	Property buyers (for existing dwellings)	• Identification of the land they are investigating, particularly using aerial imagery to relate it to fixtures they can identify. • Investigation of the surrounding area of a purchase.
	Property buyers (off the plan)	• Identification of the land they are investigating, particularly using aerial imagery to relate it to fixtures they can identify. • Investigation of the surrounding area of a purchase.
		• Research into surrounding developments and how they may impact the potential purchase (i.e. high apartment blocks causing shadowing, residences close to common boundaries).
	General users	• Research into development in areas. • Establishing a understanding of the changes occurring within their suburb.

Table 2.2 Identification of the digital cadastre users.

As identified in *Table 2.2*, online digital cadastres for 2D boundaries are primarily used for identification of land parcels and their relationship to the surrounding environment. Accurate boundary location and definition are still related back to the original survey plans and any definition of lot boundaries still requires that use of a registered surveyor.

The emerging trends in land administration due to the complexity of developments within high-density areas suggest that cadastral design needs to evolve to meet the marked requirements and web services are becoming the focal point of spatial queries for professional and public end-users (Wallace & Williamson 2006). Similarly with the densification of urban areas the interaction between land parcels and the rights, restrictions and responsibilities becomes more complex. With policy changes to improve environmental and social impact of housing, the pressure for cadastres to form the central portal for professional and public use (Intergovernmental Committee for Surveying and Mapping 2015).

2.4 Conclusions

With the growing population and the trend towards urban consolidation in the Greater Sydney area, the trend towards developments that require more complex cadastral definitions is simple to identify. The focus of high-density suburbs is the concept of creating communities which often results in multiple shareholders with differing levels of priority within one building. As a result the subdivision requirements tend towards more complex stratum subdivisions based on the use of the land parcel, potentially further subdivided under a strata scheme, the complex relationships between all stakeholders increases the points of conflict within developments.

It also has been identified that digital cadastres and mapping portals are a widely used spatial feature for the acquisition of land data and providing visualisation of lot relationships. However the nature of 3D boundary relationships is not fully demonstrated under the current cadastral mapping software and limit the end-user's ability to access spatial data and understand the relationship between 3D land parcels. This was identified as being a key feature for non-surveying end-users in relation to complex survey plans, such as stratum subdivisions, where the lack of knowledge in cadastral surveying can limit the users understanding of the plan.

From the literature review a need to investigate methods of presenting digital 3D cadastral information was identified and the direction of this research project established. The information from this research was used to develop the methodology and evaluation criteria which will follow in Chapter 3.

Chapter 3 Methodology

The research project used a combination of research into the impacts and application of urban consolidation and the boundary definition methods used to combat potential conflicts followed by the investigation of the visualisation in four case studies to evaluate the application of 3D modelling methods in relation to digital cadastres.

The research project was undertaken in four main components:

1. The literature review, focusing on the causes and impact of urban growth and the challenges this presents to modern town planning within the Greater Sydney area. This investigated the two relevant components of urban growth: population growth and urban consolidation. It also focused on the provision of amenity within areas of high urban consolidation and the development methods that can be utilised to provide services for denser communities.
2. Also, as part of the literature review, both the current surveying legislation and the plan formats used to represent boundary data were analysed and the current methods of portraying 3D land parcels investigated. A review of these plan formats examined the efficiency of data presentation and the suitability for non-surveying end-users, being professional organisations, government departments and the general public, to be able to interpret the information. The introduction of LandXML as a electronic submission format alongside drawn boundary plans was also researched in its application to non-stratum land parcels.
3. The modelling component used three case study sites to consider the suitability of original data provided, the application of coordinate calculations for 3D land parcels and the suitability of Google Earth and the NSW Globe cadastre as a portal for access to spatial data. The three case studies are located within major urban hubs within the Greater Sydney area and feature subdivisions that utilise mixed use developments on separate titles within one building. The appropriateness of data visualisation in Google Earth was then analysed as to how it meets a 'fit for purpose' test, as outlined in the evaluation criteria below, and was examined regarding the criteria established. The development of the digital representation focussed on the end-user of digital databases and as an additional format that works in parallel to the drafted survey plans similar to the process currently used for 2D lots within New South Wales and their ePlan submissions using LandXML. The digital data does not replace the plan of definition but allows the data to be quickly imported into digital databases and supplied to relevant end-users.

4. The final step is the evaluation of the data visualisation methods and the application to a digital cadastre alongside the current plan format for boundary definition. From these first three sections, a criteria for evaluation was developed to address the shortfalls where the currently data visualization methods do not adequately demonstrate the land parcel locations and may cause problems for non-surveying end-users. This analysed the suitability of Google Earth and the NSW Glove portal as medium for 3D data presentation and what the benefits of incorporating this methodology into current survey plan submission to Land and Property Information.

When considering the application of the final use of the models, the difference between survey accuracy and GIS accuracy was considered. Survey accuracy relates to the legal boundary definition as shown on a survey plan and established through the use of reference marks while GIS accuracy indicates a level in which the data can still be used within an electronic mapping system. For the purposes of digital cadastres and their application to real world scenarios survey accuracy is not achieved and the digital formats do not replace the survey plan of redefinition. In the research project the models created reflect the size and shape of the legal boundaries but small discrepancies exist between the models and survey plans due to rounding and ease of surface modelling. The purpose of these models is to provide a 3D view of the physical size and relationship of the stratum lots and not replace the survey plan as the definition of legal boundaries. Despite the advancements in GIS technology and accessibility, digital cadastres do replace the need for a registered surveyor and survey plan for the definition of legal boundaries (Guyton 2010).

3.1 Modelling Process

The purpose of the project is to investigate the viability of the conversion of stratum subdivision plans, used for vertical boundary definition, to 3D models capable of being rendered in a digital cadastre via the Google Earth software.

In the three case studies, the survey data has been previously collected and the stratum subdivisions are registered deposited plans. The calculation method used to create these plans from the field data was done on slice based approach, splitting the building into individual floors. These are labelled on the plans with any floor above the street being known as levels and any floor below street level being known as basements with the numbering scheme for each starting from the street and heading outwards, i.e. basement numbers start at one at the highest and work down. Amendments to this naming system can be used and Case Study 3 will later show the use of a mezzanine level that is included in the subdivision.

Wireframe models were created of all lots within the subdivision using the 2D calculation files as the base. These files consist of the boundary dimensions and text describing the vertical limitation of each component. The wireframe model was constructed by applying these vertical elements to the line work based on each level's plan and then an overall wireframe of the lot in its entirety will be extracted. An export of the wireframe model was taken into modelling software and a 3D solid created for each lot and compiled with the adjoining lots in the correct spatial relationship. Layer management and colour coding was used consistently throughout the modelling processes to enable visibility control of the lots at the final viewing stage in Google Earth. Consideration was given to the automation of this process and this is discussed further in Chapter 6.

The model then underwent georeferencing to enable the model to be loaded in the correct position once imported into Google Earth. This coordinate reference is not of survey accuracy but a suitable accuracy to be integrated with the NSW Globe digital cadastre. This was completed using SketchUp's inbuilt georeferencing function which is compatible with Google Earth. The model was exported to the KML format and viewed in Google Earth.

In the three case studies, a series of 2D calculation drawings were created and provide an easy transition to plan drafting in the current New South Wales format and 3D wireframes were not used by the surveyor, however investigation is undergoing on a company level to investigate the use of wire frames for calculation purposes. The techniques used by surveyors to design their stratum subdivisions will always vary depending on the individual's personal choices, software preferences and the standard practice of individual firms but all aim at producing the same format of plan output.

3.2 Software Choices

To identify suitable software for the modelling process the following requirements were identified:

1. Required to be compatible with the original survey data format and suitable to complete survey calculations.
2. Has the ability to create wireframe models from the survey calculation file without significant time implications.
3. Has the ability to convert wireframe models into solid objects.
4. Provides an export to the KML format.
5. Allows for georeferencing to be applied to the models.
6. Has the ability to view 3D object in the same environment as the New South Wales Globe cadastre.

No single program met all the requirements so there are three software programs that were used in modelling process. These are AutoCAD 2016, SketchUp 2016 and Google Earth. All were available resources for the duration of the project and meet the requirements for the component of the project they were represented.

The decision to use AutoCAD for a base modelling software is based on the format file of the survey data for the case studies that will be explored. It is a common software platform used in the surveying industry and is available for use throughout the research project. The original data being used to create the models was originally calculated using AutoCAD so maintaining the software reduces conflicts of data through conversion. While the survey data could be converted to other survey packages, the availability and familiarity of the software package also made AutoCAD as suitable choice for survey calculations and the development of wireframe models and allowed for efficient time management for the research project. However due to the lack of KML integration in AutoCAD products, currently it requires additional plug-ins and software, an alternative software was sought for the intermediate step between the wireframe model and the final visualisation in Google Earth. Research into modelling packages found SketchUp to be a suitable choice and it had the features identified as necessary for the process. This software is freely available and is developed by Google so is strongly integrated with their other products including Google Earth and has a native KML conversion built into the software. At this stage Autodesk, the software developer of AutoCAD products, does not allow direct export to the KML format from its products however third-party software add-ons are available to include this export feature.

The choice of Google Earth as a platform for a the final digital representation of the case studies was made based on one of the forms of existing digital cadastres in New South Wales. There are two publically available digital cadastral maps being SIX Maps and NSW Globe which are both operated and maintained by NSW Land & Property Information. SIX Maps is an internet based portal can be accessed via the common internet browsers. This enables the database to be widely available yet limits the extent of the rendering capabilities of the software. It has no 3D capabilities and requires minimal processing capabilities in computing requirements. The alternative digital cadastral map is NSW Globe. This is a KML database that can be viewed through Google Earth and contains the same metadata and boundary information as SIX Maps however requires specific software to access the data. Google Earth is a free software package and has 3D rendering capabilities which makes it a suitable choice, combined with the NSW Globe database, for demonstrating 3D integration with existing digital cadastres.

Given the nature of the survey industry there are a number of different software packages that are utilised by companies. For long term implications and accessibility from survey packages to a viable electronic form for the New South Wales digital cadastre, specific software add-ons could be developed similar to the tools created and made available to surveyors to comply with the recent ePlan and LandXML submission changes (NSW Land & Property Information 2016).

The three software programs chosen for the research project meet the requirements for each stage and are either freely available or already used for the case study sites. Familiarity with AutoCAD and the ease of learning associated with SketchUp mean less time will be spent learning the software and the focus can be on the modelling process. The use of Google Earth as for final presentation allows the models to be analysed in the same environment as an existing New South Wales digital cadastre.

The process followed from the survey plan through to Google Earth is shown in *Figure 3.1*.

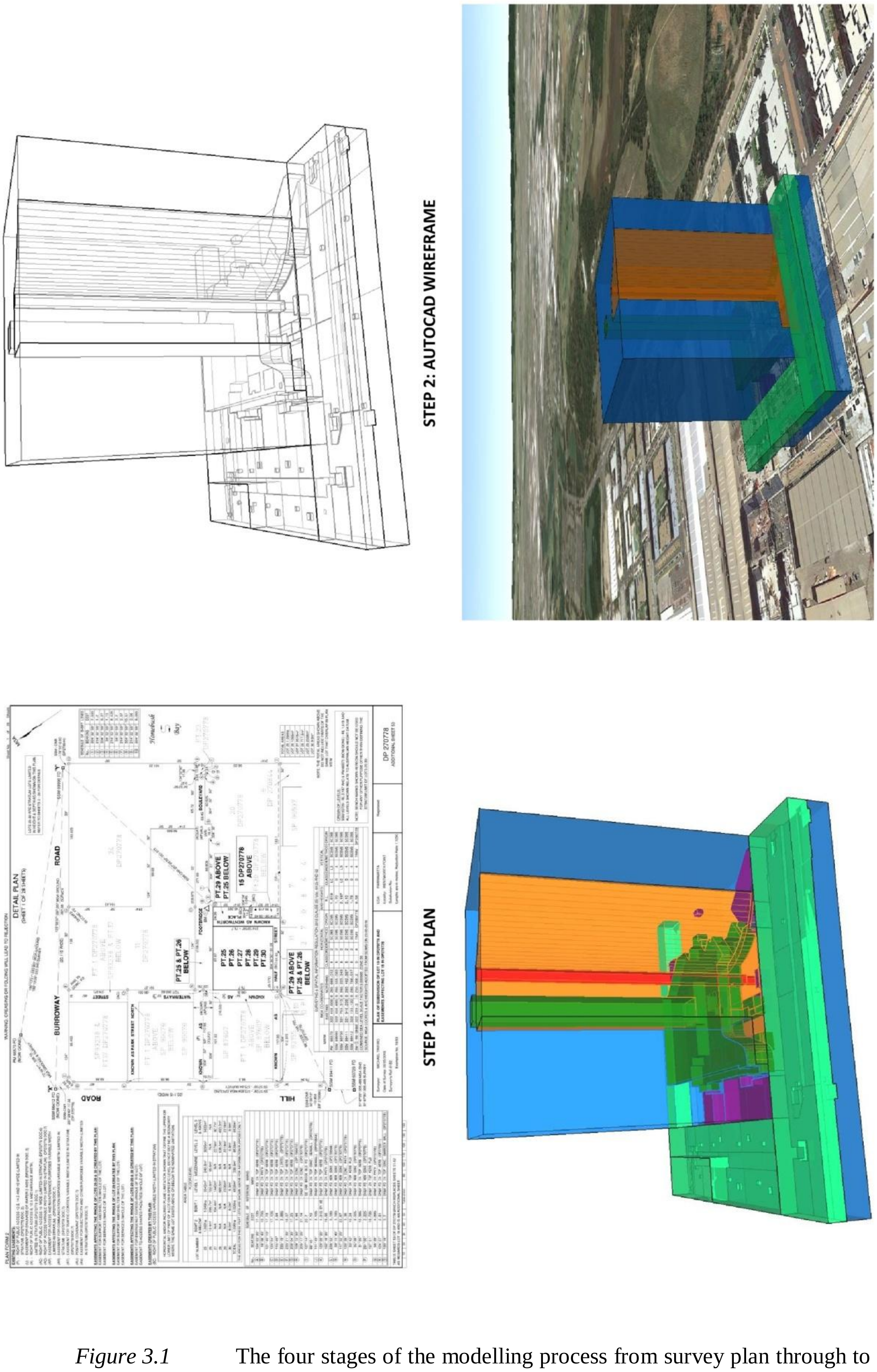

Figure 3.1 The four stages of the modelling process from survey plan through to Google Earth.

3.3 Evaluation Criteria

The first step of developing the evaluation criteria was to identify the target audience and projected use of the digital cadastral map. As identified in Chapter 2, the users of digital cadastres fall within three categories:

- Surveying professionals;
- Non-surveying professionals;
- General public.

The common element identified above across users of digital cadastres in the ability to establish a position of a cadastral lot in relation to the surrounding environment for the purposed of identification and understanding the relationship to adjoining land. This identification undertaken remotely from the site and does not require survey accurate boundaries. The ability to complete site analysis remotely can improve time and cost requirements of a project. Based on this usage, single occupancy land parcels with no vertical restrictions are easy to display in a digital format but the system doesn't cope with stratum subdivisions.

Having established the uses of digital cadastres, the following evaluation criteria was designed to establish the impacts and viability of 3D digital boundary representation in cadastres and the impact for the users of the systems.

There are seven points that were used to analyse the case studies as a collective group and how it applies to the three categories of cadastre users.

The evaluation questions are:

1. Is the Deposited Plan/Strata Plan suitable for quick identification and assessment of the lot location?
2. Does the model improve the ability to identify and assess?
3. Is the accuracy of the model 'fit for purpose'?
4. Does the inclusion of the lot allow better access to the relevant metadata for the lot?
5. How does the creation of an additional format impact the time, and therefore cost, requirements for the subdivision?
6. Does the model represent the physical land parcel location and how well does this demonstrate the physical attributes onsite?
7. What benefits does the model add to a digital cadastre for the end-user?

3.4 Case Studies

The decision was made to use three stratum subdivisions and then follow on with the further strata subdivision of one of the case studies. Each case study was chosen to represent a particular area of development as identified as being typical within the Greater Sydney area.

These include:

1. Low-rise development zoned as mixed use and incorporating residential and commercial components of the development and subsequent subdivision.
2. High-rise development, again zoned as mixed use containing residential and commercial and located in an existing suburb undertaking urban infill.
3. Combined low-rise and high-rise development in a new suburb as part of a planned community development and containing multiple uses including residential and retail, same as the previous two case studies, but also containing council infrastructure and public access roads.
4. The strata subdivision of the stratum subdivision from the first case study to investigate the application of 3D visualisation on the final subdivision format of the majority of apartment developments.

The case studies are outlined in the following and are then explored in more detail in Chapter 4.

3.4.1 Case Study 1: Wentworth Point

This site is located in the new suburb of Wentworth Point in the Inner West of Sydney. It is situated on the western foreshore of Homebush Bay and was previously an industrial estate now being reclaimed for high density living. The portion of this suburb that will be the focus of the study is a site on the north end of Hill Road. The site cover approximately 9 hectares and it being developed as a community title comprised of multiple apartment dwelling towers, roads with public access and amenities including a school, shops and a library.

This site is a particularly challenging in stratum subdivision. Basement car parking is located under the majority of the site, including being situated below roads used for public access. Earlier in 2016 Bennelong Bridge across Homebush Bay was constructed to connect Wentworth Point to Rhodes on the eastern foreshore. This was subdivided into its own lot and a portion converted into the road lot of the community plan and a section dedicated to the Roads and Maritime Services. Due to the size of this development, a portion of the site was used for the purposes of this research project being the bridge connection, adjoining high-rise and low-rise buildings and the relationship of the public access roads to the basements. The investigated portion includes one road lot, compiled of five individual lots, one residential lot, one retail lot and three multi-use lots to be dedicated to the local government area.

Figure 3.2 Multi-view aerial photograph of the mixed use development at Wentworth Point (NearMap 2014c).

3.4.2 Case Study 2: Eastwood

This site is located centrally in Eastwood located in the Northern Suburbs of Sydney and is situated in an area consisting of mixed use residential and retail along Rowe Street and high density residential along First Avenue.

The finished development has a mix of four, five and six storey buildings and three levels of basement parking. The subdivision contains three stratum lots which are based on usage, with two residential lots and one retail lot. These three lots were then further subdivided into strata lots with the stratum subdivision becoming the base plan.

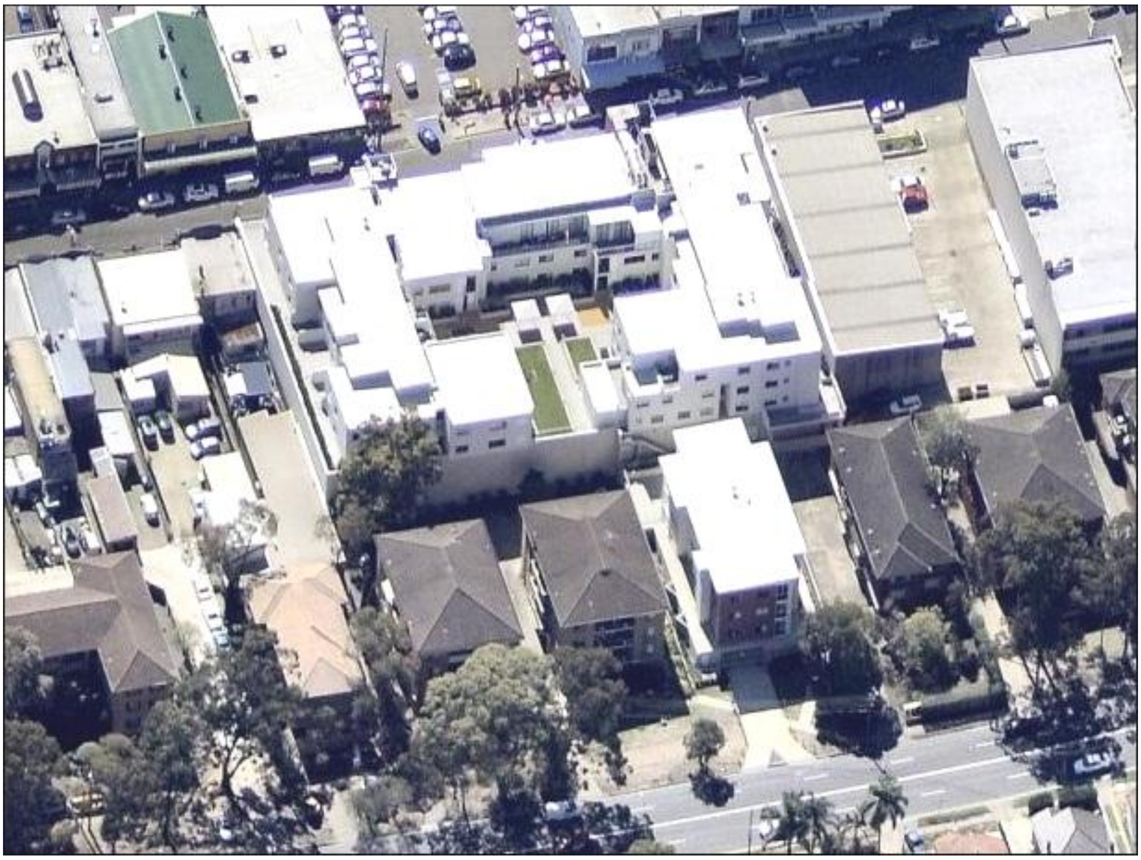

Figure 3.3 Multi-view aerial photograph of the mixed use development between Rowe Street and First Avenue (NearMap 2014b).

3.4.3 Case Study 3: Burwood

This site is located centrally in Burwood in the Inner West of Sydney. Similarly to the previous case studies it falls with mixed use zoning and in this scenario is located one street block from the main street precinct and opposite the Burwood railway station.

This development consists of twenty-five stories and four levels of basement parking. The subdivision contains eleven lots; one retail, nine commercial and one residential. The residential lot, retail lot and four commercial lots have been further subdivided in strata schemes.

Figure 3.4 Multi-view aerial photograph of the mixed use development on Deane Street (NearMap 2014a).

This case study will then be taken to the next stage and investigate the application of the modelling process on the strata subdivision undertaken on four of the stratum lots. Out of the eleven stratum lots, five have been further subdivided under a strata scheme. These include the retail lot, three commercial lots and the residential lot. For the purposes of the case study the residential strata will not be modelled due to time limitations but the other four strata plans will demonstrate the interactions between the two methods of subdivision.

3.5 Conclusions

This chapter outlines the methodology devised to analyse the case studies and the choices made regarding the software for the research project. There is a large range of available software used in surveying but they primarily fulfil the fame functions so the decision to use familiar software packages will aid in the effectiveness and time management of the research.

The other outcome of this chapter is the identification of the target users of digital cadastres and the development of the evaluation criteria. The criteria will be utilised in Chapter 5 for the analysis and evaluation of the case studies and establishing outcomes for the research project.

Chapter 4 Case Studies and Modelling

4.1 Case Study 1: Wentworth Point

4.1.1 Site Description

The development site at Wentworth point is a community title plan covering approximately 9 hectares. It consists of seven individual development sites that form the staging of construction along with a network of roads (see *Figure 4.1*). For the purposes of the case study Block B, the creation of Wentworth Place and the extension of Footbridge Boulevard and Half Street will form the focus. At this stage Block A, Block D and Block G are finished buildings and Block C, Block E and Block H are still in the planning and construction stages.

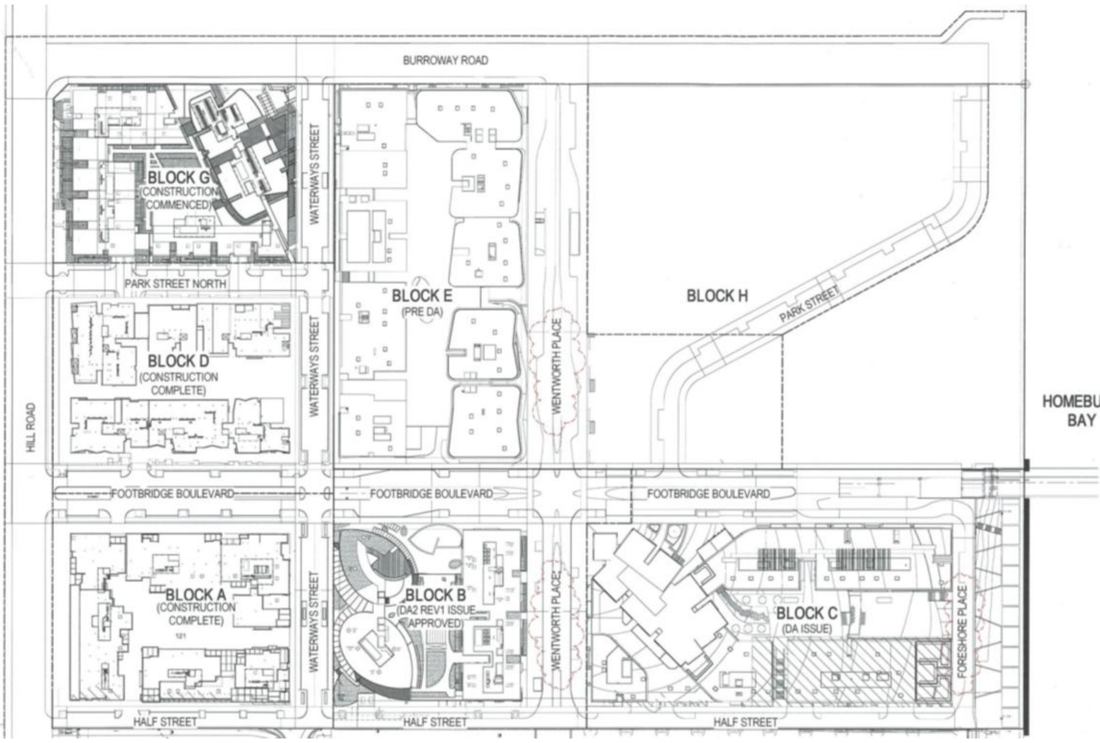

Figure 4.1 Site layout of the development site at Wentworth Point (Scott Carver Architects 2016).

The building consists of a twenty five storey tower and a eight storey tower and these two building are then joined at level 3 and below. There is basement parking under the entire site and roads around the perimeter. The components of each lot in the subdivision are described below in *Table 4.1*.

Land Parcel	**Description**	**Includes**
Lot 15	Road	• Portion of Wentworth Place above Block C
Lot 20	Road	• Portion of Footbridge Boulevard above Block B.
Lot 21	Road	• Portion of Footbridge Boulevard above Block C.
Lot 23	Road	• Portion of Footbridge Boulevard above Block C that includes bridge abutment and will be transferred to Roads and Maritime Services.
Lot 25	Residential	• Car-parking and storage cages on Basement 2 • Car-parking and storage cages on Basement 1 • Lobbies and high-rise apartments on Level 1 • Building manager's room on the Mezzanine • High-rise and low-rise apartments on Level 2 • High-rise and low-rise apartments and podium garden on Level 3 • High-rise and low-rise apartments on Level 4 and above (high-rise to Level 25 and low-rise to level 8)
Lot 26	Retail	• Grease arrester on Basement 2 • Car-parking, storage cages, grease arrester, lift and waste storage on Basement 1 • Retail space with street frontage and access to the mezzanine on Level 1 • Building manager's room on the Mezzanine
Lot 27	Library	• Car-parking on Basement 1 • Library and waste storage room on Level 1 • Library on Level 2 • Skylight and space above on Level 3 and above
Lot 28	Plaza	• Lift on Basement 2 • Lift on Basement 1 • Public open space on Level 1 • Space above plaza on Level 2 • Space above lift on Level 3 and above
Lot 29	Road	• Extension of Half Street, creation of Wentworth Place and bus stop on Footbridge Boulevard on Level 1

Table 4.1 Stratum subdivision of the subject land being Block B, Block C and Footbridge Boulevard at Wentworth Point.

As seen in *Table 4.1* all levels contain at three or more lots and therefore all levels area shown on the stratum subdivision up to Level 3 and the definition at Level 3 then applies to all levels above and has the heights defined as unlimited. Similarly Basement 2 has the depths defined as unlimited.

The stratum lots are further subdivided under individual strata schemes:

- Lot 25 - 55 residential apartments;
- Lot 26 - 6 retail units.

The construction of the road is suspended above residential basements. In Block B, the road and basement were completed at the same time and have connected into existing roads at Half Street and Footbridge Boulevard. The extension of Footbridge Boulevard spanning the north-east portion of Block C is raised bridge on concrete pylons. This means that Block C is limited in height to the underside of the road boundary for this portion of the land and at this stage Block C is currently under construction so the basement will be built up to meet the existing structure. Footbridge Boulevard then continues east across Homebush Bay to connected Wentworth Point and Rhodes. The bridge is maintained by Roads and Maritime Services.

The road lots are subdivided from the development site and then consolidated into Lot 1 of the community plan. This conversion plan replaces the sheet series of the previous conversion plan. In the portion of the site modelled the road lot consists of the previous Lots 15, 20, 21 and 29, now known as part of Lot 1. These four lots were subdivided at different stages and development applications.

As the subject land is a community title plan, all road lots are created with an easement for public access over the road reserve benefiting the local government area and allowing for public access and parking along these roads. This effectively creates public roads despite being private property and maintenance falls with the community association. For the general public there is no discernible difference in the use of the roads within the area compared to a traditional subdivision.

The area around Wentworth Point is reclaimed land along Homebush Bay and due to the proximity with the waterfront the development is built from the surface level compared to traditional excavation. This means the Basement 2 is effectively ground level and the majority of roads are built at Level 1 and slope down to join the existing roads, Hill Road and Burroway Road, and the waterfront along Homebush Bay.

The decision to use raised roads for the design is due to a combination of reasons. Site specific limitations due to the proximity of Homebush Bay, shown by the lowest floor level in Block B is RL1.50 AHD, would result in high costs if traditional excavated basements were constructed. The raised roads also allow for expanded basement parking to meet development application conditions of a minimum of one car space per strata lot and improve the value of some unit through offering additional car spaces.

The residential, retail and library lots of the subdivision contain components on multiple levels with the main unit areas on level 1 and above combined with car parking in the basements. Due to the car park allocations, this results in the individual components of the lots not being vertically adjoining and can been seen in the *Figure C.5* (see *Appendix C*) for the breakup of the retail lot. The other three lots in the subdivision include the road, plaza and library lift and these do not require car parking in the basement levels.

Following the stratum subdivision the residential and the retail lots will be further subdivided as strata and the library and plaza are will be removed from the community plan and ownership transferred to Parramatta City Council. The retail lot, being Lot 26 in Deposited Plan 270778, will be further subdivided into five retail units and a building managers unit and the residential lot, being Lot 25 in Deposited Plan 270778, contains 451 apartments in the final subdivision. This further subdivision of both lots will be completed under a strata scheme and the fieldwork and plans have been completed at this stage but are still pending on the registration of the stratum plan.

The original concept for Block B considered two lots, separating the high-rise and low-rise into individual lots and strata plans. While this was later amended into one residential lot due to site completion dates the original proposal offered benefits to the development. Firstly this allowed for the total number of participants in the strata schemes to be reduce allowing for simpler owners corporations and management logistics.

The complexity of stratum subdivision and further strata schemes results in a number of involved parties in the management and logistics of the building. These are shown below in *Table 4.2*.

<table>
<tr><td colspan="2">Community Association
- responsible for the management of all land in Deposited Plan 1177634</td><td rowspan="3">Parramatta City Council
(Auburn City Council prior to merger, now Parramatta City Council)
- responsible for the library and plaza
- the beneficiaries of the right for public access over the roads in Lot 1
- operates in conjunction with the Community Association and Building Managements Scheme.

Roads and Maritime Services
- responsible for Lot 23 on the bridge which contains the abutment before the bridge span across Homebush Bay</td></tr>
<tr><td colspan="2">Building Management Scheme (Block B)
- responsible for the lots that occupy the building of Block B and area shown in sheets 53-80 of Deposited Plan 1177634</td></tr>
<tr><td>Owners Corporation (Residential)
- Lot 25
- responsible for the management of the residential strata subdivision</td><td>Owners Corporation (Retail) - Lot 26
- responsible for the management of the retail strata subdivision</td></tr>
</table>

Table 4.2 Hierarchy of management schemes involved at Wentworth Point

Due to the complexity of the Block B subdivision, survey plan outlining the boundary definition is a large plan. The subdivision of Footbridge Boulevard is 22 pages and the subdivision of Block B is 28 pages. These are sections are added to the community plan, Deposited Plan 270778, as additional pages and at the completion of Block B the community plan is 80 pages. See *Appendix C* for the relevant sections of Deposited Plan 270778.

4.1.2 Data Models

The modelling process utilised the methodology outlined in Chapter 3 with each lot within the subdivision created as an independent component with layer control added. this provides the end-user with the ability to isolate or retrieve spatial queries for a particular lot. Below *Figure 4.2* and *Figure 4.3* show the final wireframe model for this case study, with the former comprising of the entire case study area and the latter without the bridge component to allow a closer view of the detail within the Block B development site. *Figure 4.4* and *Figure 4.5* demonstrate the models within the working environment of Google Earth.

Refer to *Appendix B* for full set of model drawings for Case Study 1.

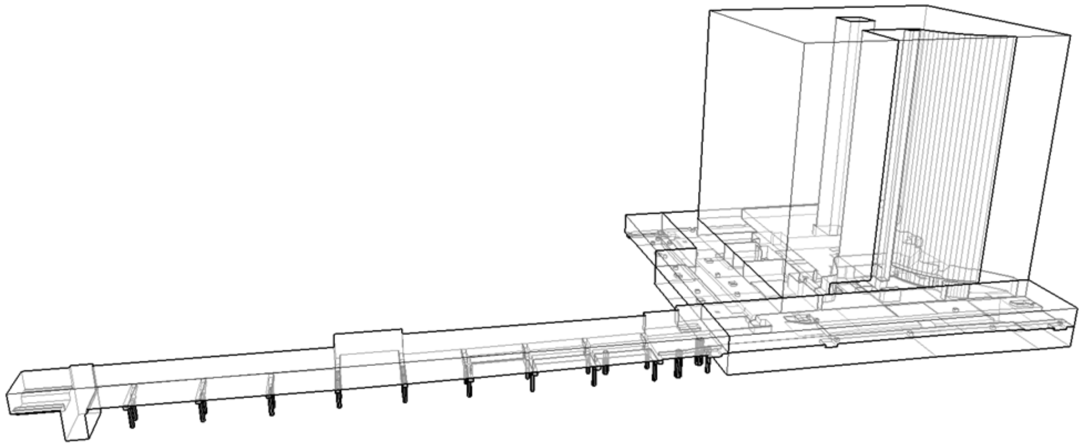

Figure 4.2 Wireframe model of the stratum lots including the bridge.

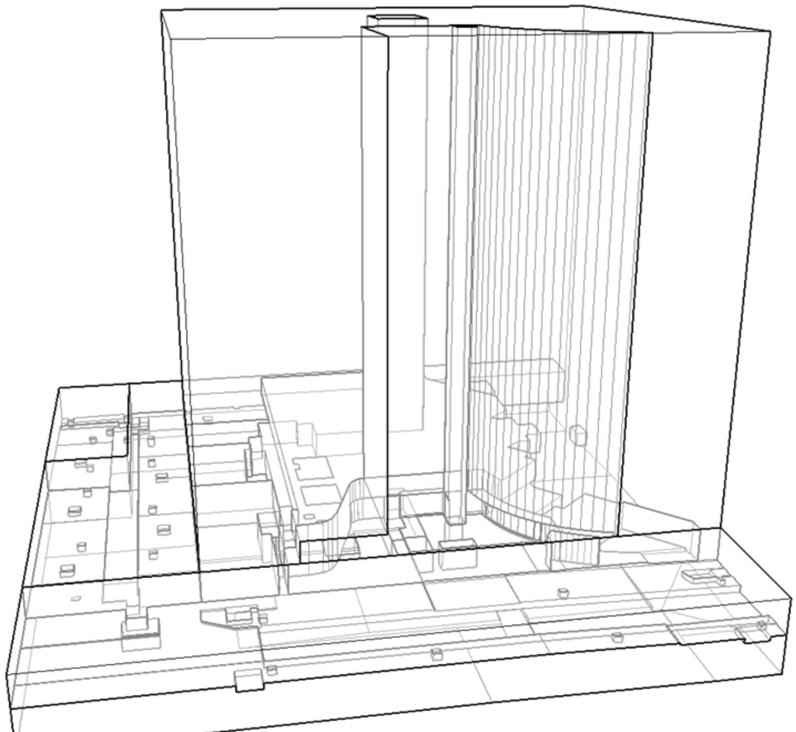

Figure 4.3 Wireframe model of the stratum lots excluding the bridge.

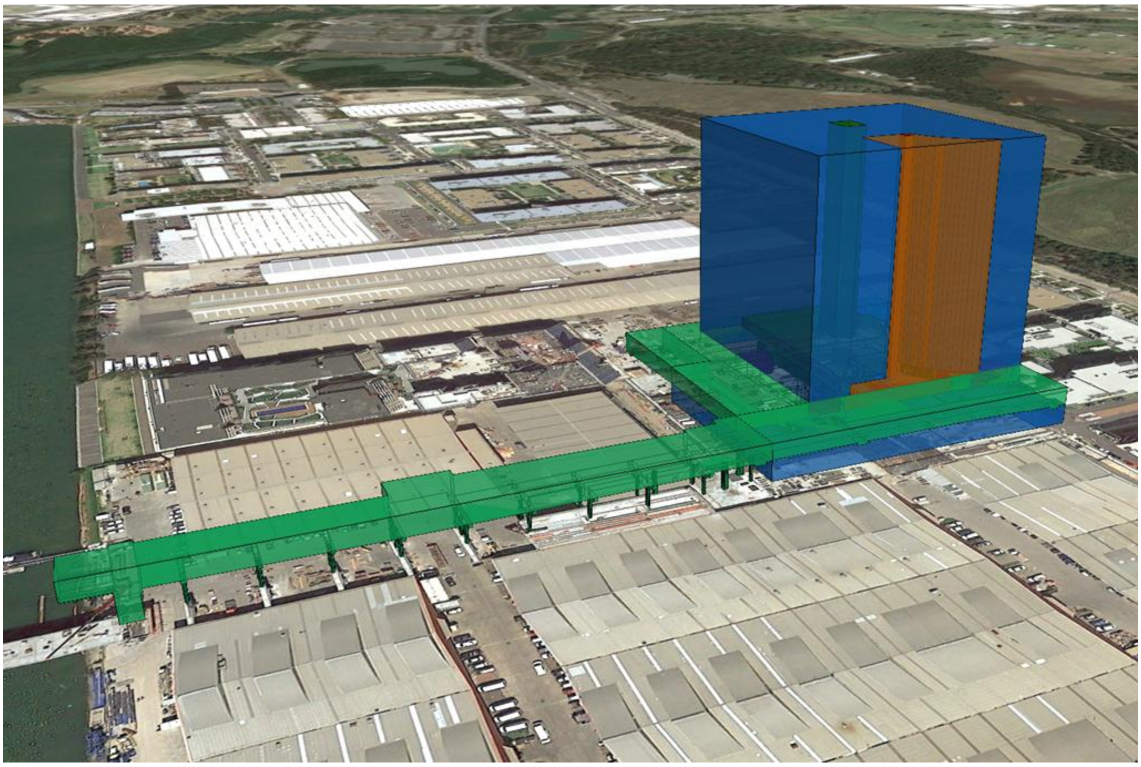

Figure 4.4 Presentation of the stratum model in Google Earth including the bridge.

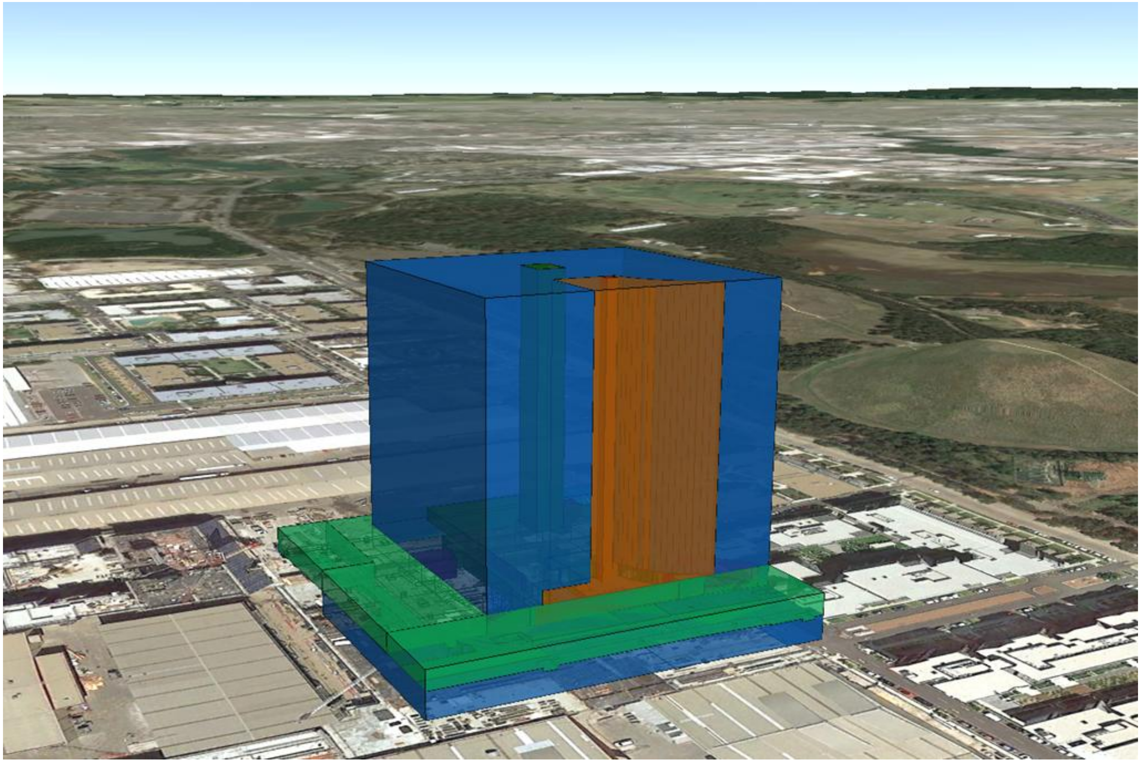

Figure 4.5 Presentation of the stratum model in Google Earth excluding the bridge.

4.1.3 Limitations

The first noticeable difference between the 3D models and survey plan is the application of the outer vertical restrictions. As discussed in Chapter 2 the height limitations of a non-stratum Torrens title are in regards to reasonable and expected use. This definition of land ownership is then adjusted for a stratum subdivisions. The lowest and highest parcels allow for the unlimited aspect demonstrated in standard land parcels but the intermediate lots are then restricted based on a height definition on AHD. This can clearly be seen in Deposited Plan 270778 (see *Appendix C*) with the limitations at Basement 2 and Level 3 being unlimited in depth and height respectively. In the creation of the model representing the land parcels, the inclusion of the unlimited elements in unfeasible in plotting the model however the scope of the model is not to replace the survey plan but provide a digital representation for database purposes. This means that the unlimited nature of the parcel is less relevant that the physical space the building itself occupies. For the purposes of the case studies, and the following two case studies, the lower limit of the model is represented by the lowest floor level in the basement and the upper limit by the roof level. These levels allow the models to provide an overall view of the total cubic space the lots fill within their usable limits.

Due to the lot layout and dominance of the residential lot, many of the smaller parcels in the basements do not have a clear distinction when the whole model is visible. Layer control within the digital model improves this aspect and allows the isolation of an individual parcel. For example in Case Study 1 Lot 25 is the dominant portion when the model is viewed in its entirety as seen in *Figure 4.d* and the location and shape of the smaller lots is obscured. However through layer control in Google Earth, Lot 25 can be turned off allowing the relationship of the other land parcels to be seen clearer.

Another issue with modelling surfaces in Google Earth is the lack of support for curved surfaces. In Case Study 1, part of the arced face of the high-rise towers adjoins the community plaza. As a result there is a boundary line along the facade of the building and on the survey plan this is defined using an arc. However in the modelling process this was not able to be replicated true to its shape but a visual representation of the arc was achieved for the model by breaking the arc into short chords and creating the surface with a series of flat planes.. Therefore the surface is not an accurate representation of the original boundary but in the 3D visualisation is visually appears similar with viewed in the digital cadastre.

The issues arising from the modelling process as a whole will be discussed further in Chapter 5.

4.1.4 Conclusions

The development at Wentworth Point demonstrates a complex community with the mixed use zoning being used for a multitude of functions. The concept of the development is to create a community with all the facilities required so along with the standard high-rise apartments there are retail spaces, a shopping centre and a library. The development demonstrates the need for stratum subdivision due to the mixed-use nature of the building and the respective interactions with the surrounding community title plan.

Further planned development at Wentworth Point is listed below and each of these development sites will be subdivided into stratum lots followed by a strata subdivision in the same format as Block B:

- Block C - a four lot stratum subdivision including two residential lots, a retail lot and a road load followed by three strata subdivision including 431 residential apartments, 272 residential apartments and 6 retail units.
- Block E - a six lot stratum subdivision including two residential lots, two commercial lots, a town square lot and a road lot followed by two strata subdivisions including 398 residential apartments and 445 residential apartments.
- Block H - still in the design stage but an estimated 1000 residential apartments and shopping centre with retail space.

The modelling process for Case Study 1 demonstrated a significant improvement in the visualisation of the spatial data when comparing the models, as seen in *Appendix B*, to the original survey plan, as seen in *Appendix C*. This is due to the complexity of this subdivision, the features of the overall community subdivision including the bridge and roads and the nature of the building layout in Block B.

4.2 Case Study 2: Eastwood

4.2.1 Site Description

The development site at Eastwood has an area 4326m^2 and frontage onto two streets, Rowe Street and First Avenue. The land along Rowe Street is forms part of the main street and commercial precinct of Eastwood while First Avenue consists of low-rise residential unit developments. The area's zoning is mixed-use.

The development consists of a five and six storey complex fronting Rowe Street and a four story building fronting First Avenue along with basement car parking under the entire site. The components of each lot in the subdivision are described below in *Table 4.3*.

Land Parcel	**Description**	**Includes**
Lot 1	Residential (Rowe Street)	• Car-parking and storage cages on Basement 3 • Stairs and Lift on Basement 2 • Stairs and Lift on Basement 1 • Stairs and Lift on Basement 1 • Stairs and Lift on Level 1 • Stairs and Lift on Level 2 • Apartments on Level 3
Lot 2	Commercial	• Car-parking and storage cages on Basement 3 • Grease arrester on Basement 3 • Car-parking and storage cages on Basement 2 • Car-parking and storage cages on Basement 1 • Retail/commercial space on Level 1 • Retail/commercial space on Level 2
Lot 3	Residential (First Avenue)	• Car-parking and storage cages on Level 1 • Apartments on Level 2 • Apartments on Level 3

Table 4.3 Stratum subdivision of the subject land at Eastwood.

The stratum lots are further subdivided under individual strata schemes:

- Lot 1 - 55 residential apartments;
- Lot 2 - 47 retail/commercial units including one large shop space for Aldi;
- Lot 3 - 12 residential apartments.

The hierarchy of involved parties for this case study is simpler than Case Study 2 and is shown below in *Table 4.4*.

<table>
<tr><td colspan="3" align="center"><u>Building Management Scheme</u>
- responsible for the lots that occupy the building</td></tr>
<tr><td align="center"><u>Owners Corporation (Residential - Rowe Street)</u>
- Lot 1
- responsible for the management of the residential strata subdivision</td><td align="center"><u>Owners Corporation (Retail)</u>
- Lot 2
- responsible for the management of the retail strata subdivision</td><td align="center"><u>Owners Corporation (Residential - First Street)</u>
- Lot 3
- responsible for the management of the residential strata subdivision</td></tr>
</table>

Table 4.4 Hierarchy of management schemes involved at Eastwood.

The subdivision at Eastwood is a simpler lot layout compared to Case Study 1. There are only three land parcels and the boundary lines follow floor levels and regular building areas. The survey plan for this case study is 10 pages. See *Appendix C* for Deposited Plan 1177634.

4.2.2 Data Models

The data models were completed in the same format as Case Study 1. *Figure 4.6* demonstrates the wireframe model of the three lots within the development and *Figure 4.7* demonstrates the model within the working environment of Google Earth.

Refer to *Appendix B* for full set of model drawings for Case Study 2.

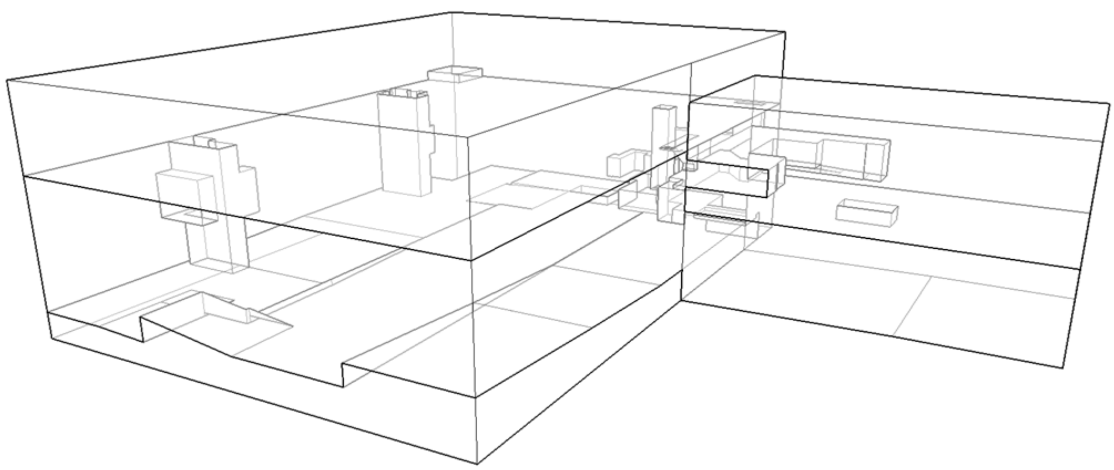

Figure 4.6 Wireframe model of the three stratum lots.

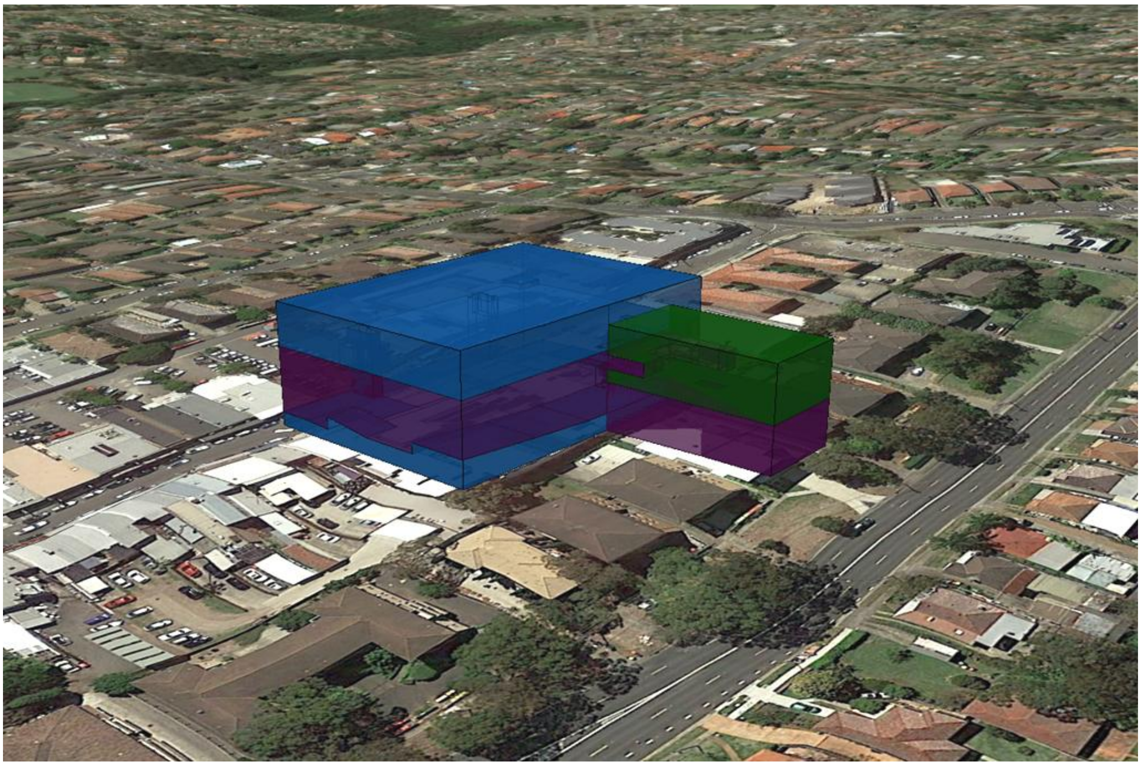

Figure 4.7 Presentation of the stratum model in Google Earth.

4.2.3 Limitations

The same height limitations apply as discussed in Case Study 1.

For this case study the lot domination aspect from Case Study 1 with many of the divisions between the land parcels being on a floor based boundary. The exemption to this is the lift and stairwell cores for Lot 1 which exist within the main area of Lot 2. These can be seen in the wireframe model and within Google Earth the layer control allows their location to be visualised.

This subdivision consisted of straight stratum limit boundaries that for the majority of the site are parallel or perpendicular and due to the nature of the subdivision many components encompassed a large 2D portion of the available land. Therefore the modelling for this site was more focussed on the vertical boundary definition between floors than the horizontal limitations of individual components being subdivided out as demonstrated in Case Study 1.

The issues arising from the modelling process as a whole will be discussed further in Chapter 5.

4.2.4 Conclusions

The development analysed for this case study is an example of a simple form stratum subdivision. The boundaries between lots are typically between levels or surrounding access routes for upper levels. The two residential lots are distinct and separate buildings with their own parking and street access which has lead to the decision to split into two individual lots, followed by individual strata plans. This decision is one of geographical separation rather than move towards reducing the number of units in the strata plans.

In this case study, the survey plan is not significantly complex in the boundary definition, especially compared to the other two case studies, but is still 10 pages and requires knowledge of both survey principles and building features of the development to understand the position and relationship of the individual lots. For the non-surveying end-use of the plan this detail is better represented through the 3D models than the survey plan.

4.3 Case Study 3: Burwood

4.3.1 Site Description

The development site at Burwood has an area of 2067m^2 and has a frontage to roads on three sides and the final frontage of the land is to a private lot with a five storey existing building. It is located one street block from the main retail area of Burwood, is opposite the Burwood train station and within walking distance of the Burwood Westfield Shopping Centre. The area is zoned as mixed used and the suburb is undergoing a massive shift in high density development and utilisation of the streetscape for retail and commercial purposes.

Figure 4.8 Rendering of the external layout of the development at Burwood (Urban Link Architecture 2012).

The development consists of a twenty five storey complex on the corner between Deane Street, Mary Street and George Street and four levels of basement parking. The components of each lot in the subdivision are described below in *Table 4.5*.

Land Parcel	Description	Includes
Lot 1	Retail	• Car-parking and storage cages on Basement 2 • Car-parking and storage cages on Basement 1 • Retail space on Lower and Upper Ground
Lots 2 - 10	Commercial	• Stairs and lift on Basement 4 • Stairs and lift on Basement 3 • Car-parking and storage cages on Basement 2 • Car-parking and storage cages on Basement 1 • Commercial space and lift on Levels 2 to Level 10 • Lift on Level 11
Lot 11	Residential	• Car-parking and storage cages on Basement 4 • Car-parking and storage cages on Basement 3 • Driveway, stairs and lift on Basement 2 • Driveway, stairs and lift on Basement 2 • Lobby, stairs and lift on Lower and Upper Ground • Stairs and lift on Level 1 to Level 10 • Apartments on Level 11 and above

Table 4.5 Stratum subdivision of the subject land at Burwood.

The stratum lots are further subdivided under individual strata schemes:

- Lot 1 - 21 retail units;
- Lot 2 - 3 commercial units;
- Lot 5 - 10 commercial units;
- Lot 6 - 10 commercial units;
- Lot 11 -130 residential apartments.

The hierarchy of involved parties for this case study is simpler than Case Study 3 and is shown below in *Table 4.6*.

<table>
<tr><td colspan="6">Building Management Scheme
- responsible for the lots that occupy the building</td></tr>
<tr><td colspan="2">Owners Corporation (Retail)
- Lot 1
- responsible for the management of the retail strata subdivision</td><td colspan="2">Owners Corporation (Commercial)
- Lot 2
- responsible for the management of the commercial strata subdivision</td><td colspan="2">Owner (Commercial)
- Lot 3
- owner of individual lot</td></tr>
<tr><td colspan="2">Owner (Commercial)
- Lot 4
- owner of individual lot</td><td colspan="2">Owners Corporation (Commercial)
- Lot 5
- responsible for the management of the commercial strata subdivision</td><td colspan="2">Owners Corporation (Commercial)
- Lot 6
- responsible for the management of the commercial strata subdivision</td></tr>
<tr><td colspan="2">Owner (Commercial)
- Lot 7
- owner of individual lot</td><td colspan="2">Owner (Commercial)
- Lot 8
- owner of individual lot</td><td colspan="2">Owner (Commercial)
- Lot 9
- owner of individual lot</td></tr>
<tr><td colspan="3">Owner (Commercial)
- Lot 10
- owner of individual lot</td><td colspan="3">Owners Corporation (Residential)
- Lot 11
- responsible for the management of the residential strata subdivision</td></tr>
</table>

Table 4.6 Hierarchy of management schemes involved in Burwood.

The subdivision at Burwood is a simple stratum for Levels 1 and above as the entire floor is an entire lot except the lift and stairwell cores however the details for the ground floor and basements have some complex components. The survey plan for this case study is 21 pages. See *Appendix C* for Deposited Plan 1197996.

4.3.2 Data Models

The data models were completed in the same format as the previous two case studies. *Figure 4.9* demonstrates the wireframe model of the three lots within the development. This case study also introduced strata schemes into the modelling and *Figure 4.10* demonstrates the wireframe model with four of the strata subdivision superseding the stratum lots. *Figure 4.11* and *Figure 4.12* demonstrate both the original stratum subdivision and the stratum/strata subdivision models within Google Earth.

Refer to *Appendix B* for full set of model drawings for Case Study 3.

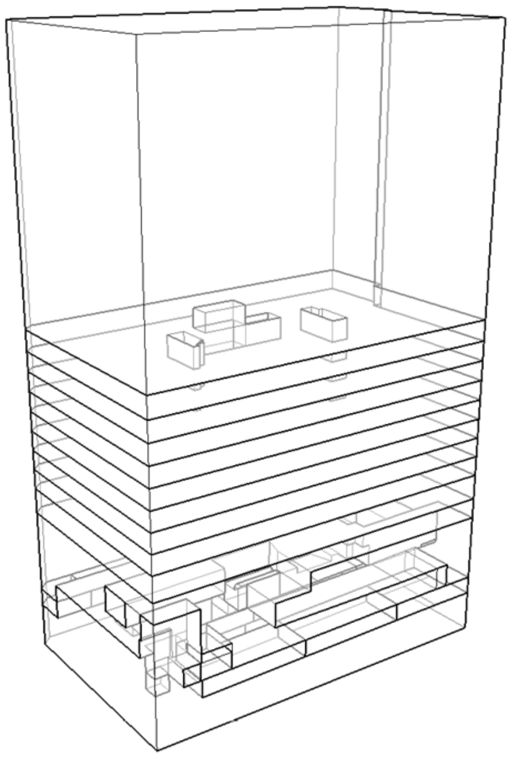

Figure 4.9 Wireframe model of the eleven stratum lots.

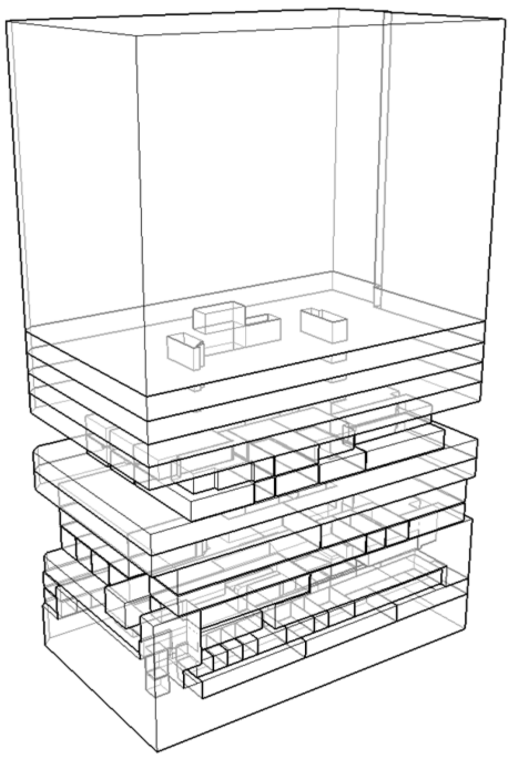

Figure 4.10 Wireframe model of the seven stratum lots and four strata subdivisions.

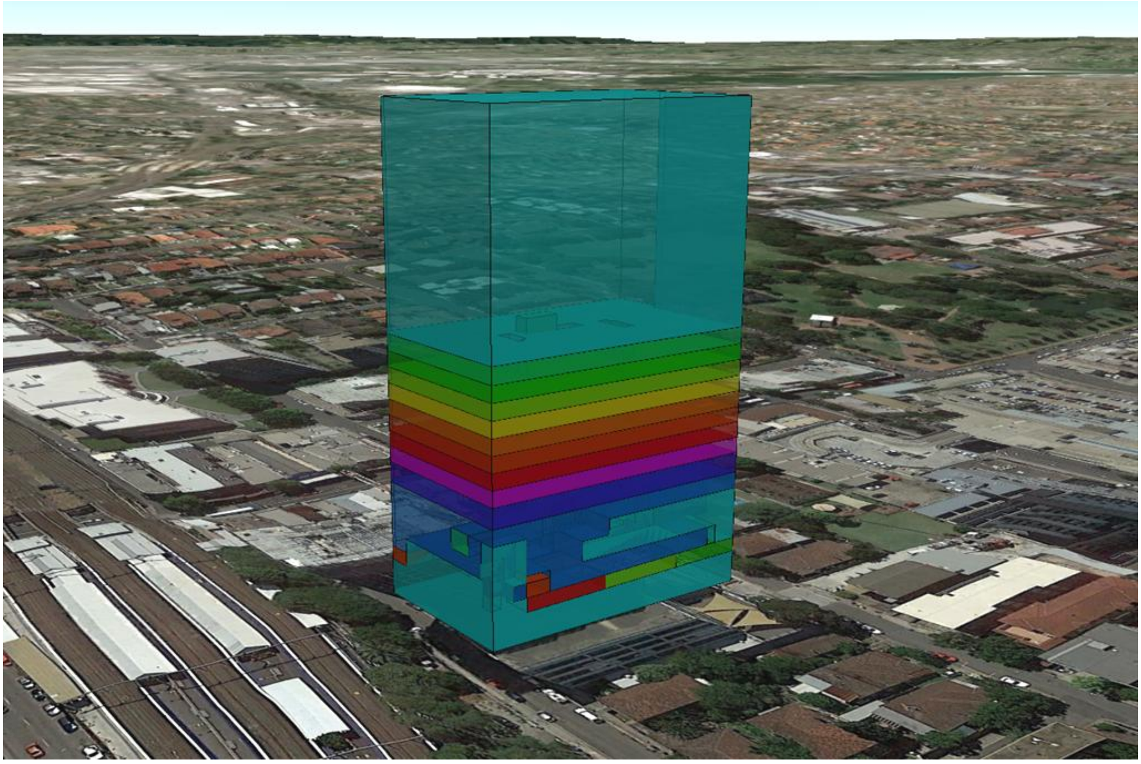

Figure 4.11 Presentation of the stratum model in Google Earth.

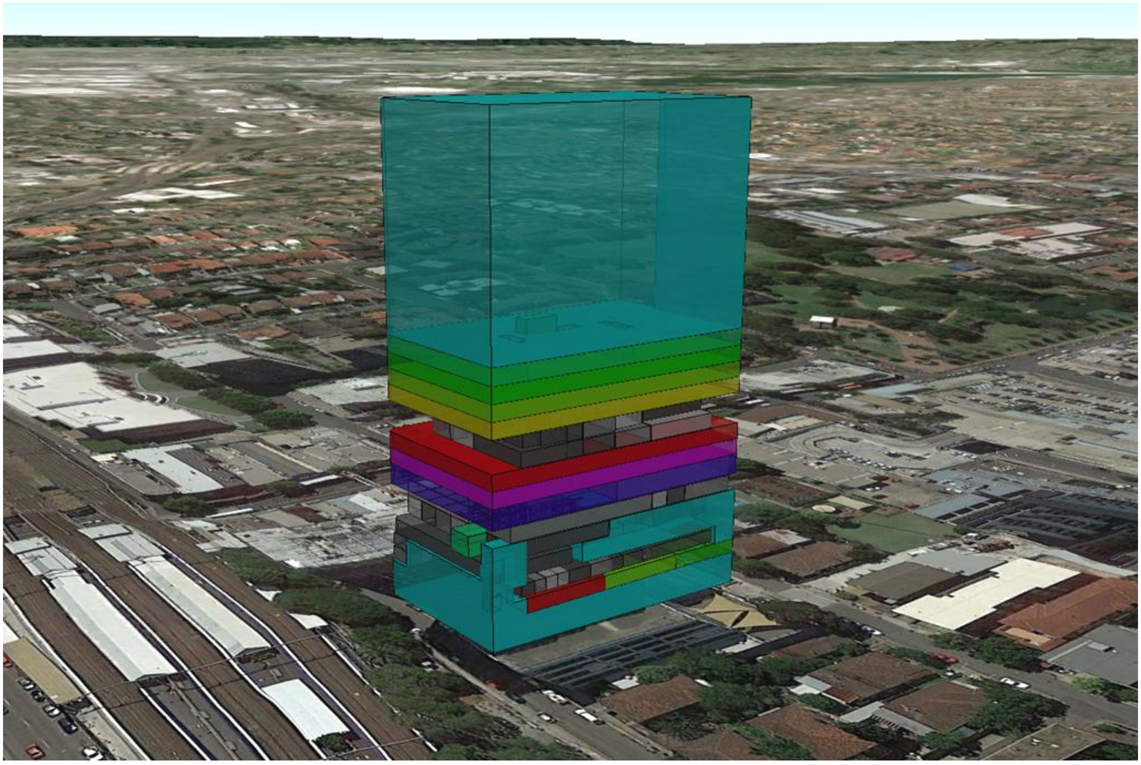

Figure 4.12 Presentation of the stratum and strata model in Google Earth.

4.3.3 Limitations

For the stratum component this case study demonstrated the same limitations as the two previous case studies.

The strata component of this case study however introduced some new limitations on the modelling. Firstly, strata plans in New South Wales area structure based. Lots are either defined by structures denoted by thick lines or dimensioned thin lines that are referenced from structures. As a result units contained completely within a structure have no dimensions on the plan and the defining aspect of the lot is the area on the plan. Therefore to create the model the original survey CAD file is required and while these plans are drawn to scale drafting differences are not always survey accurate for the line work within the CAD file as the strata plan is drawn from architectural rather than from survey accurate location of the building. These variations do not affect the strata plan as the definition is from structures and the area but made the modelling process complication when trying to merge strata lot positions within the stratum lot. The basement car spaces however are based on survey position of columns and walls and dimensioned due to the lack of structural features surrounding the area and were simpler to merge with the stratum lot data.

The other issue with the strata modelling was the lack of definition for common property. Common property covers all components of the building not allocated to a lot and also encompasses all structural elements including the external walls, floor and ceiling of a lot compared to stratum lot boundaries that typically are within the floor slab or along the centreline of walls. This results in gaps in the model, i.e. walls between units and gaps between the stratum and the strata vertical limits. For strata modelling the process would be unnecessary to incorporate all common property elements but the model could provide an additional element for Building Information Models as a cadastral layer to complement the other building infrastructure data.

The issues arising from the modelling process as a whole will be discussed further in Chapter 5.

4.3.4 Conclusions

The development at Burwood contains a larger number of stratum lots compared to the previous two case studies however the stratum subdivision was relatively simple due to the building layout and lot distribution. The decision to separate the commercial lots by stratum rather than strata was a commercial decision that allowed for buyers to choose how they utilise the floor of the building they purchased. As seen through the strata modelling four of the commercial and retail stratum lots have been subdivided under a strata scheme at this stage and the rest remain as one lot.

This case study represents a simple high lot stratum subdivision and this presents well in the Google Earth visualisation. The choice to include strata lots within the model also adds an additional component of spatial data available and through the use of layer control and end-user can isolate the strata plan and its base stratum lot. This provides end-users with control over the models and allows them to analyse the components that are relevant for their spatial queries. Overall the model for this case study would improve the end-users ability to understand the multi-layer schemes that operate within the one building complex/

4.4 Conclusions

Overall the case studies demonstrate the nature of stratum and strata subdivision in a 3D format and highlight the complexity of the lot relationships in a clearer manner than the original survey plans. The modelling process for this case study demonstrated that there was a significant improvement in the understanding of the subdivision and the relationship between the lots and was specifically noted in this case study due to the complexity of the building layout and lot distribution. It can be clearly seen that the models, as seen in *Appendix B*, would improve the understanding for the end-user compared to the original survey plan, as seen in *Appendix C*. This is likely to be more prominent with non-surveying end-users who may not have the technical skills and cadastral understanding to interpret complex stratum plans.

Chapter 5 Results

5.1 Evaluation

The following evaluation criteria was developed in Chapter 3 and will be applied for the case studies to the three categories of end-users: surveying professionals, non-surveying professionals and general public.

1. Is the Deposited Plan/Strata Plan suitable for quick identification and assessment of the lot location?
2. Does the model improve the ability to identify and assess?
3. Is the accuracy of the model 'fit for purpose'?
4. Does the inclusion of the lot allow better access to the relevant metadata for the lot?
5. How does the creation of an additional format impact the time, and therefore cost, requirements for the subdivision?
6. Does the model represent the physical land parcel location and how well does this demonstrate the physical attributes onsite?
7. What benefits does the model add to a digital cadastre for the end-user?

In *Table 5.1* and *Table 5.2* these questions are addressed in relation to the case studies for both the stratum and the strata subdivision. The case studies were considered as a collective group as many questions result in the same answer and the division between the improvements to current plan formats was not dependant on the site analysed by the original subdivision method. Hence the strata subdivisions are evaluated separately to the stratum subdivisions.

Criteria	Surveying Professionals	Non-Surveying Professionals	General Public
1	• Identification is not quick but has the skill set to understand the plan format.	• Depends on their level of survey knowledge, most case not suitable for lot identification.	• Not a suitable plan for general public to identify the lot location.
2	• Yes, provides spatial perspective to the subdivision.	• Yes, provides spatial perspective to the subdivision and allows an understanding of the relationship of the land parcels..	
3	• Yes, only digital cadastre maps are not survey accurate but are used as tools to understand survey plans.	• Yes, for this category if accurate survey work is required then a registered surveyor is sought.	
4	• The presence of individual lots within the model allow for better allocation of metadata and the ability to search for land parcels based on attributes such as title reference or street address.		
5	• Yes, it does impact time but depending on the scope of work the client may prefer the additional work.	• Yes, but for developers and other clients the additional cost may be beneficial improving communication.	• The impact is at client level but the improvement of registration times give a better use of government funds.
6	• Represents the boundary position, doesn't show the building shape. However has the potential to be combined with Building Information Models as a cadastral layer and be merged with models of the physical building and infrastructure.		
7	• Data validation, faster registration process, clearer instructions from clients.	• Easier spatial queries, visualisation of the plan, simpler format for those not familiar with survey plan formats.	

Table 5.1 Evaluation criteria for the stratum subdivision case studies.

Criteria	Surveying Professionals	Non-Surveying Professionals	General Public
1	• Yes, easy to follow with the combination of location plans and floor plans.	• Yes, the location plan demonstrates the footprint shape of the building and the floor plans typically show common property, i.e. hallways, lifts and stairs, making it easier to identify lot locations.	
2	• Not significantly in relation to building position and common property., the currently plan format is structure and floor level based and easy to identify. • However, the ability to identify and locate parts of lots that are separate on the plan i.e. unit, car space and storage cage.		
3	• Yes, only digital cadastre maps are not survey accurate but are used as tools to understand survey plans.	• Yes, for this category if accurate survey work is required then a registered surveyor is sought.	
4	• Currently the digital cadastral maps only show the overall strata plan, so individual metadata is not attached to the lot but instead a spreadsheet attached to the strata plan itself. The presence of individual lots within the model allow for better allocation of metadata and the ability to search for land parcels based on attributes such as title reference or street address.		
5	• It does add time, but due to the simple format it is not significant and can be undertaken with the draft strata plan. • NSW Land & Property Information is investigating methods of digital files for strata plans to improve data validation and registration time, so long term a digital output may become a stand similar to the proposals for ePlan.		
6	• The strata plan models typically represent the shape of the building more true to shape due to the common property areas not being shown in the model. • There are discrepancies to the building outline due to common property structures not being shown.		
7	• With metadata for each lot, the model would allow for spatial queries to be made allowing easy identification. • For example, strata lots typically have an apartment, a car space and a storage cage and with the model these could be identified and located more easily than traditional paper plans.		

Table 5.2 Evaluation criteria for the strata subdivision case study.

It can be seen from above that in the stratum subdivision case studies the introduction of 3D models significantly improved the usability of stratum plans and could improve the digital cadastre map for the end-users, both surveying and non-surveying users. Given the complexity of stratum subdivisions, the plans are complex and require extensive knowledge of surveying practices to understand making it particularly complicated for non-surveying end-users of the plan to acquire spatial information from the data.

The lot boundaries in both stratum and strata don't represent the physical building onsite. In stratum subdivisions the lots cover all the land at each level so even the airspace is allocated to a lot therefore the lot shape doesn't not represent the building shape. In Case Study 1, portions around the arced facade do following the building shape but this is coincidental with a change in management between internal units and the external plaza. For strata subdivision, the 3D model represents the lots which typically fall within the physical limitations of an apartment unit, storage cage or allocated space within a basement. While the sum of the strata lots does not incorporate the entirety of the original lot, the portions of common property have not been shown in the model therefore not portraying the entire building. The inclusion of common property into the 3D model could address this issue of a more accurate representation of the features onsite.

While the 3D cadastral model does not fully represent he building itself, the construction of models representing the land parcels is a layer that could be incorporated into Building Information Models (BIMs) as another asset layer. BIMs are becoming a common tool in high-density development for mapping the physical building and the infrastructure contained and 3D modelling of cadastral boundaries could add to the complexity of data contained within these models.

From the evaluation it can be seen that 3D visualisation does improve the understanding of lot relationships, spatial positioning and access to metadata within the digital cadastral maps. It has more benefits for the stratum subdivisions due to the complex nature of the survey plan compared to strata subdivisions where the plan is structure based and relatable for a non-surveying end-user however both formats are more clearly defined when modelled in a 3D format.

5.2 Software Restrictions

There are some issues regarding software choices that should be given consideration when discussing the application of the modelling data. In the modelling stage of the research project there was only two main issues discovered with the modelling process. These were the inclusion of curved boundary lines in the model and the georeferencing methods used in SketchUp. The other consideration that should be given to software and 3D modelling is the variety of CAD packages used by survey firms and how they each deal with data presentation.

The first issue with the modelling that was discovered during the investigation of the case studies and this is the application of modelling surfaces in regards to curved boundaries. Case Studies 2 and 3 stratum subdivisions were comprised of straight boundary lines, with the majority being perpendicular or parallel to the building orientation to reduce the complexity of the plan and allow the use of a note stating the bearings of all lines are thus unless otherwise noted on the plan. This can be seen in *Appendix C* on all of the case study Deposited Plans. Case Study 1 differs, as has boundaries defined using arcs which on the 3D visualisation will be curved surfaces. The building in Case Study 1 has a curved facade and while the majority of boundaries do not follow the facade there is a portion between the outdoor plaza lot and the residential lot which is based on the facade.

The problem that arose from the curved boundary was in the modelling software used, SketchUp, creating the curved surfaces was not intuitive and fell outside of the methodology used for the modelling. A solution was found for the research project which segmented the arcs into short lines and a series of narrow surfaces was created along the curved boundary. This can be seen in *Appendix B* in *Figure B.4* and *Figure B.7*. In the final visualisation in Google Earth this representation of the curved surface is not survey accurate but presents the shape of the boundary model appropriately for the purposes identified in Chapter 2 of a digital cadastral map. Advanced CAD modelling packages, such as AutoCAD, have the scope to model curved surfaces but due to time limitations of the research project this was not investigated. It is also important to consider that modelling requiring in depth procedures, compared to simply creating 3D rectangular shapes, increases the time and skill required to incorporate modelling into the procedure of stratum subdivisions. The majority of stratum subdivisions typically follow straight line boundaries and will not require complex modelling however, with the increasing trend towards complex architectural features in high-rise, features such as curved facades are becoming more common.

The second concern from the software used for the research project is the method of georeferencing used in SketchUp. The georeferencing method in SketchUp uses aerial imagery from Google Earth to physically allocate lat/long coordinates for the placement when loaded in Google Earth. This was completed by correlating aerial features to boundary lines using the NSW Globe overlay and then matching the model to a similar position. The result places the 3D models in approximately the correct geographical location but they are not connected to the existing digital cadastral map. It should be considered that Deposited Plans show connections to MGA coordinated survey marks where available so future applications of integrating 3D models into the digital cadastral maps can incorporate the same methods currently used by non-stratum Deposited Plans and the integration of the lot geometry into mapping software. The other concern with georeferencing is the application of the vertical position. Stratum plans use AHD to define levels and while this relationship to the surrounding lots could be placed at the correct level the terrain mapping in Google Earth does not allow visualisation of elements that fall below the ground surface level. In the final KML file, see attached in *Appendix B*, it can be seen that the models have been placed above the surface level so all the basements are visible however this does not represent the AHD position of the lot correctly in relation to surrounding features.

The final software consideration is not specific to the research project but considers the application of modelling methods in the surveying industry. There are numerous survey software packages available that are used within the industry and each use different methods of data management and export. With the development of the use of ePlan within New South Wales, packages have been developed as add-ons to current software enabling the LandXML format export and it is feasible to consider that similar software add-ons could be developed and utilised for 3D boundary export. This is a potential area for further research.

5.3 Time Analysis

The modelling process undertaken to convert the 3D lots from survey calculation files to models suitable for Google Earth does take time to complete so this section will look at the extra time required to process models as part of the overall office work component of the case studies. All three case studies were completed survey plans prior or during the research project so the billable office hours can be assessed based on the real world scenario. This includes all office time from reduction of raw data to lodgement at NSW Land & Property Information. The time required for amendments to the plan due to requisitions following lodgement in the examination period has not been included as the three case studies would not be comparable as Case Study 1 is under examination at the conclusion of the research project.

In the three case studies undertaken the stratum plans took between two and 11 weeks of office work to get the raw survey data into a calculation file and drafted to the correct format, depending on the complexity and detail within the development. In comparison the time required for non-stratum Torrens subdivisions or strata subdivisions is significantly less with many small subdivisions, i.e. under 10 lots being similar size to the case study stratums, taking one to two weeks to completion. *Table 5.3* shoes the breakdown of the time spent on each of the case studies, noting that the office components is from the completion of the jobs in billable work hours and the modelling times area from this research project. For the purpose of this analysis the unit 'days' represent an 8 hour work day. Given the fieldwork component will remain the same the following time analysis was based from the office work times. The extra time spent on the modelling process can be analysed as a portion of the total time and total office time for the job.

Description	**Office**	**Modelling**	**Total**	**Percentage**
Case Study 1: Wentworth Point	50.5 days	4.0 days	54.5 days	7%
Case Study 2: Eastwood	21.0 days	2.0 days	23.0 days	8%
Case Study 3: Burwood	10.5 days	3 days	13.5 days	22%

Table 5.3 Time breakdown of the three case studies for the stratum subdivision.

As can be seen from the numbers, the modelling time is only a small component of the total time required for stratum subdivisions due to the complex calculations and drafting requirements/ Case Studies 1 and 2 had similar portions of time dedicated to the modelling process however it can be seen that the modelling formed a higher percentage for Case Study 3. this is due to the site circumstances, for Case Studies 1 and 2 the construction setout was completed by another firm and all survey fieldwork for the cadastral work required detailed as-builts of the slabs for the step downs and level changes/ However for Case Study 3 the construction setout was done in-house so the construction surveyors completed as-builts throughout the work and these were compared to the original calculation files. Therefore a large portion of the time required for calculations was actually completed during the construction phase and the client invoiced for the work under that category. When the stratum plan was completed the majority of the calculations were already completed and the time consuming component was only the drafting. Generally this is reflected within the estimates given to clients seeking stratum subdivisions, with the estimate being $10,000 per stratum lot standard for a building setout by another survey firm and $5,000 per stratum lot for an in-house setout building.

As it can be seen, for the stratum plans the extra time required to create 3D models is only a small percentage of the total time spent getting the plan to lodgement. For the two large case studies, Wentworth Point and Burwood, there are benefits to the client at this stage. Many large development work with models within their own system so if the surveyor can provide a cadastral model that can be imported over the design model it allows the architect and project managers to visually understand the subdivision. In the case of Wentworth Point, numerous site visits have been undertaken between the project manager, architects, registered surveyor and survey technician to fine tune the stratum subdivision and ensure the correct areas are being included in their lot. As a result, additional time added to the project during the calculations stage may be of benefit to the client and improve the project timeline in other areas through the application of clearer spatial data.

The submission of digital models with the lodgement of the survey plan also has the potential to improve registration times. Validation programs could check for voids or overlap in the created stratum lots and determine the correlation of adjoining geometry. Currently, based on experience, a complex stratum plan similar to Case Study 1 would take approximately six weeks to be examined at NSW Land & Property Information. Any improvements to the checking process would improve the time scale and labour required to register a stratum plan. Data validation and plan submission is an area with the potential for further research.

5.4 Conclusions

As it can be seen the use of models, in conjunction with traditional plan format, can improve the accessibility of stratum and strata boundaries to the end-users in both the surveying and non-surveying categories. The use of 3D visualisation allow the end-users to quickly understand the spatial relationship between lots and identify the size, shape and spatial data associated with the lot. For strata plans, however, the benefit is not as clearly defined as the stratum subdivisions due to the difference in complexity between the two plan formats. The additional time required to include modelling in the methodology has also been analysed and show form only a small portion of the time required for stratum plans.

There are software limitations that were discovered during the research project regarding georeferencing, the use of vertical datums and the variety of software packages used within the surveying industry. These all could be considered as potential areas of further research following on from this investigation into the use of modelling.

Chapter 6 Conclusions

6.1 Conclusions

High density mixed-use subdivision is becoming common with the urban consolidation within Sydney and has lead to increased potential of conflicts between end-users regarding boundary locations and the associated rights, restrictions and responsibilities. New South Wales cadastral regulations allow vertical subdivisions in the form of stratum and strata plans but these are complex plans that are difficult for the end-user to relate to the features onsite and understand the boundary limitations. This research project investigated the application of 3D modelling for stratum and strata boundaries and the visualisation of the spatial data within Google Earth using the KML file format.

The main objectives were to investigate whether the use of 3D models for stratum and strata in improving visualisation methods for digital spatial data.

A number of conclusions were found:

- *Conclusion 1*

  The models greatly increased the end-users understanding of 3D boundaries through the provision of visual, interactive data in a spatial platform that supports 3D data, in the case of the project being Google Earth. Layer control and camera control allow the user to isolate specific lots and navigate to view target areas in close up.
- *Conclusion 2*

  The benefit of modelling was more prominent for stratum subdivisions compared to strata subdivisions. This relates to the level of complexity within the original survey plan. Strata plans are currently user-friendly and due to their structure based definition can be easily read where as stratum plans are more involved with areas of equal height limitations being divided into stratum limits that then form the whole stratum lot.
- *Conclusion 3*

  The range of end-users of digital spatial data goes beyond the surveying industry and covers a range of non-surveying professions and general public users.
- *Conclusion 4*

  Following from conclusion 3, the uses of digital spatial data are not to replace traditional survey plans and boundary definition but instead compliment the current plan formats and allow access to spatial data in alternative forms. Boundary definitions are not replace with 3D models and accurate survey work still requires a registered surveyor despite the more accessible spatial data.

6.1.1 Limitations

The limitations from this research were investigated in Chapter 5 and identified as primarily involving the use of available software and how it allows for the integration of 3D spatial data, the increased time requirements on survey calculations, the georeferencing method use in SketchUp and the lack of context from the cadastral models in reflecting the building size and shape. The first three limitations identified have the potential to be resolved through the use of different software packages and the development of automation processes to assist in making survey software packages compatible with modelling and KML export.

The lack of context in cadastral models was also identified as a limitation for both the stratum and strata models. Stratum subdivisions require the entire 2D area of the lot to be accounted for at all levels of the plan resulting in cadastral boundaries that don't follow the building outline. Instead they will incorporate the usable space within the building plus the airspace surrounding the building as a portion of the lot. Typically building features close to boundaries will be shown with offsets but with the level of detail in a stratum plan there is not enough space to include the footprint of the building at each level and that lack of context of boundaries to structures is seen in both the original survey plans and the 3D models. Strata subdivision lots, on the other hand, are limited to the internal dimensions of the structural feature that defines them and portions of common property are typically shown on a strata plan to provide context of the lot location. This allows for a lot's location to be more easily identified using the identified structural features and the floor number from the original survey plan for location purposes however in the model of the cadastral lots lacks this context to structures as it simple visualises the lots location and limits.

The lack of context between the models and the physical building is an element that could make the spatial data more difficult to access for non-surveying end-user that may lack the knowledge of cadastral practices that define why the boundaries don't match the building shape. In contrast current digital cadastral maps allow 2D boundaries to be overlayed aerial imagery allowing the user to relate the boundary shape and position to physical features. The 3D cadastral models could be incorporated into Building Information Models, whuch typically already contain building and infrastructure spatial data, as a cadastral layer to enchance the level of data analysis that could be undertaken with these models. This would improve the context and rather than viewing 3D cadastral models as individual produce is instead they can form an additional layer in a larger spatial environment.

6.1.2 Future Research

With digital spatial databases common practice in the surveying industry, the next step is development is the trend towards improving the accessibility and visualisation of the data within these portals. Traditional 2D mapping software doesn't currently provide enough support for the range of subdivision methods available in New South Wales and investigation into 3D visualisation methods demonstrates that including this data in digital cadastral maps would benefit the end-user. This area of research has a significant amount of potential for future research and development.

Areas of future research were identified throughout the research project and the four main points are outlined below:

- Integration into current LandXML programming - The LandXML format can support 3D applications but the current ePlan Protocol in New South Wales does not allow for stratum or strata boundaries to be coded. Currently the process is being used for non-stratum Torrens title subdivisions but there is a potential for further research into how to expand this system to cover all New South Wales subdivisions.
- Export format from standard surveying CAD software - For the research project, the choice to use SketchUp reflected the lack of native export from AutoCAD to KML but despite its suitability as a modelling package SketchUp is not suitable as a survey program due to its lack of coordinate systems, precise drawing controls and unsuitability for survey accurate drafting. Future research could investigate the improvement of cadastral modelling and KML export from standard surveying packages.
- Automation of the modelling and drafting process - The modelling process for the research project involved the individual modelling of each lot within the subdivision. There is the potential to develop a method of creating the models automatically from the wireframe of each lot and minimise the user input. Another area of potential automation is using a 3D model to automatically create a slice flood plan with dimensions from the wireframe to create the basis of the drafted final survey plan.
- Validation program for model compatibility - The calculation of complex 3D boundaries in a 2D slice format allows for potential errors in the form of overlap or voids between lots. There is the potential for future research into developing a validation program that could analyse 3D models and detects areas of overlap or void between individual lots. Software in this area could improve in-house checking of plans and potentially be used in the examination phase prior to registration.

6.1.3 Final Remarks

The purpose of this research project was to address the nature of 3D boundaries in New South Wales and how the current visualisation methods in digital cadastral portals could be improved through the use of 3D modelling. The literature review and methodology identified the changes to the Greater Sydney area's population and the trends in housing patterns, both of which have contributed to the increase of high-density mixed-use developments and the complicated cadastral plans required to present these boundary definitions. The conflict discovered with these plans was highlighted in the clarity of spatial data for the end-user, specifically non-surveying users who may not be familiar with stratum plans, and the methodology was developed to test the improvements from using 3D models to enhance the usability of the survey plans.

The research project was successful in demonstrating the usability of 3D models for height limited land parcels and provide a parallel format to view a development that is more user-friendly than the survey plan on its own. The methodology developed has also been used for the real world scenarios and modelling will be investigated at a company level to determine positive outcomes for surveyors and clients on future stratum project.

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Appendix A: Project Specification

ENG4111/4112 Research Project

Project Specification

For:	Elizabeth Anderson
Title:	The application of visualisation techniques for stratum and strata boundaries within the New South Wales digital cadastre
Major:	Surveying
Supervisor:	Glenn Campbell
Enrolment:	ENG4111 - EXT S1, 2016 ENG4112 - EXT S1, 2015
Project Aim:	To investigate benefits of 3D modelling for stratum and strata plans within high-density urban areas and its integration with New South Wales cadastral regulations.

Programme: Issue B, 28th March 2016

1. Research the trend of housing towards high urban density and the application of cadastral principles of land ownership.

2. Research New South Wales cadastral requirements and current data presentation methods for digital cadastres including SIX Maps and NSW Globe via Google Earth and compare the data visualisation methods to equivalent plans from other jurisdiction's cadastral systems.

3. Identify the weaknesses of the stratum and strata plans and their presentation in digital cadastres for non-survey based end-users.

4. Collate data models of stratum lots and strata lots from the case studies and develop export methods of coordinates.

5. Review fieldwork data and collate into an electronic format, import models into SketchUp and preview the model visualisation within the Google Earth environment.

6. Analyse the use of 3D models and their application with respect to 'fit for purpose' alongside traditional cadastral definition formats.

7. Evaluate the benefits and weaknesses of the 3D models and the survey methodology to create them.

If time and resources permit:

8. Investigate the application of digital cadastres to other industries, outside of cadastral surveying, and their use of digital cadastres.

9. Analyse the benefit to the end-user of the addition of 3D data visualisation to existing digital cadastres.

Appendix B: Data Models

See attached KML file for full models (requires Google Earth to be installed)

Search address input:

1. 2 Waterways Street, Wentworth Point
2. 11-15 Deane Street, Burwood
3. 62-80 Rowe Street, Eastwood

Case Study 1: Wentworth Point

Case Study 2: Eastwood

Case Study 3: Burwood

Case Study 1: Wentworth Point

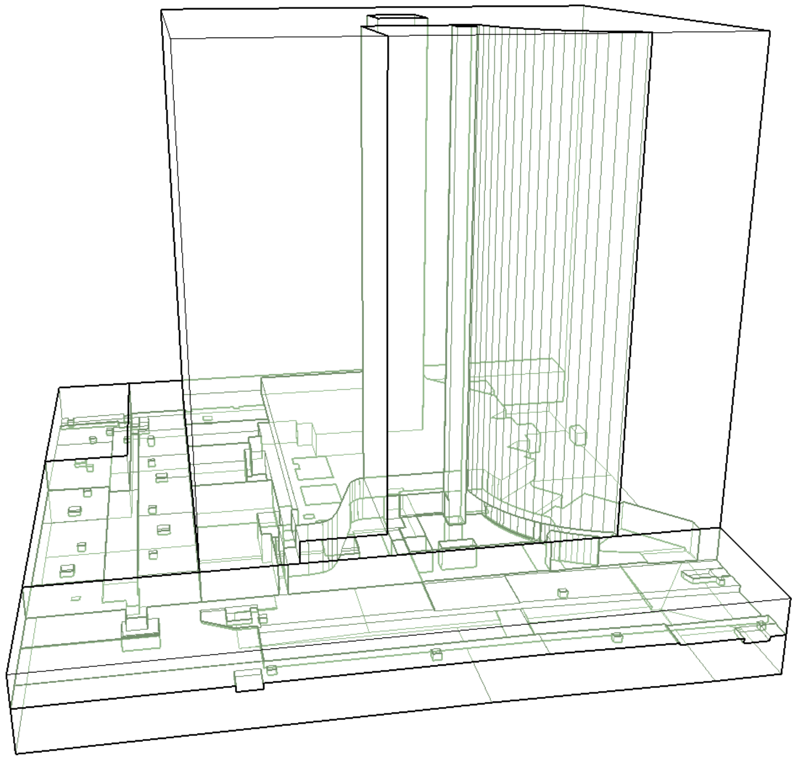

Figure B.1 Wireframe model of the stratum lots.

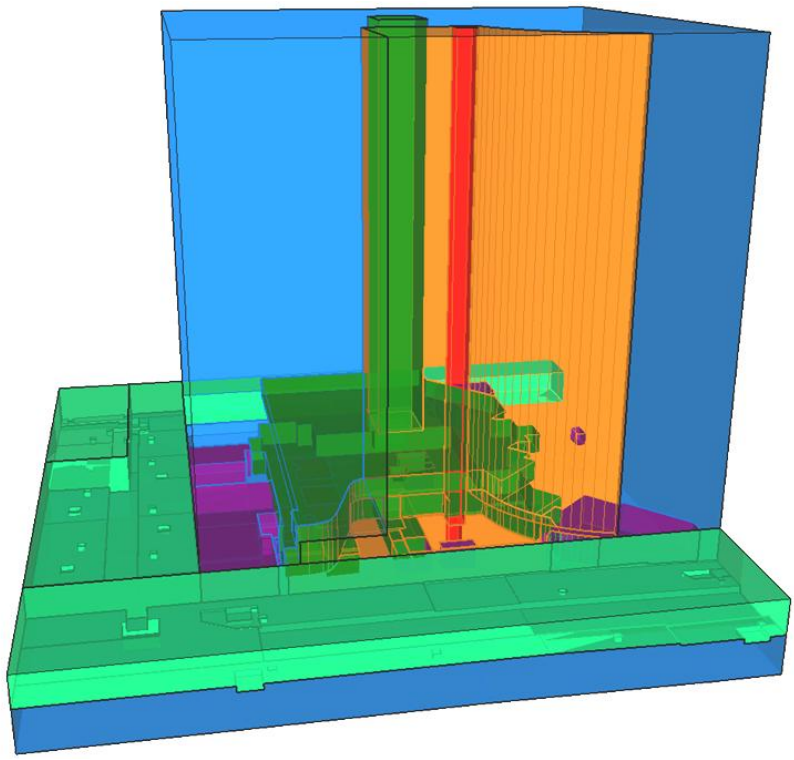

Figure B.2 Combined model of the stratum lots.

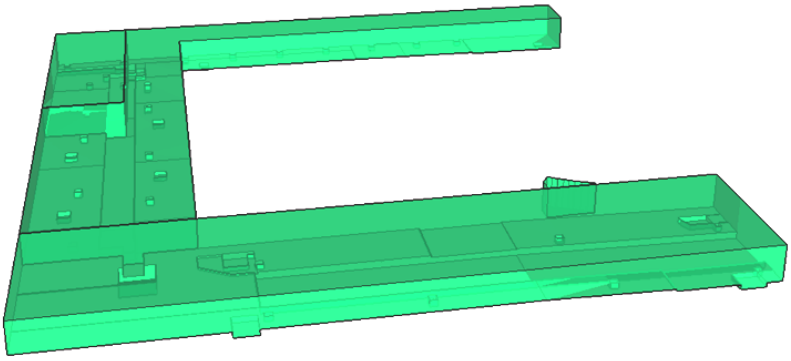

Figure B.3 Model of Lots 15, 20 and 29.

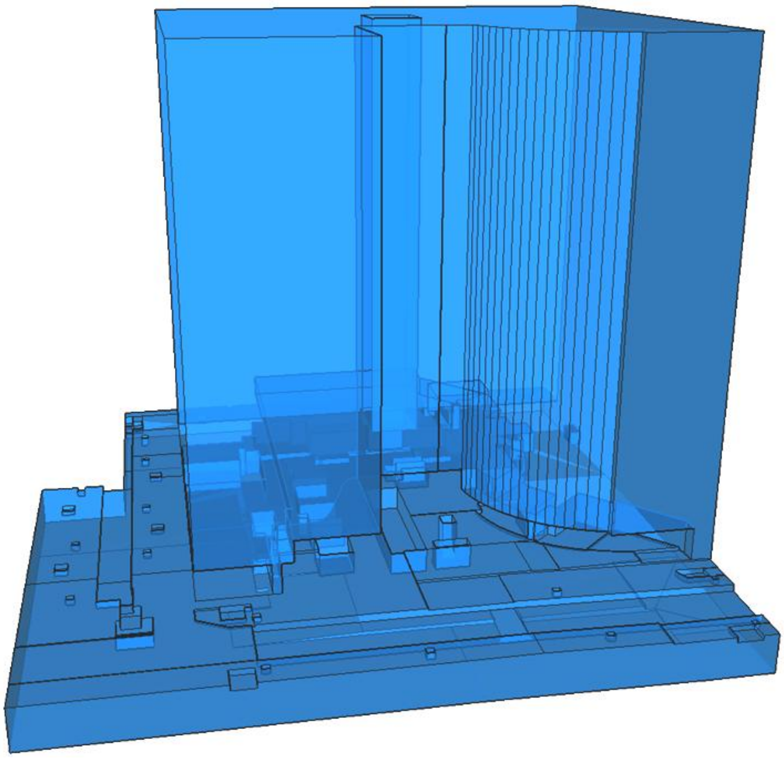

Figure B.4 Model of Lot 25.

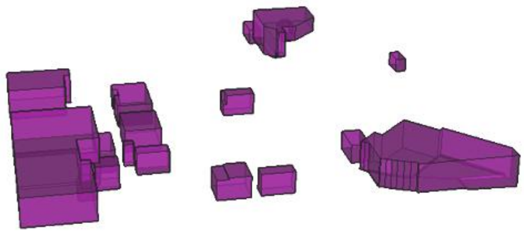

Figure B.5 Model of Lot 26.

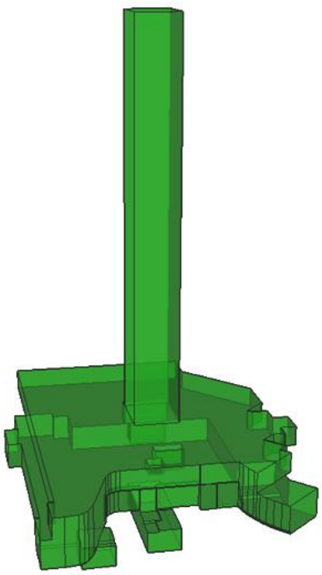

Figure B.6 Model of Lot 27.

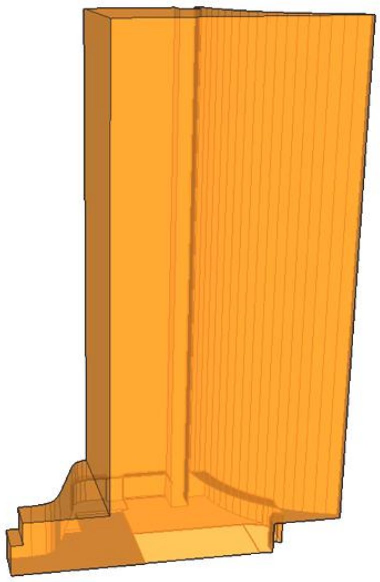

Figure B.7 Model of Lot 28.

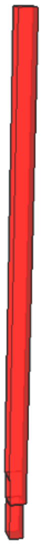

Figure B.8 Model of Lot 30.

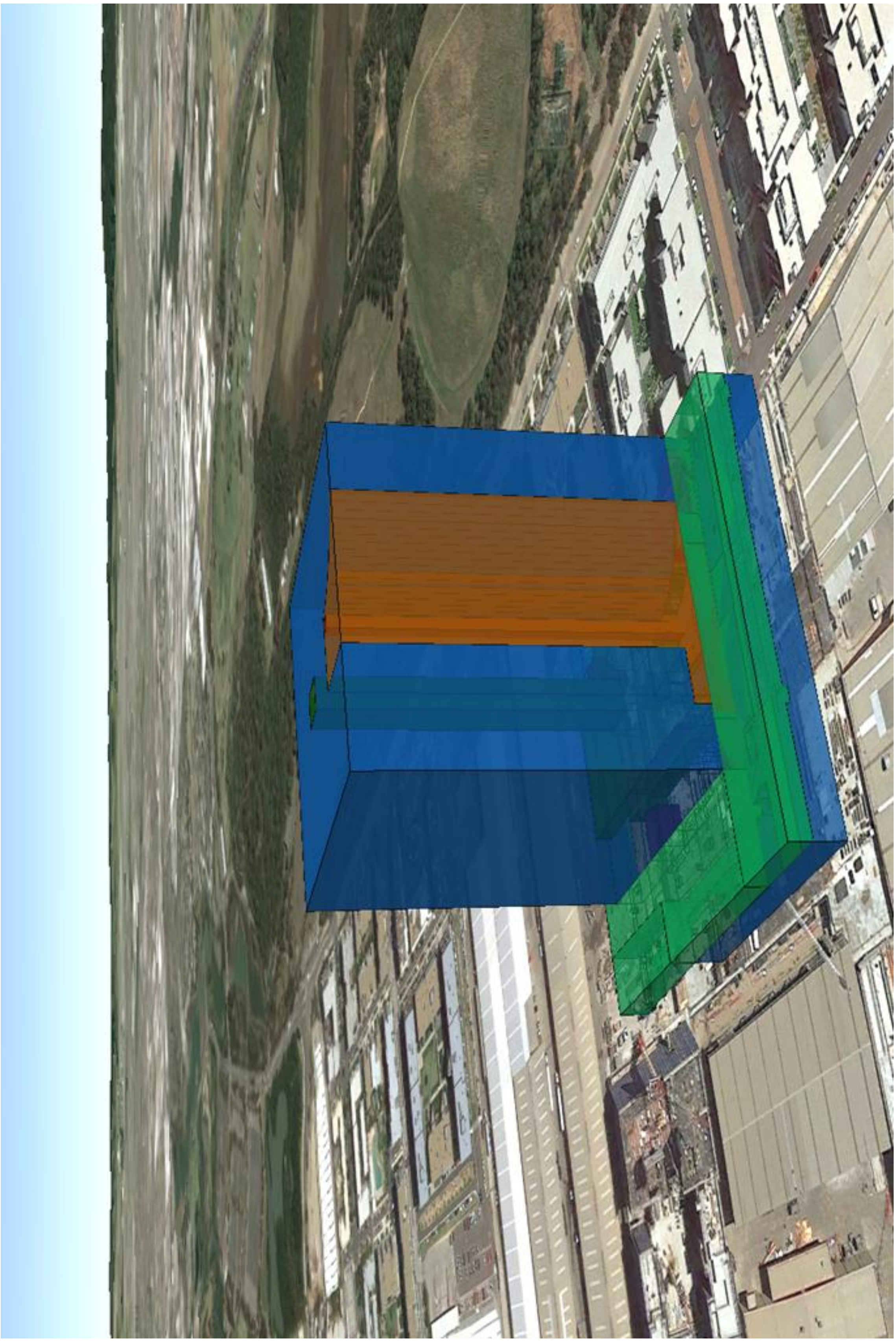

Figure B.9 Presentation of the stratum model in Google Earth.

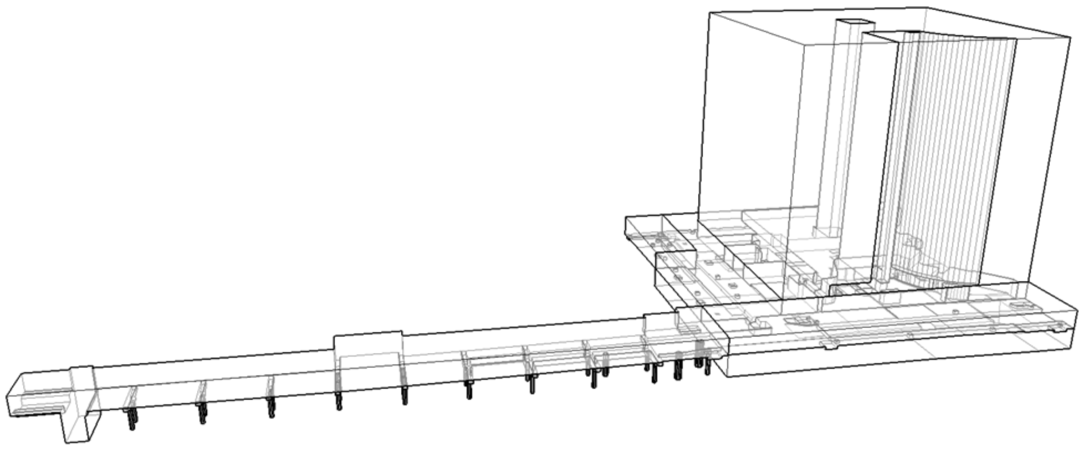

Figure B.10 Wireframe model of the stratum lots including Footbridge Boulevard.

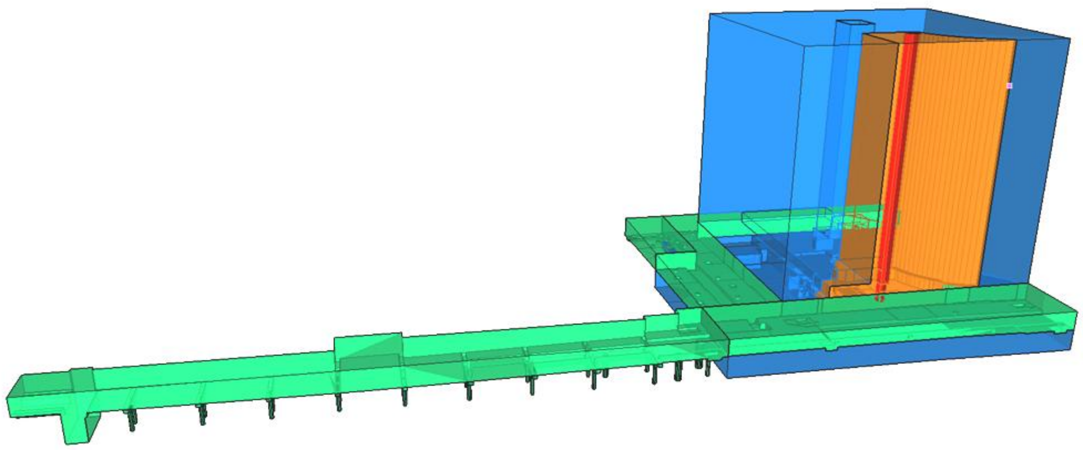

Figure B.11 Combined model of the stratum lots.

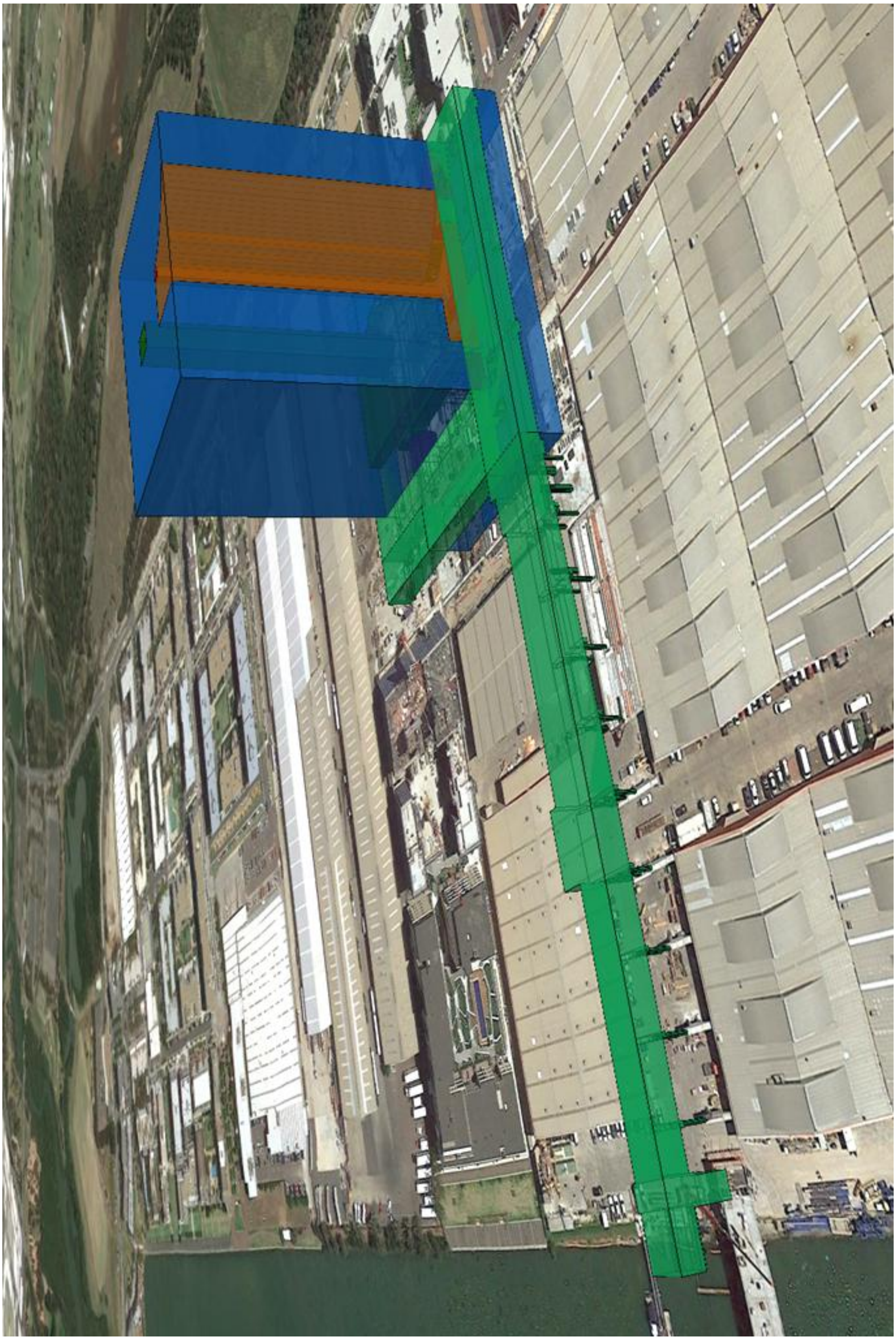

Figure B.12 Presentation of the stratum model in Google Earth including Footbridge Boulevard.

Case Study 2: Eastwood

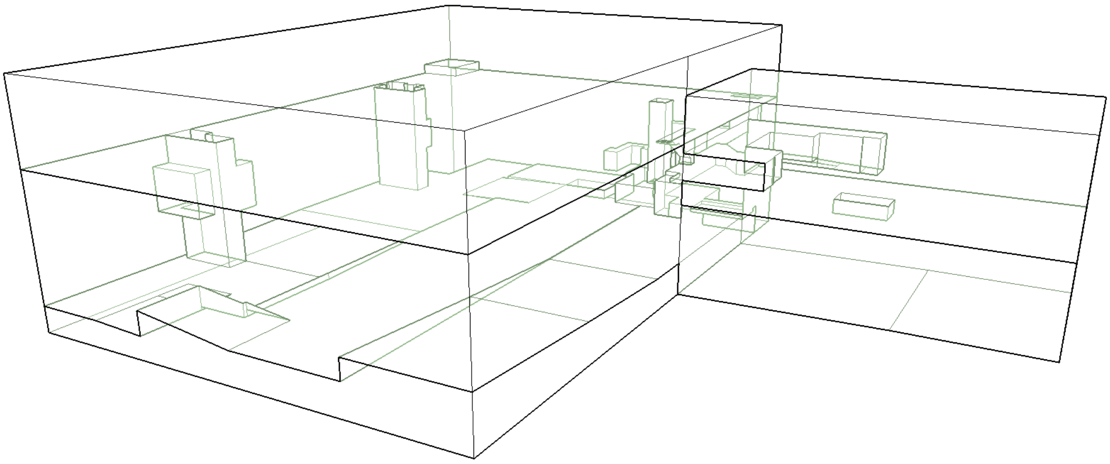

Figure B.13 Wireframe model of the stratum lots.

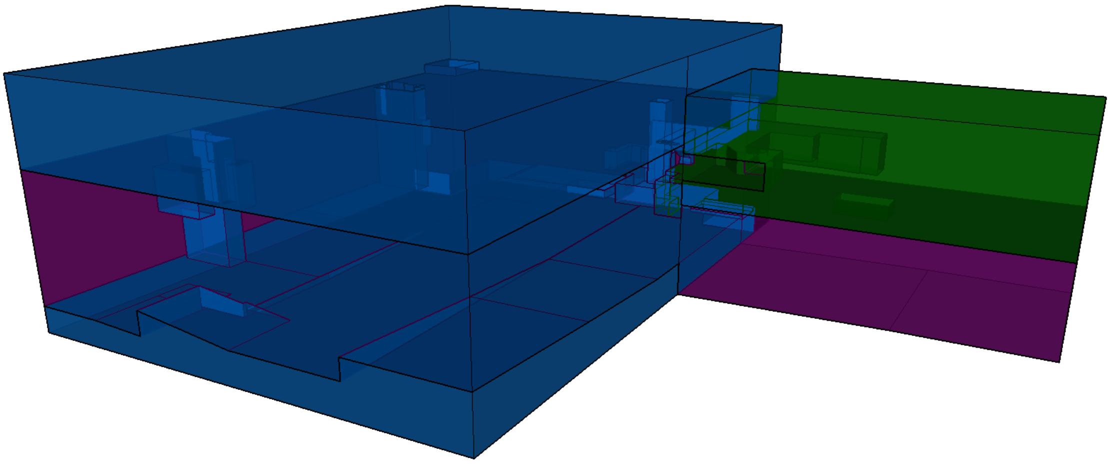

Figure B.14 Combined model of the stratum lots.

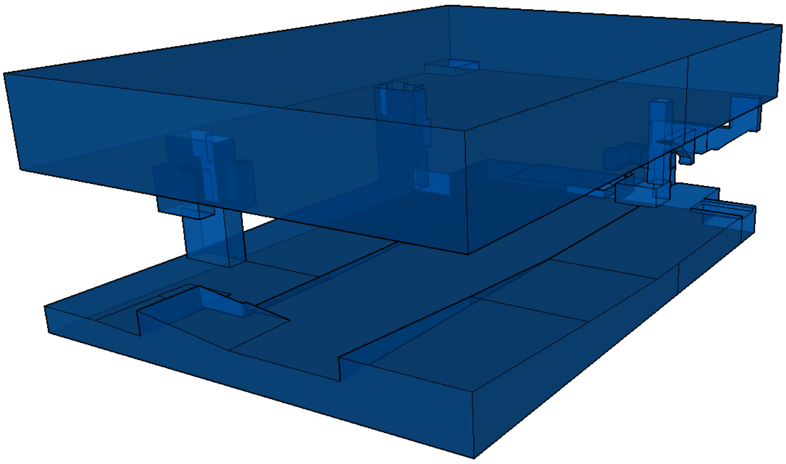

Figure B.15 Model of Lot 1.

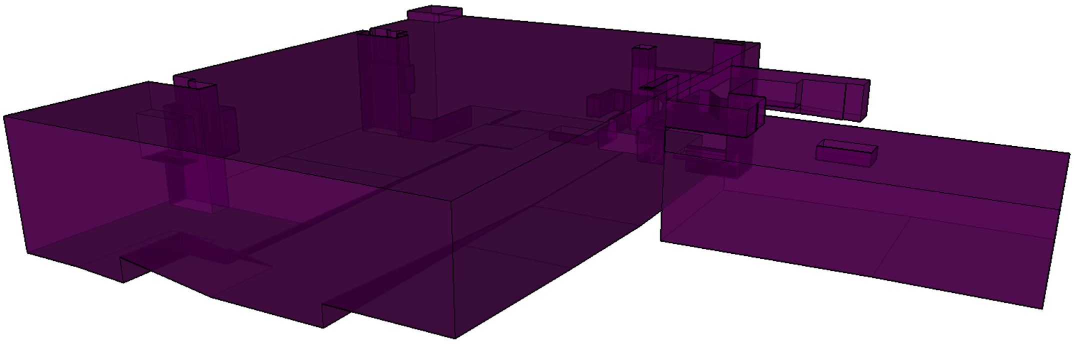

Figure B.16 Model of Lot 2.

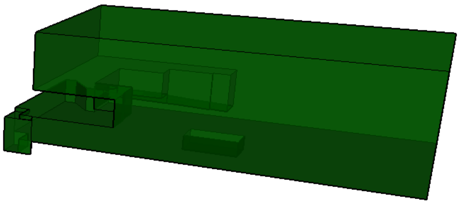

Figure B.17 Model of Lot 2.

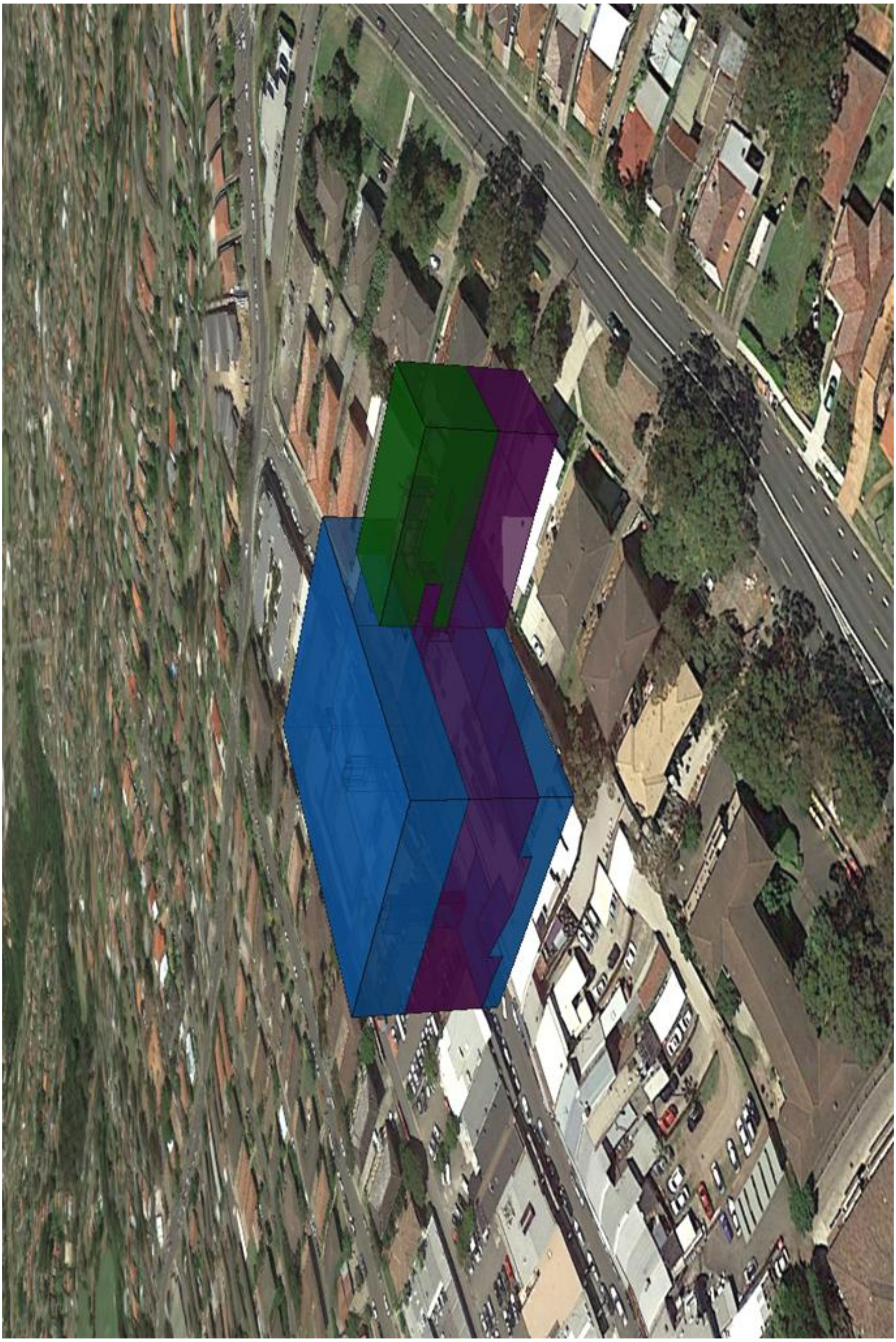

Figure B.18 Presentation of the stratum model in Google Earth.

Case Study 3: Burwood

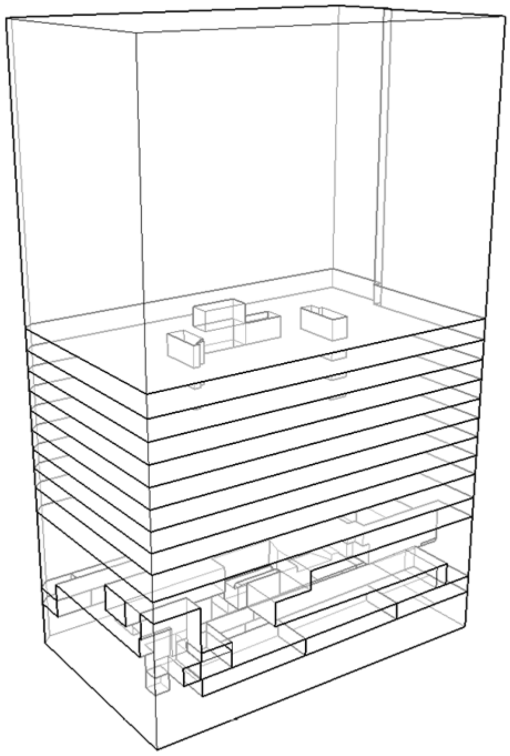

Figure B.19 Wireframe model of the stratum lots.

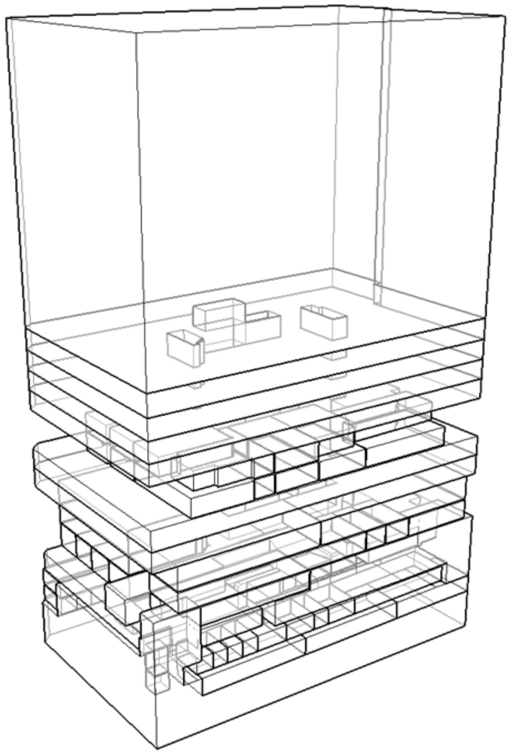

Figure B.20 Wireframe model of the stratum lots.

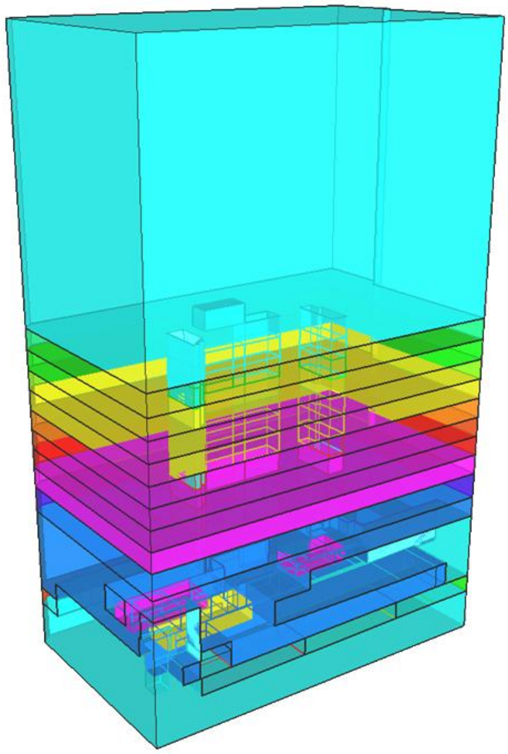

Figure B.21 Combined model of the stratum lots.

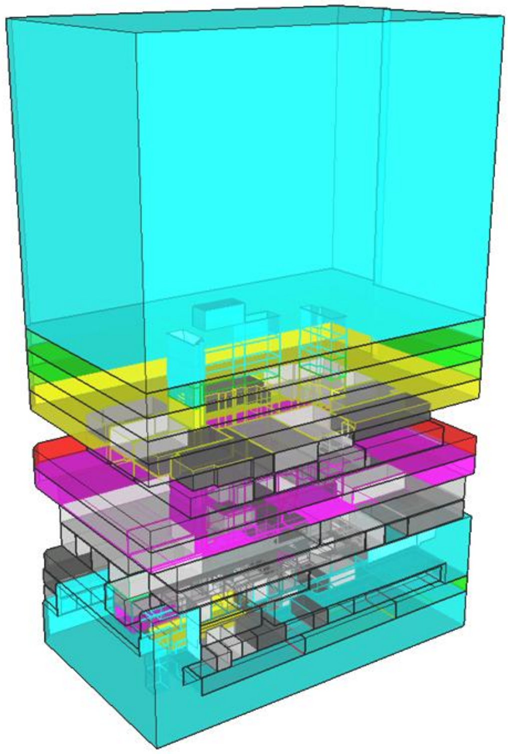

Figure B.22 Combined model of the final stratum and strata lots.

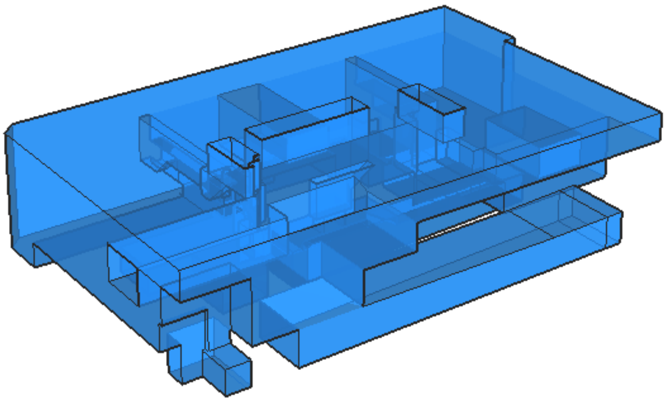

Figure B.23 Model of Lot 1.

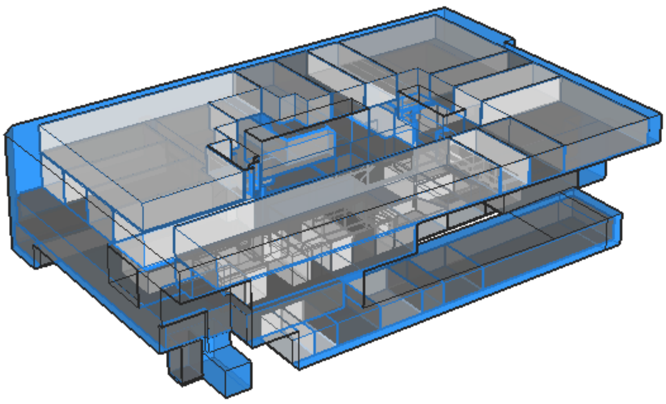

Figure B.24 Model of Lot 1 stratum and strata combined.

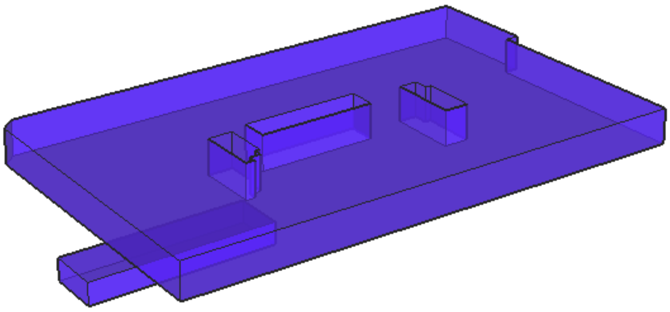

Figure B.25 Model of Lot 2.

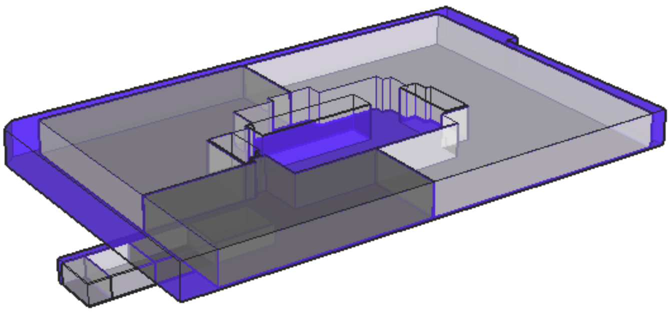

Figure B.26 Model of Lot 2 stratum and strata combined.

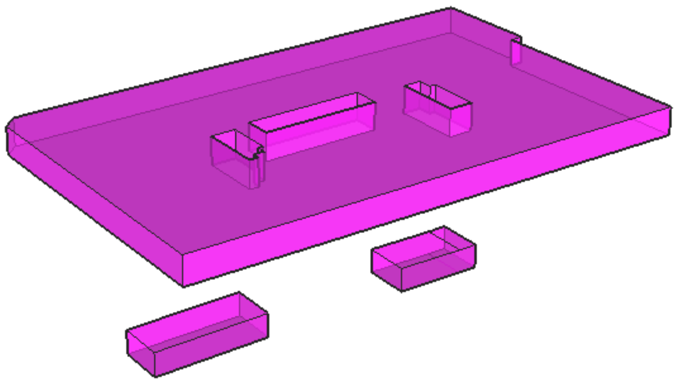

Figure B.27 Model of Lot 3.

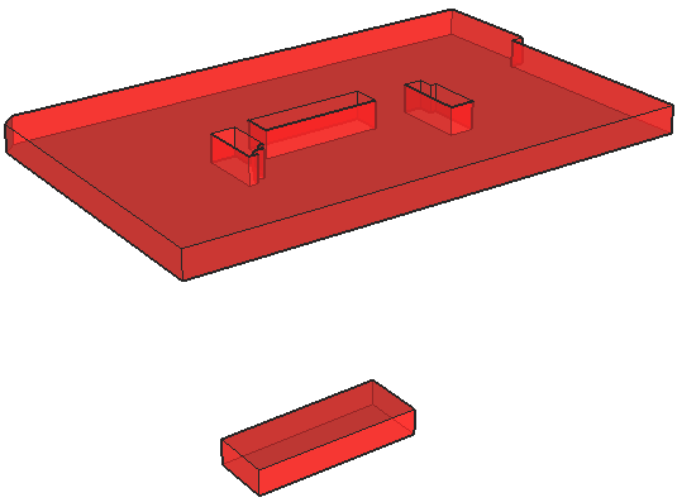

Figure B.28 Model of Lot 4.

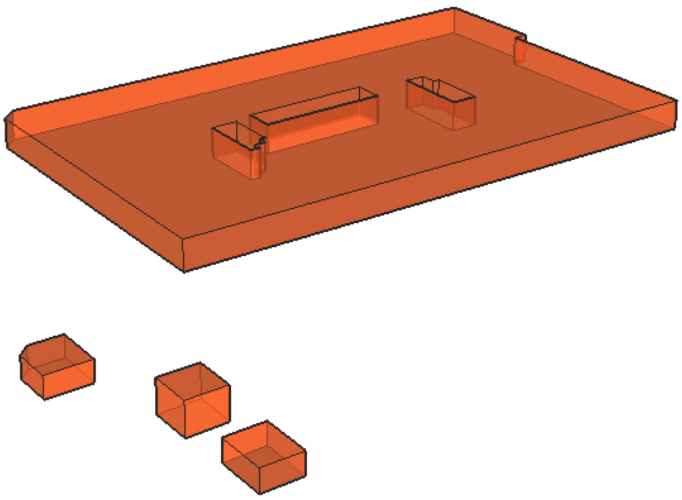

Figure B.29 Model of Lot 5.

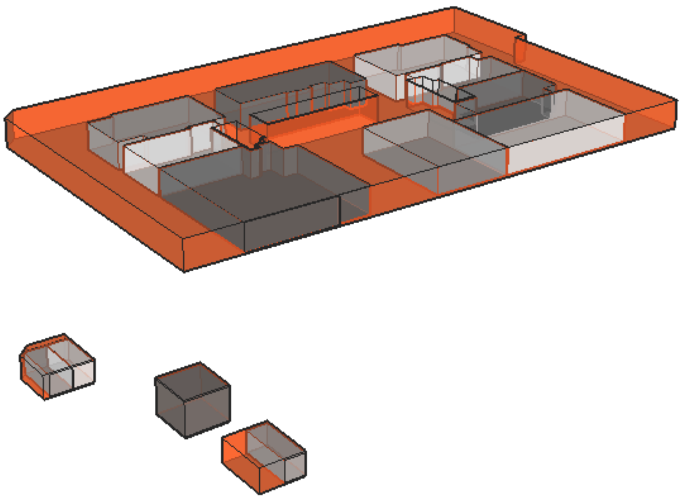

Figure B.30 Model of Lot 5 stratum and strata combined.

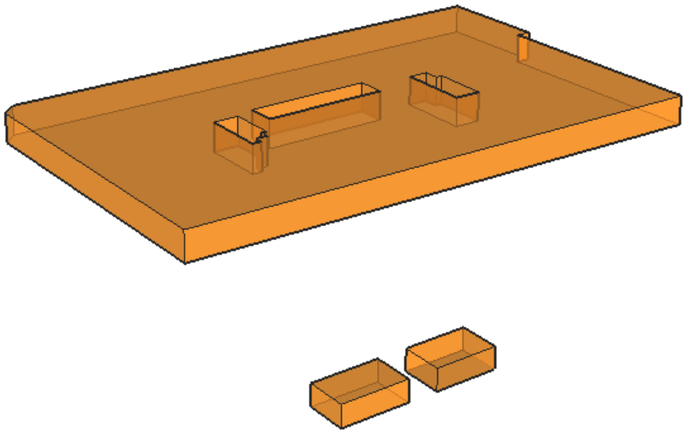

Figure B.31 Model of Lot 6.

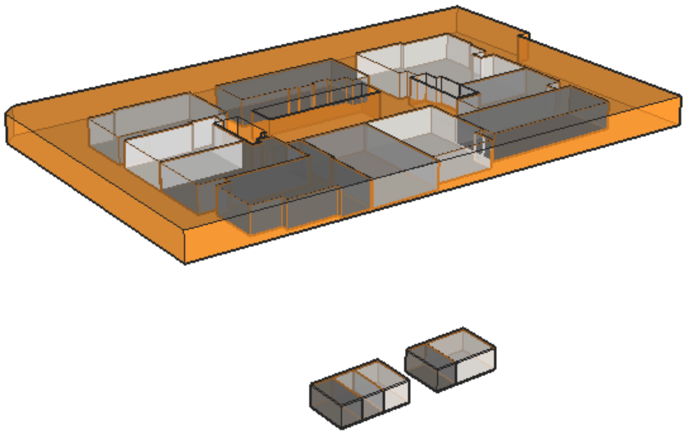

Figure B.32 Model of Lot 6 stratum and strata combined.

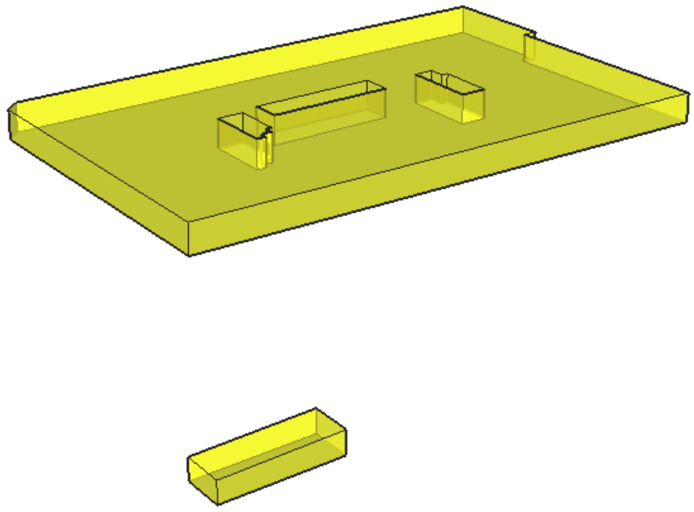

Figure B.33 Model of Lot 7.

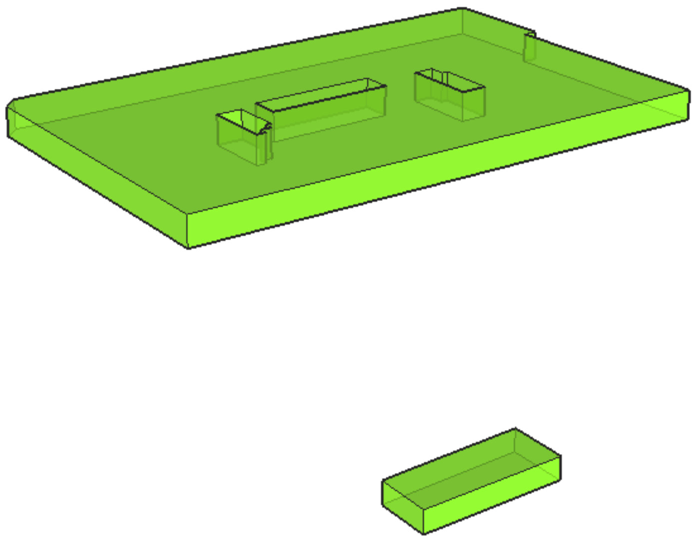

Figure B.34 Model of Lot 8.

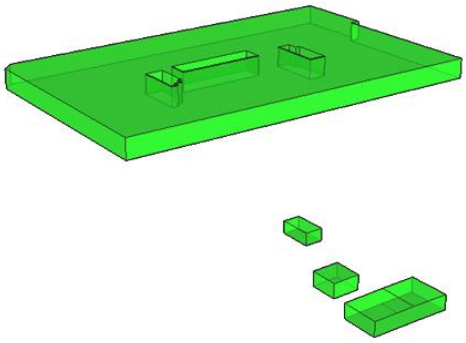

Figure B.35 Model of Lot 9.

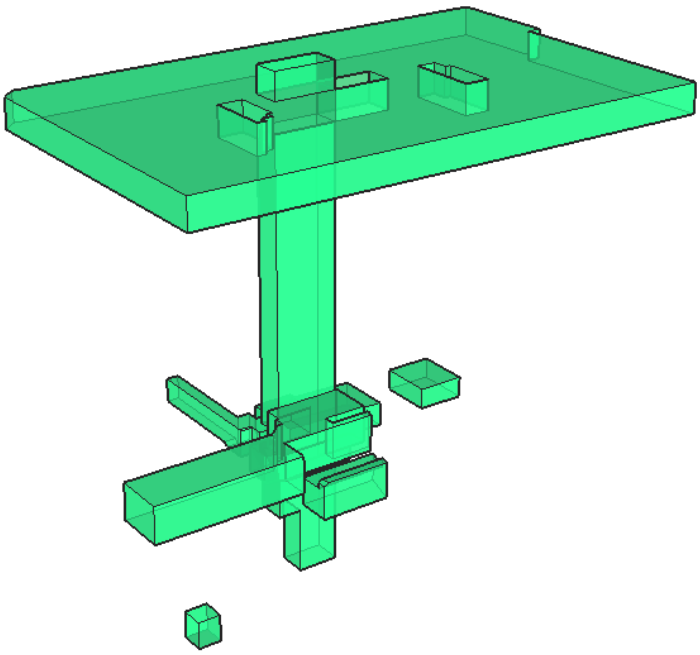

Figure B.46 Model of Lot 10.

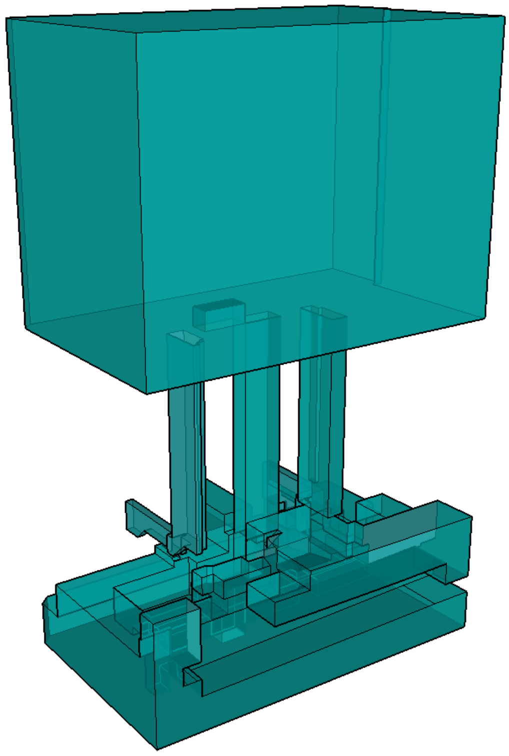

Figure B.37 Model of Lot 11.

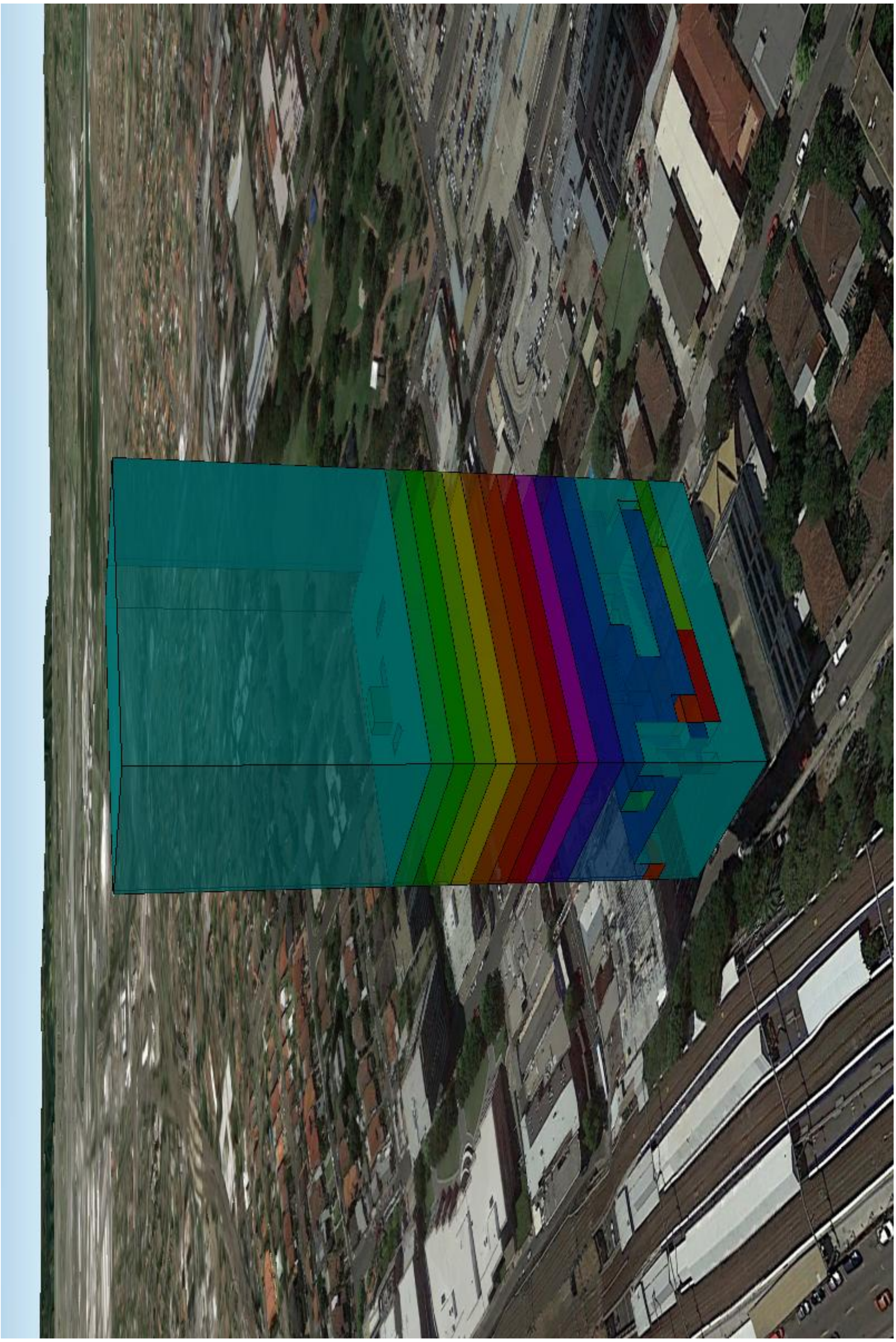

Figure B.38 Presentation of the stratum model in Google Earth.

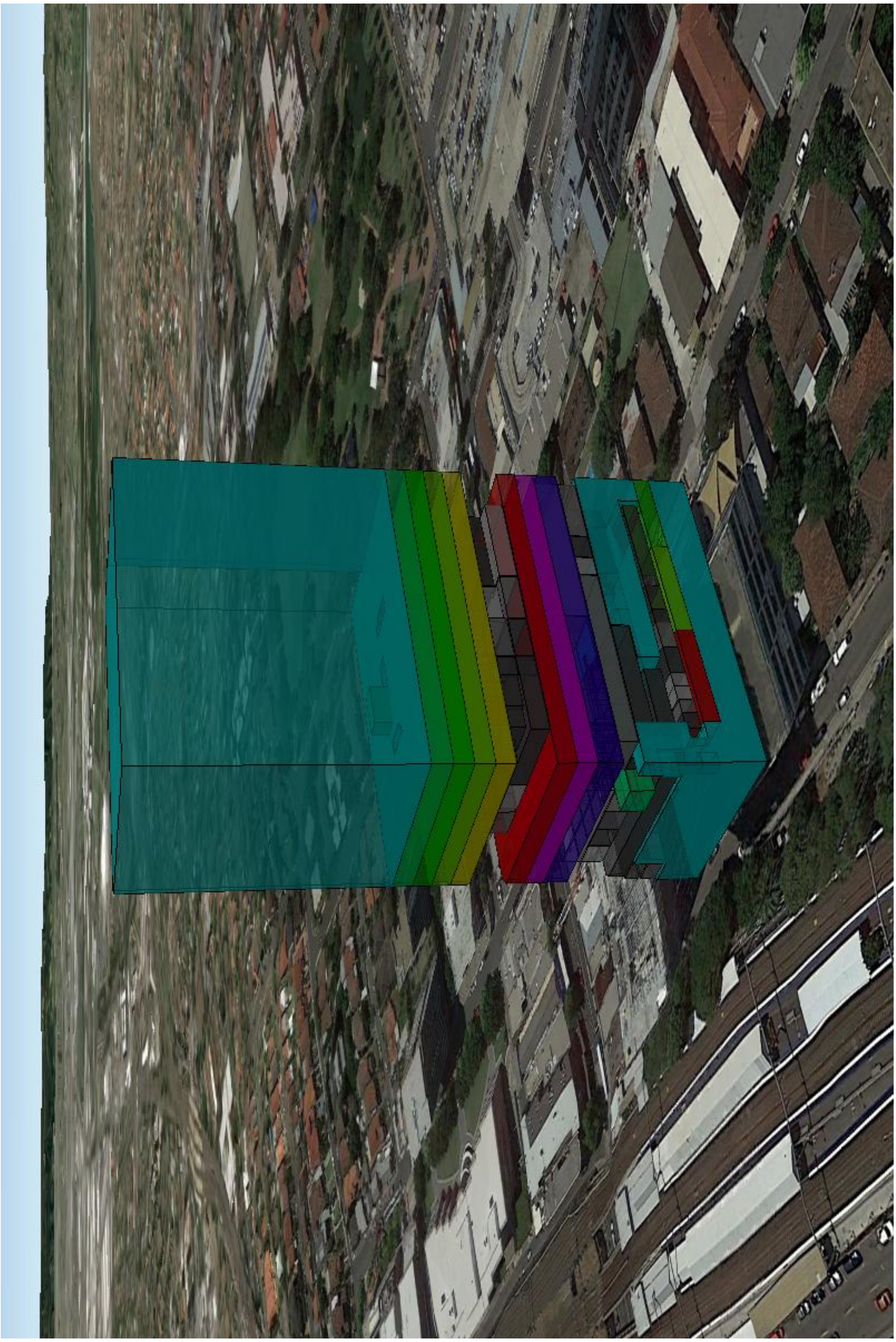

Figure B.39 Presentation of the stratum and strata model in Google Earth.

Appendix C: Survey Plans

Deposited Plan 270778

Deposited Plan 1177634

Deposited Plan 1197996

Strata Plan 90012

Strata Plan 92972

Strata Plan 93178

Strata Plan 93179

Deposited Plan 270778

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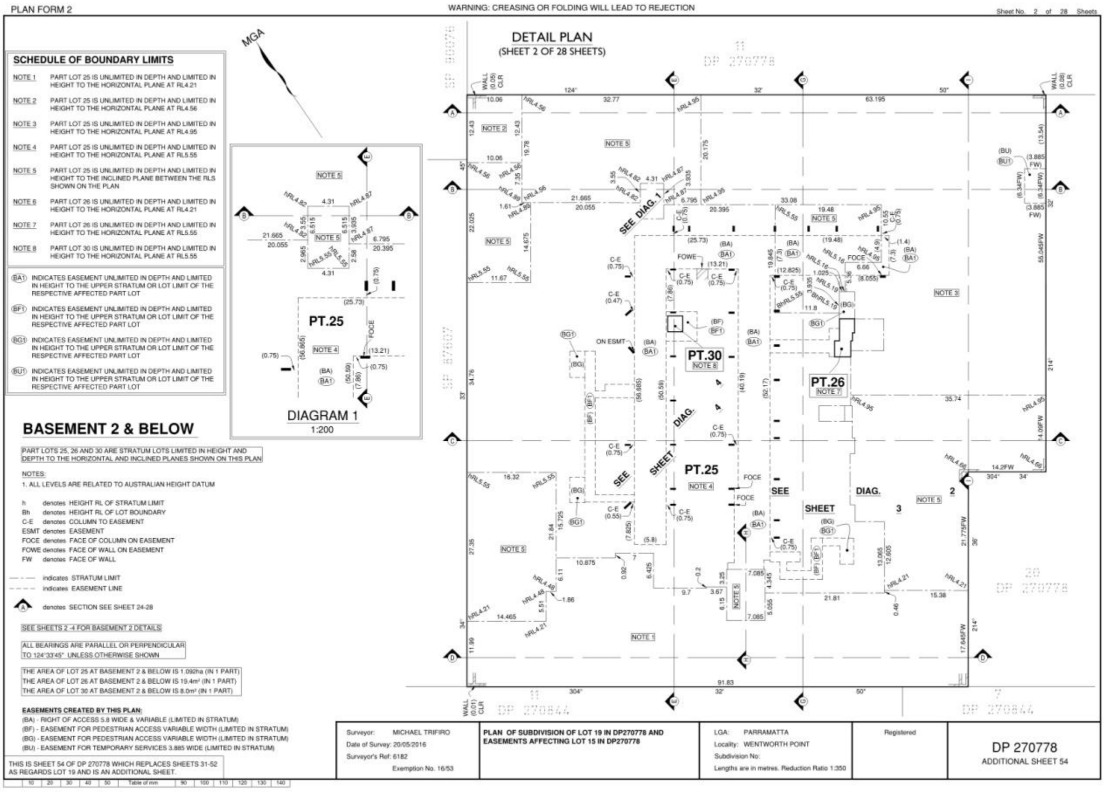

Figure C.1 Block B - Location Plan (Trifiro 2016).

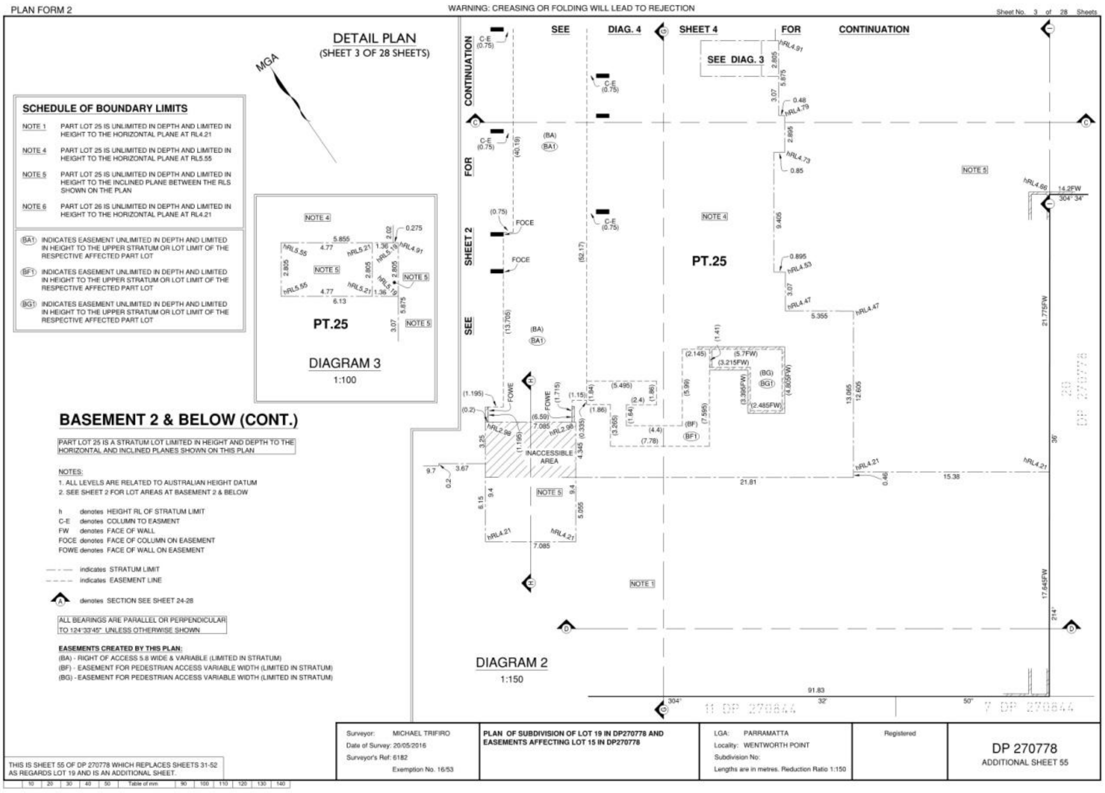

Figure C.2 Block B - Basement 2 & Below (Trifiro 2016).

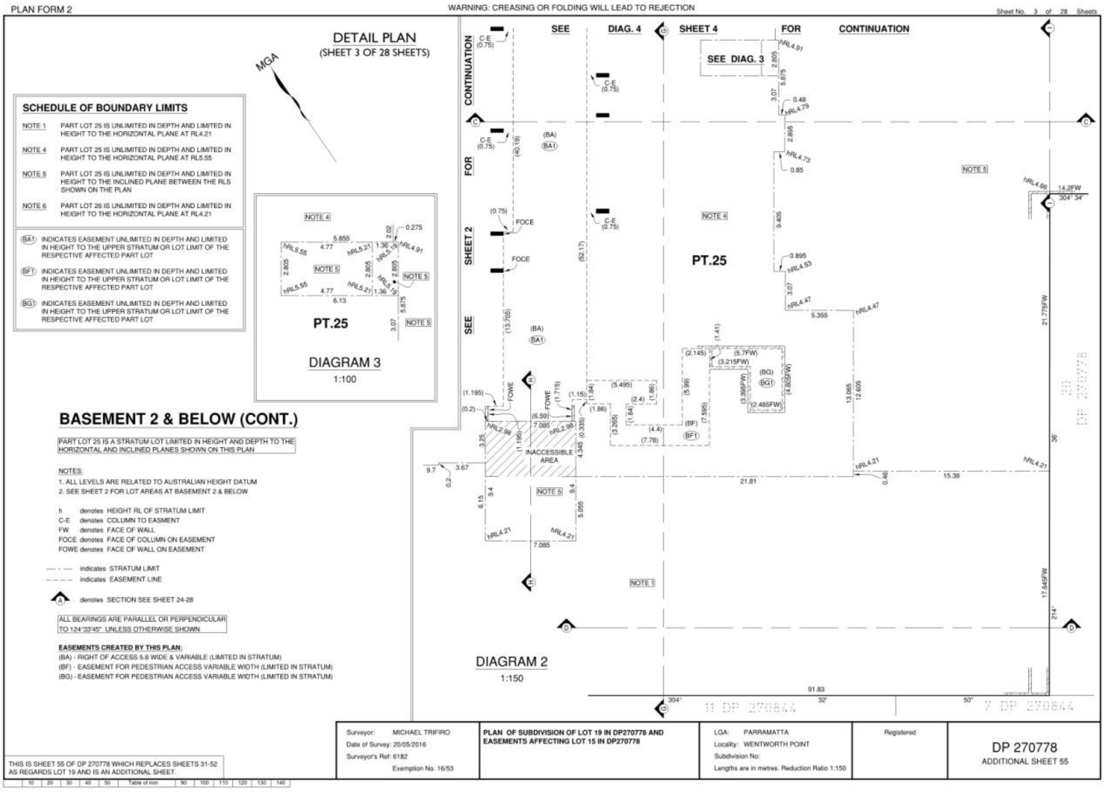

Figure C.3 Block B - Basement 2 & Below Diagrams (Trifiro 2016).

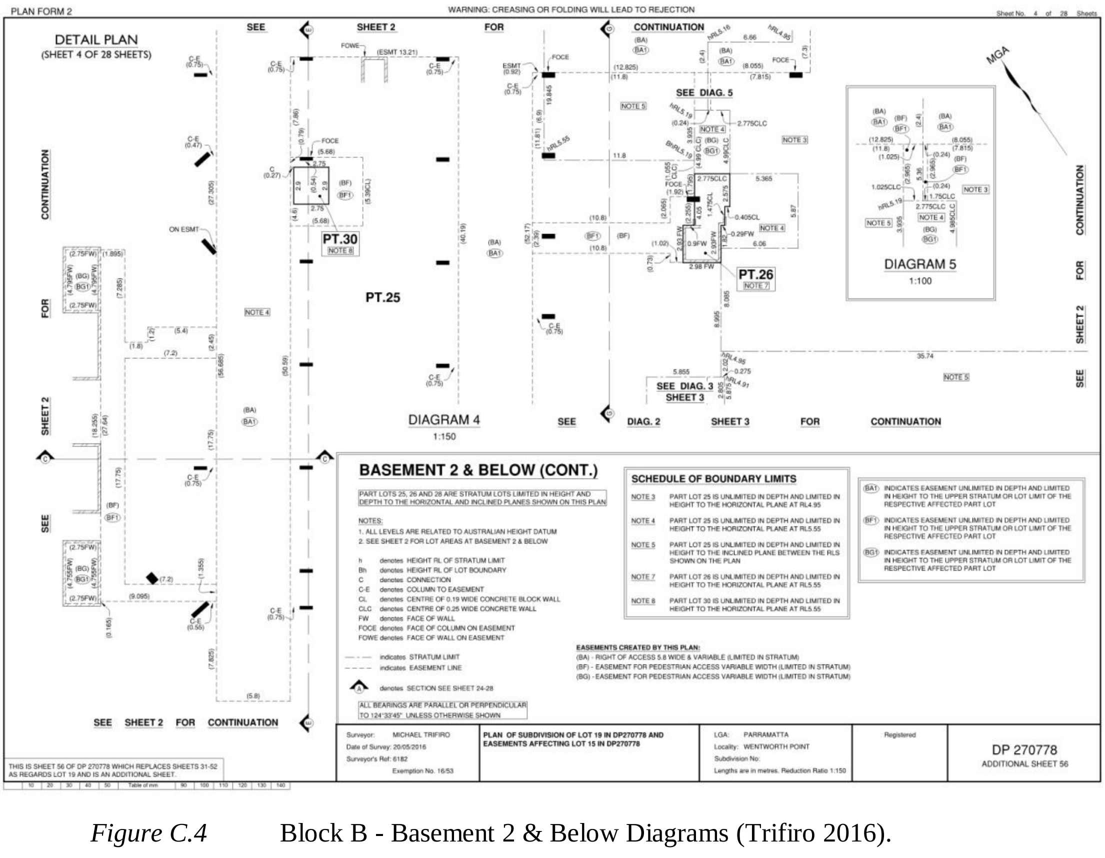

Figure C.4 Block B - Basement 2 & Below Diagrams (Trifiro 2016).

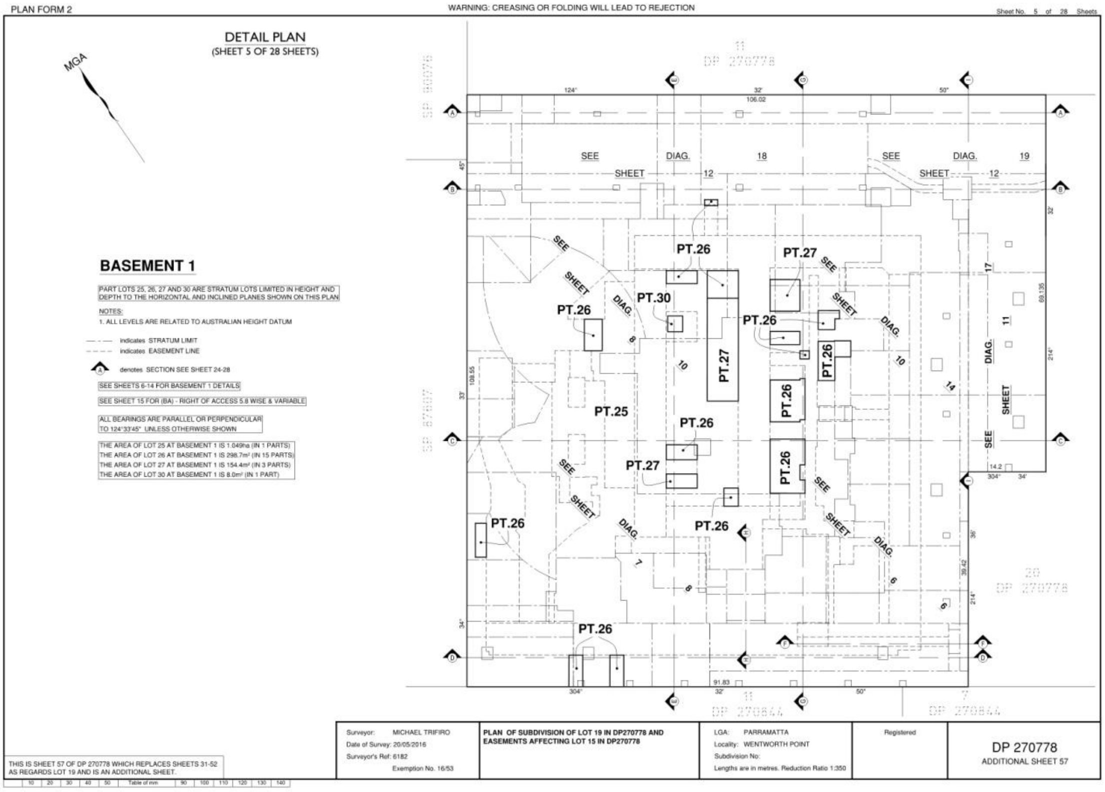

Figure C.5 Block B - Basement 1 (Trifiro 2016).

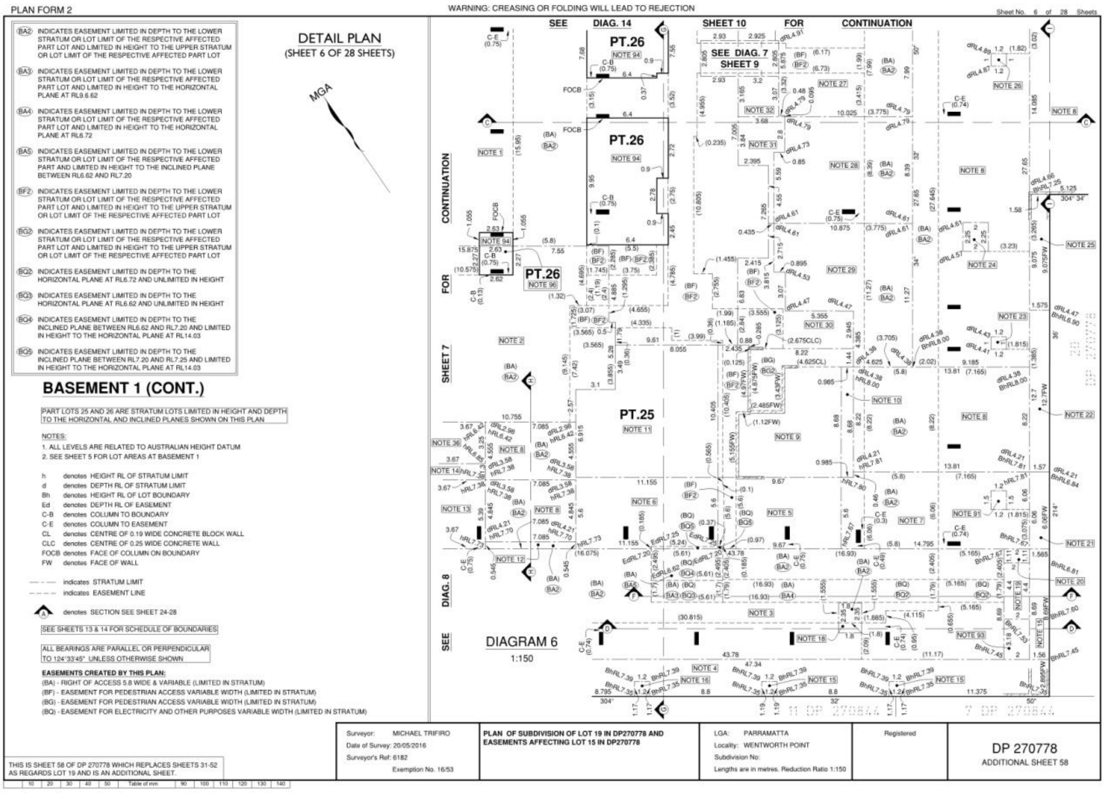

Figure C.6 Block B - Basement 1 Diagrams (Trifiro 2016).

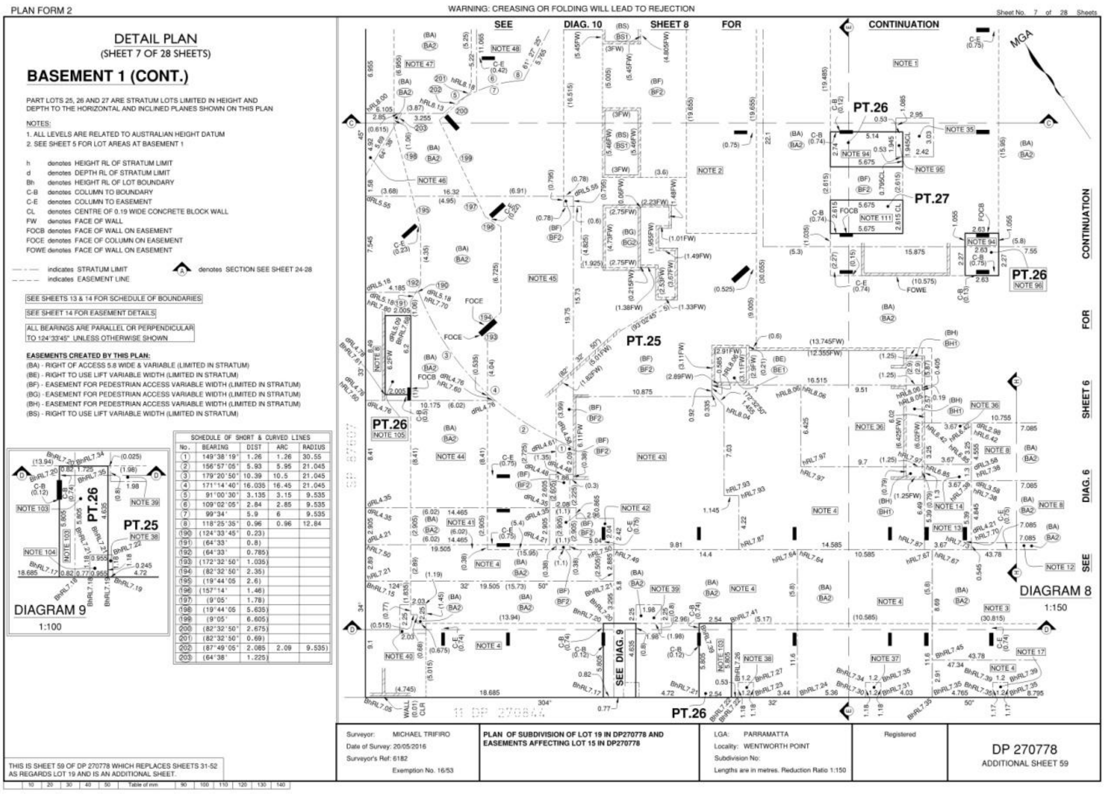

Figure C.7 Block B - Basement 1 Diagrams (Trifiro 2016).

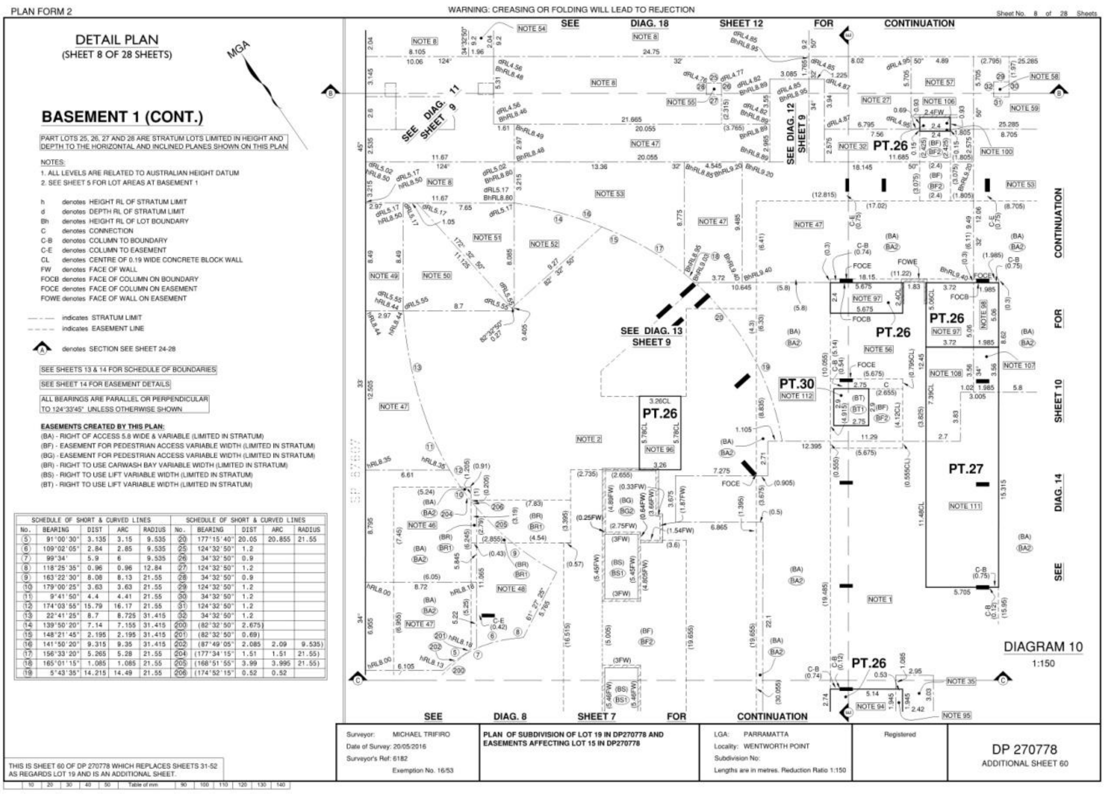

Figure C.30 Block B - Basement 1 Diagrams (Trifiro 2016).

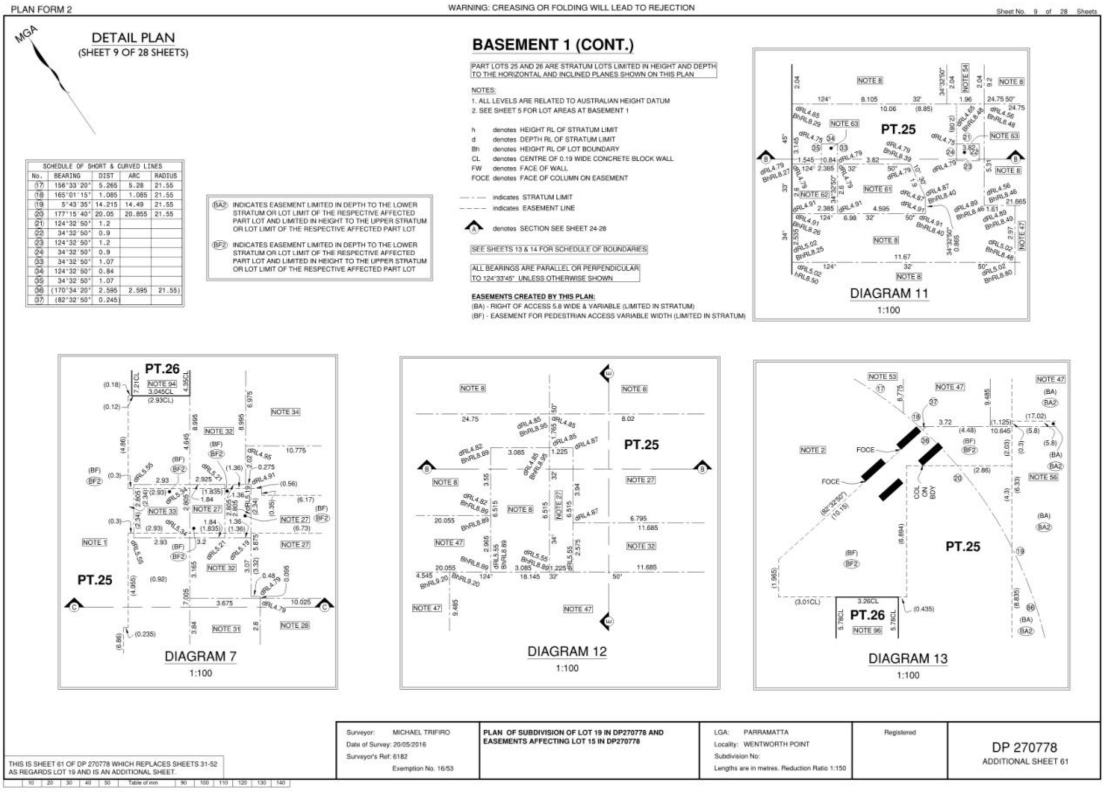

Figure C.9 Block B - Basement 1 Diagrams (Trifiro 2016).

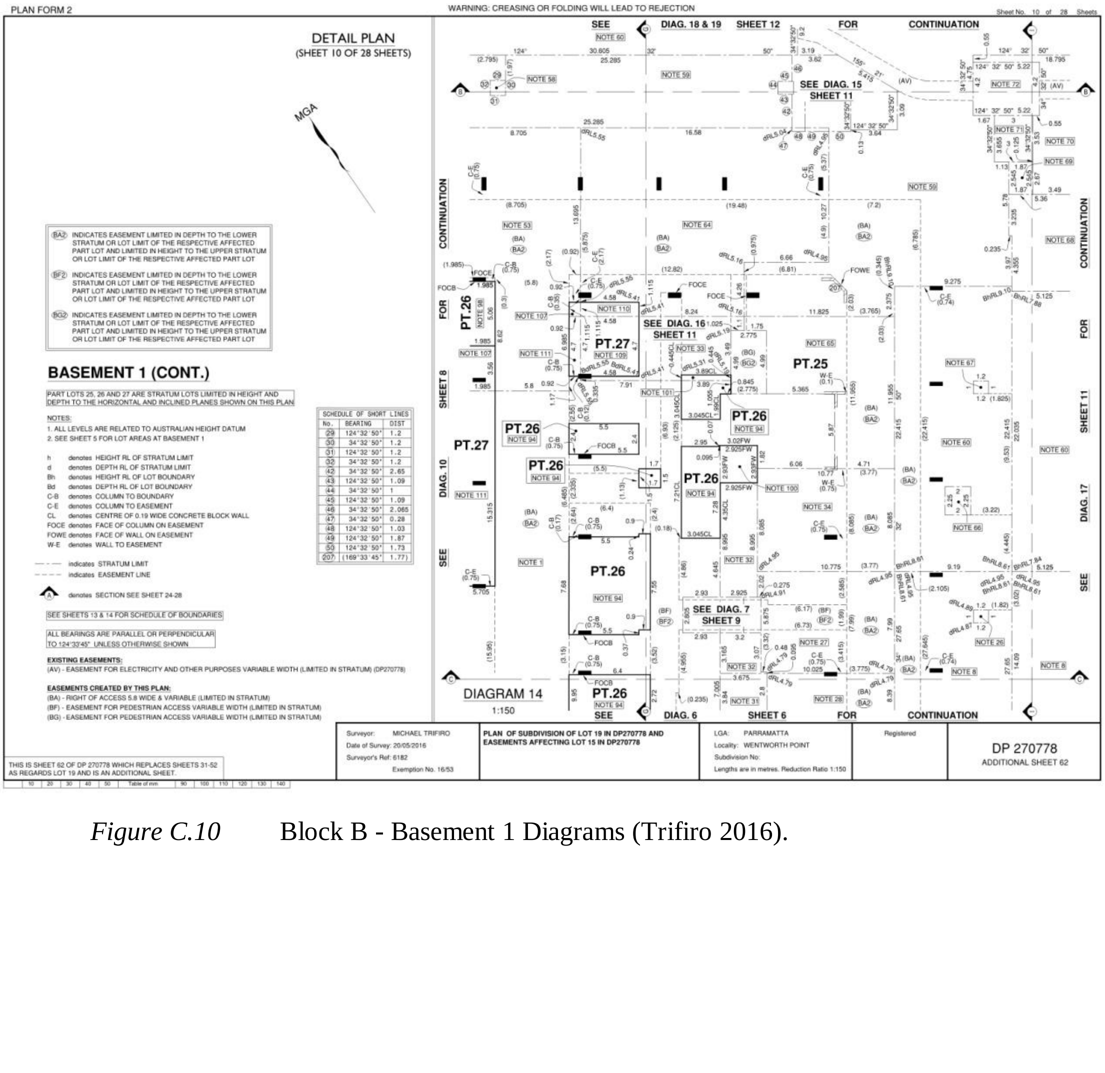

Figure C.10 Block B - Basement 1 Diagrams (Trifiro 2016).

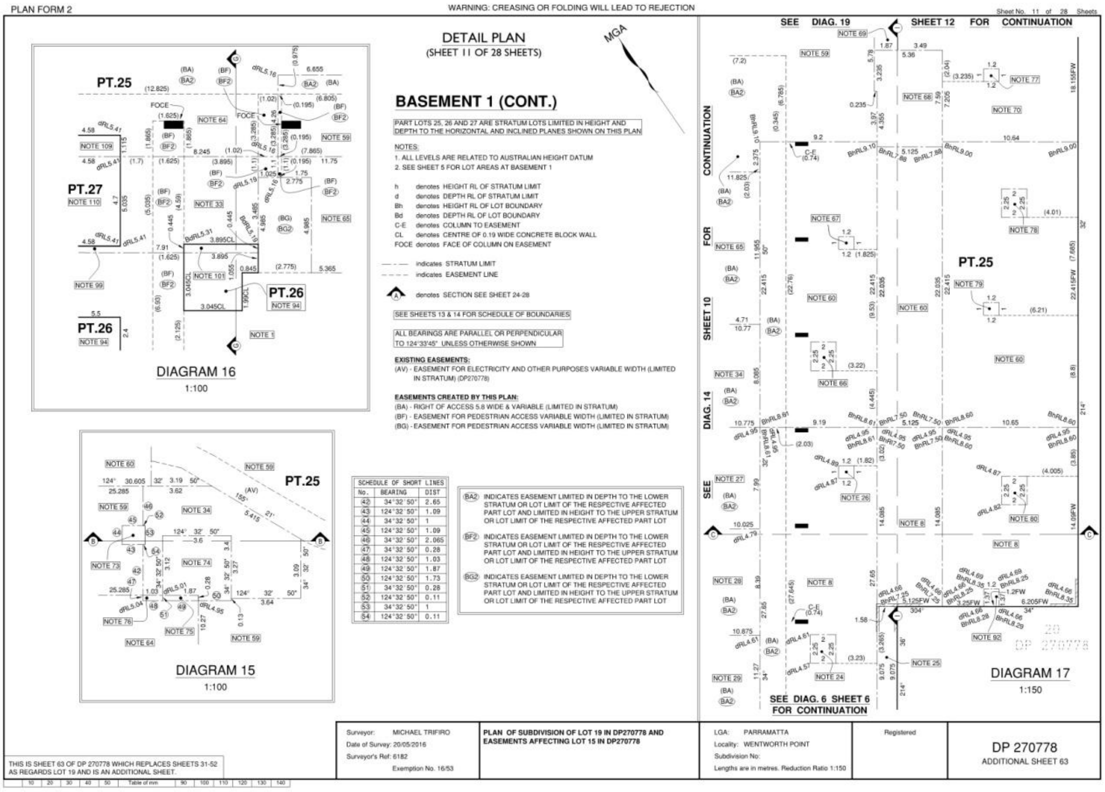

Figure C.11 Block B - Basement 1 Diagrams (Trifiro 2016).

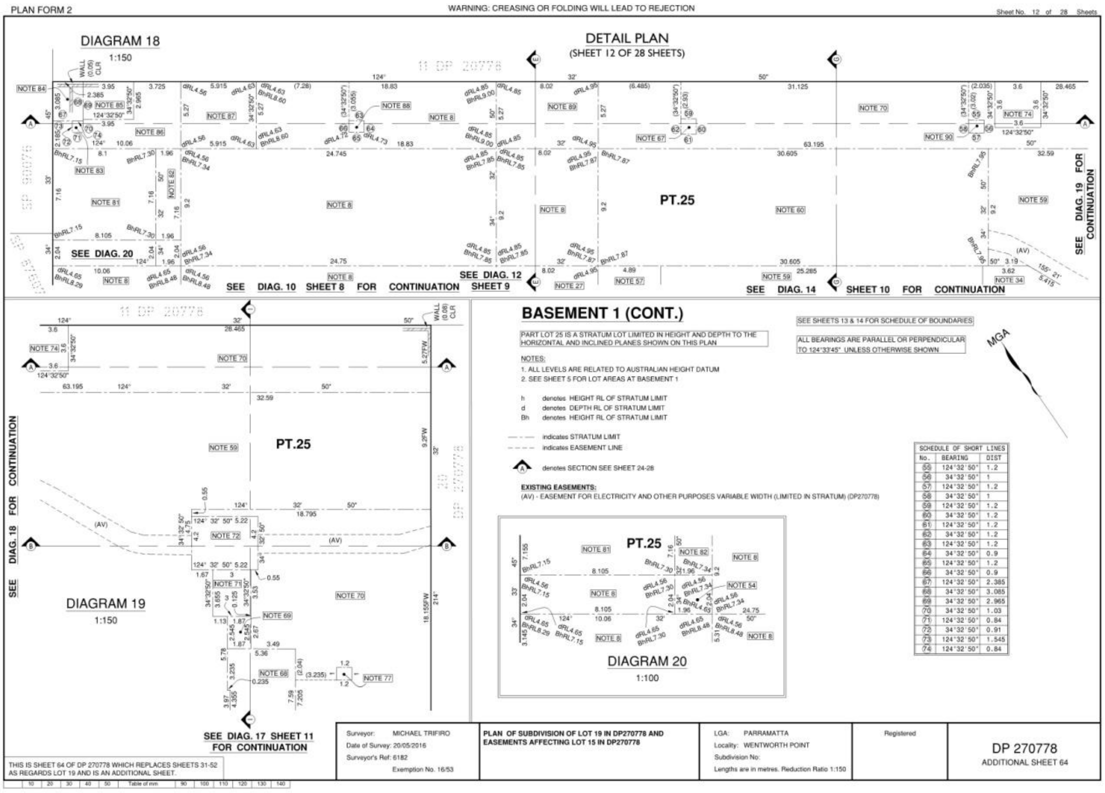

Figure C.12 Block B - Basement 1 Diagrams (Trifiro 2016).

Figure C.13 Block B - Basement 1 Notes (Trifiro 2016).

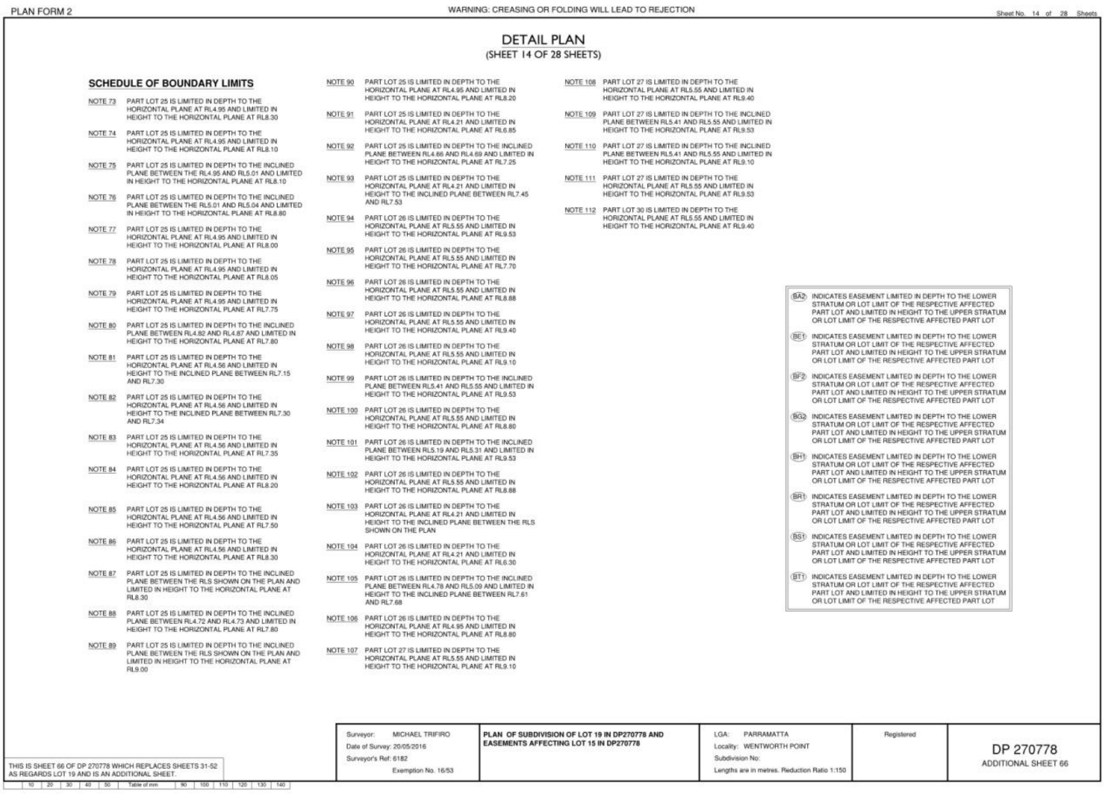

Figure C.14 Block B - Basement 1 Notes (Trifiro 2016).

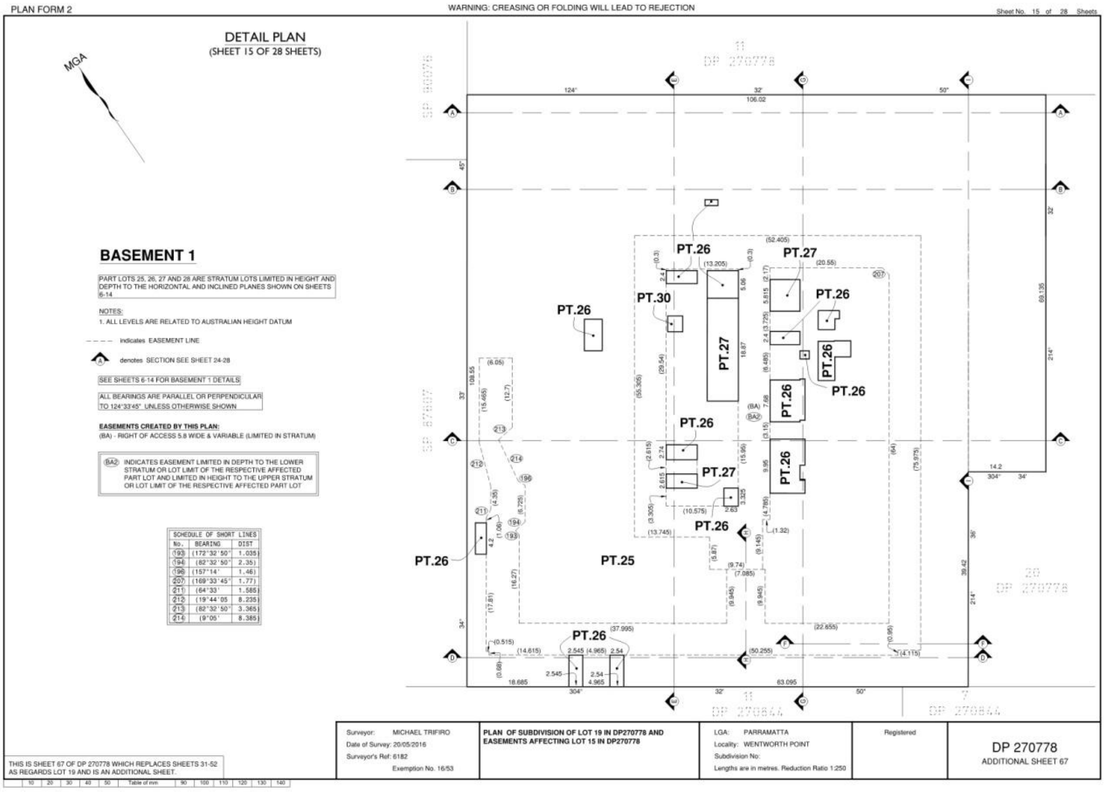

Figure C.15 Block B - Basement 1 Right of Access (Trifiro 2016).

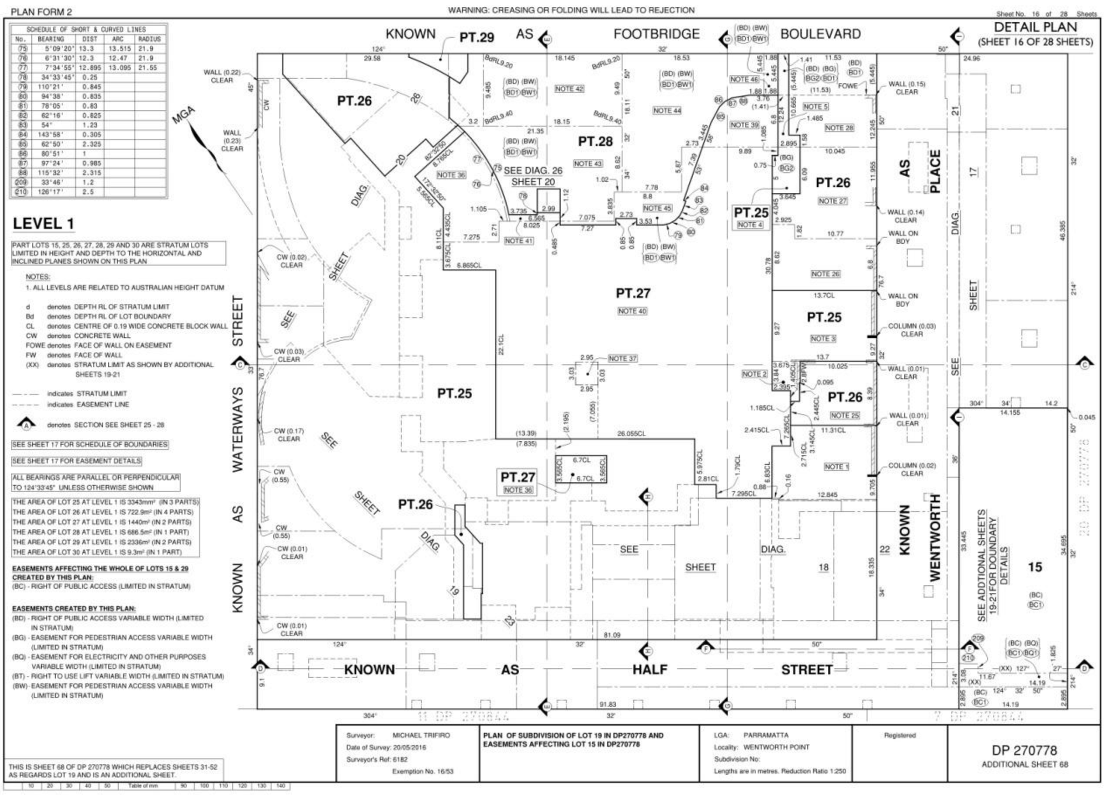

Figure C.16 Block B - Level 1 (Trifiro 2016).

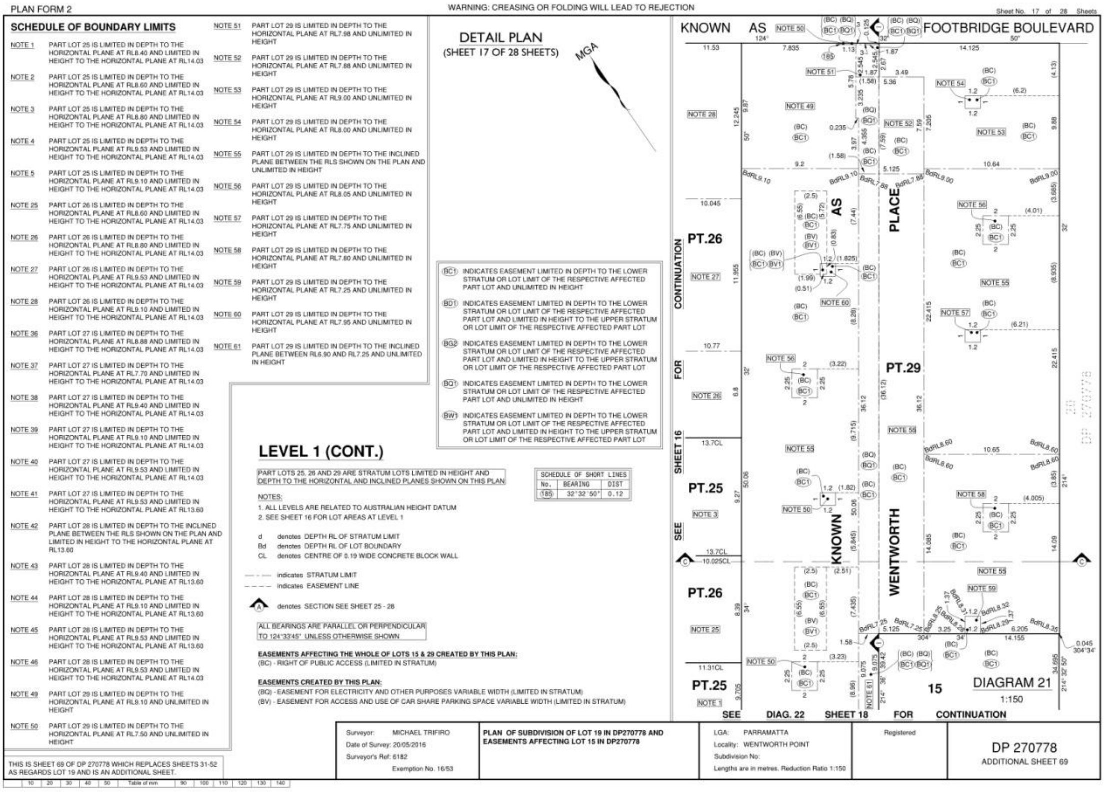

Figure C.17 Block B - Level 1 Diagrams (Trifiro 2016).

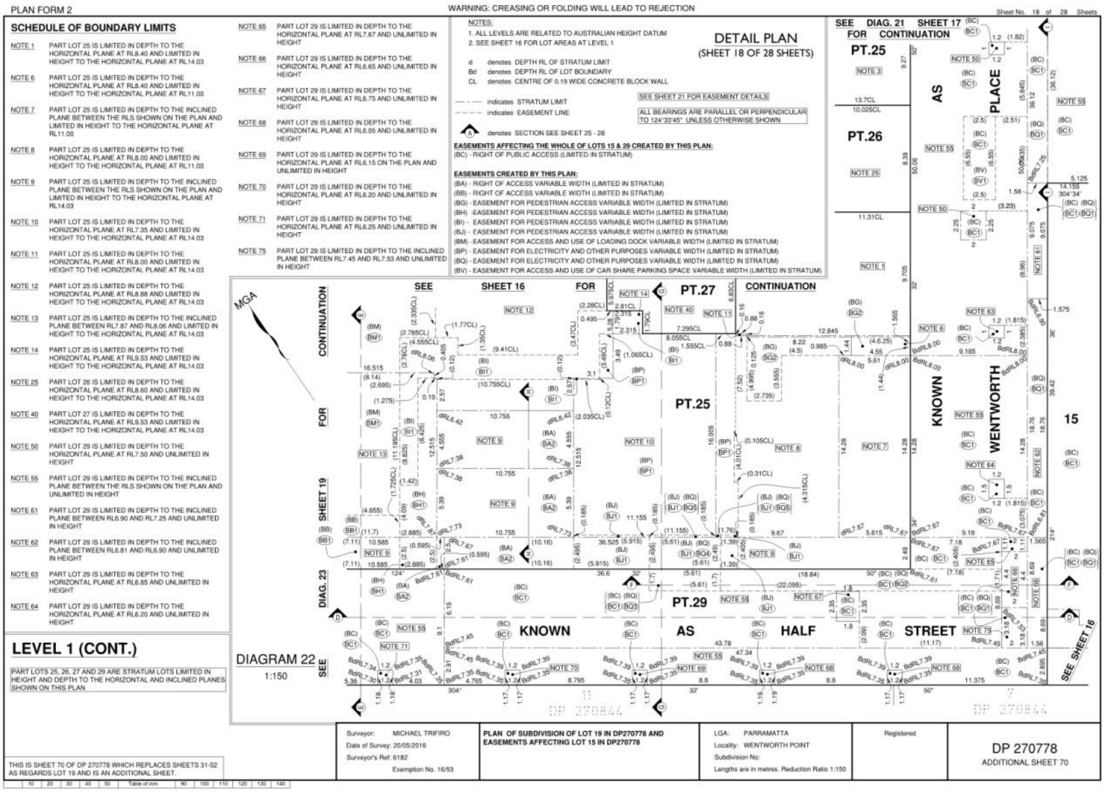

Figure C.18 Block B - Level 1 Diagrams (Trifiro 2016).

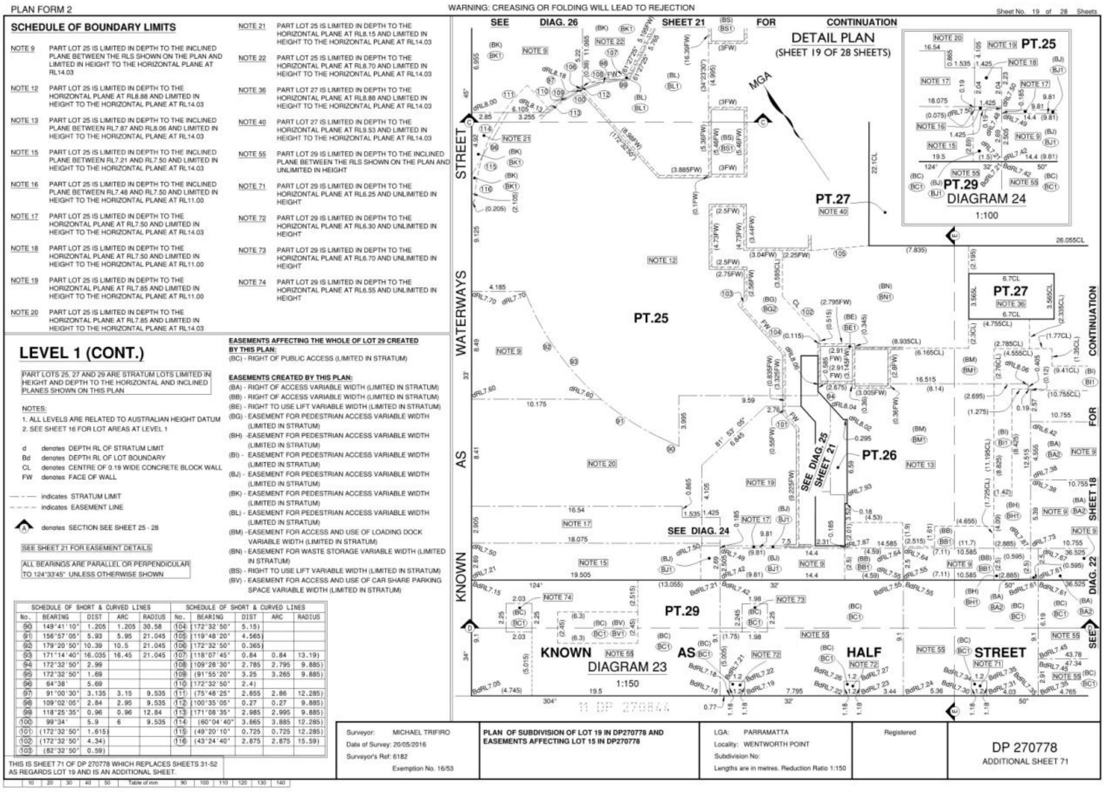

Figure C.19 Block B - Level 1 Diagrams (Trifiro 2016).

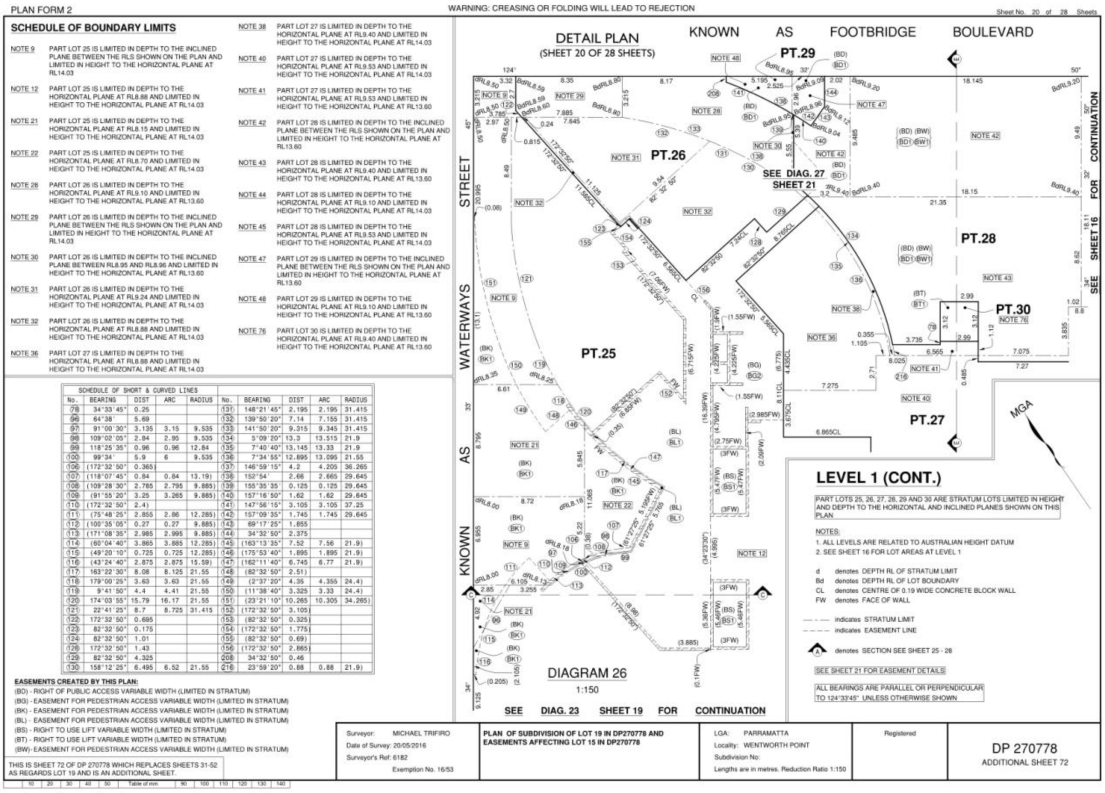

Figure C.20 Block B - Level 1 Diagrams (Trifiro 2016).

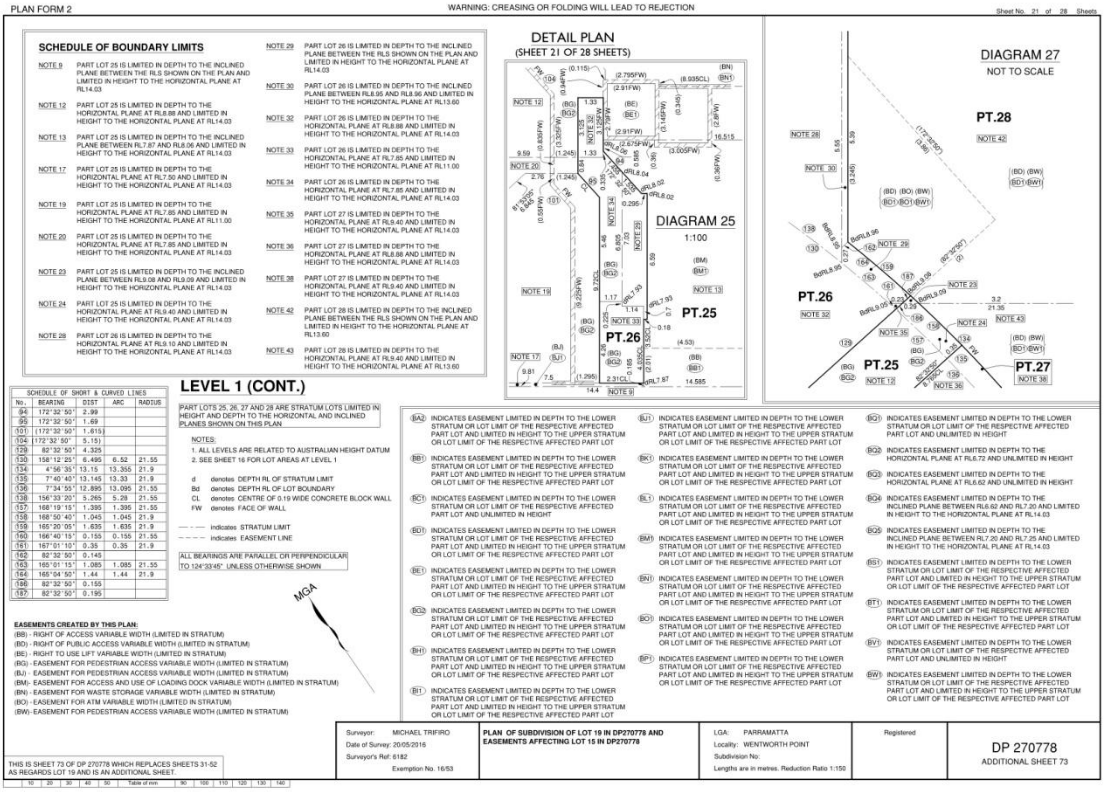

Figure C.21 Block B - Level 1 Diagrams (Trifiro 2016).

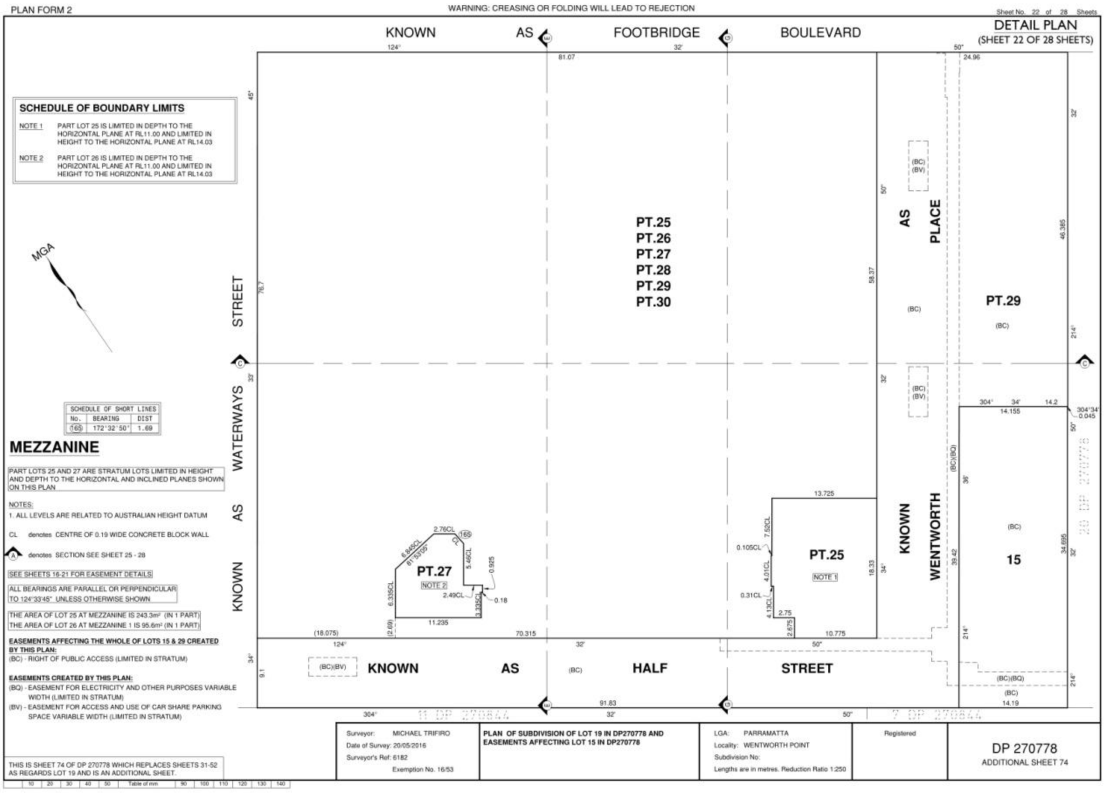

Figure C.22 Block B - Mezzanine (Trifiro 2016).

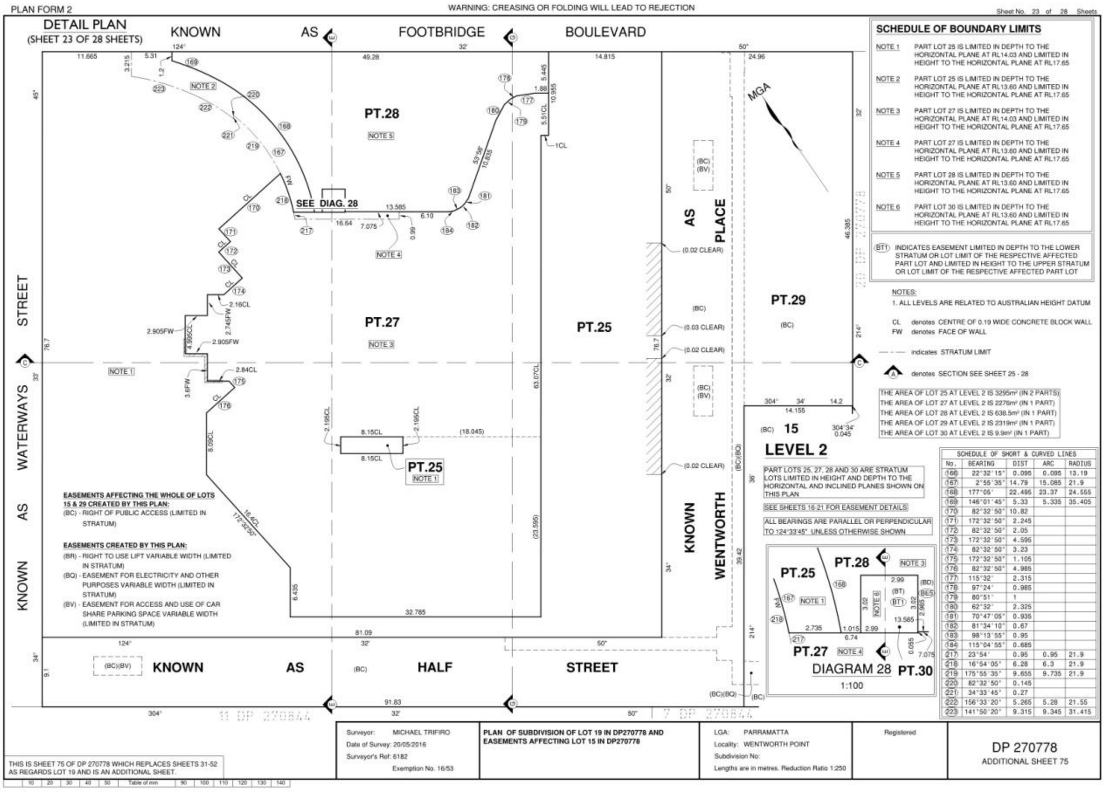

Figure C.23 Block B - Level 2 (Trifiro 2016).

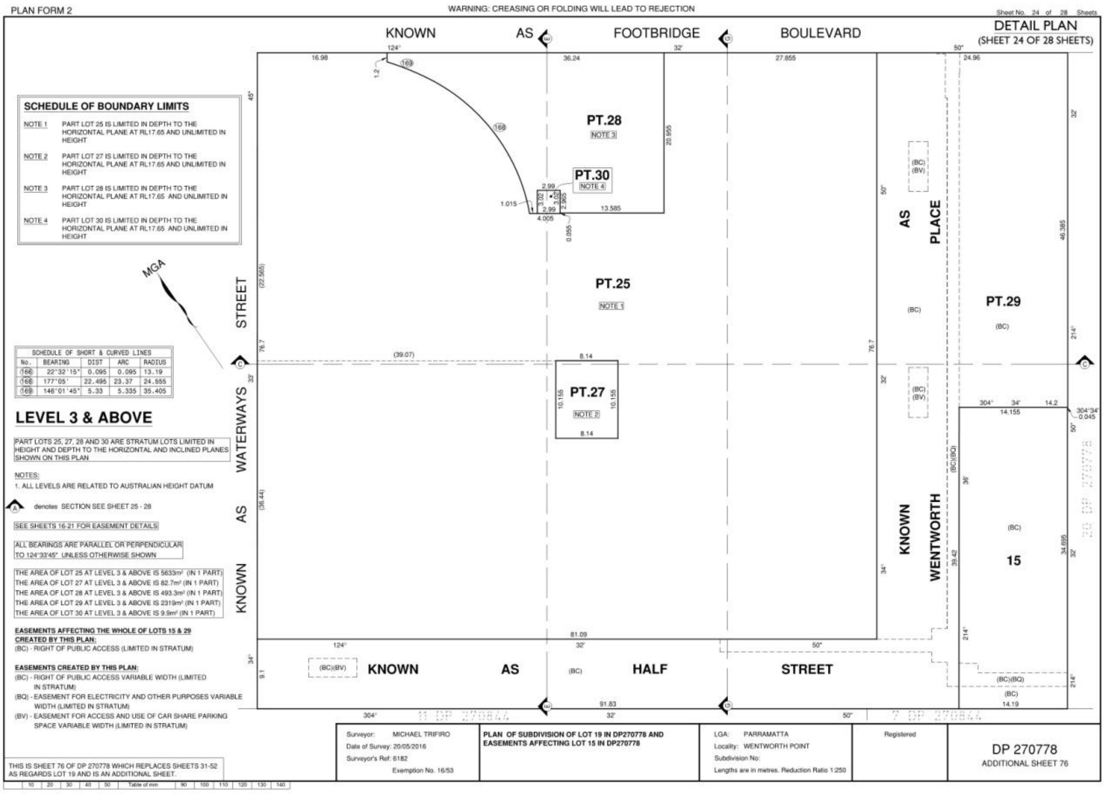

Figure C.24 Block B - Level 3 & Above (Trifiro 2016).

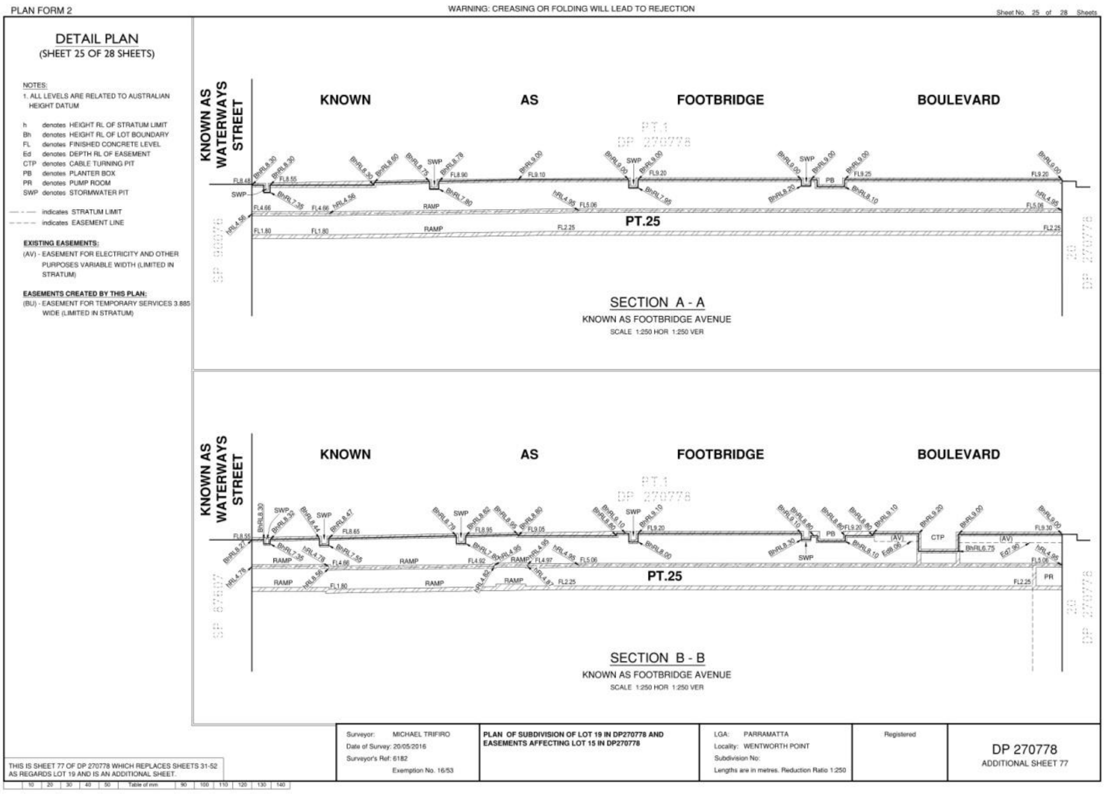

Figure C.25 Block B - Sections (Trifiro 2016).

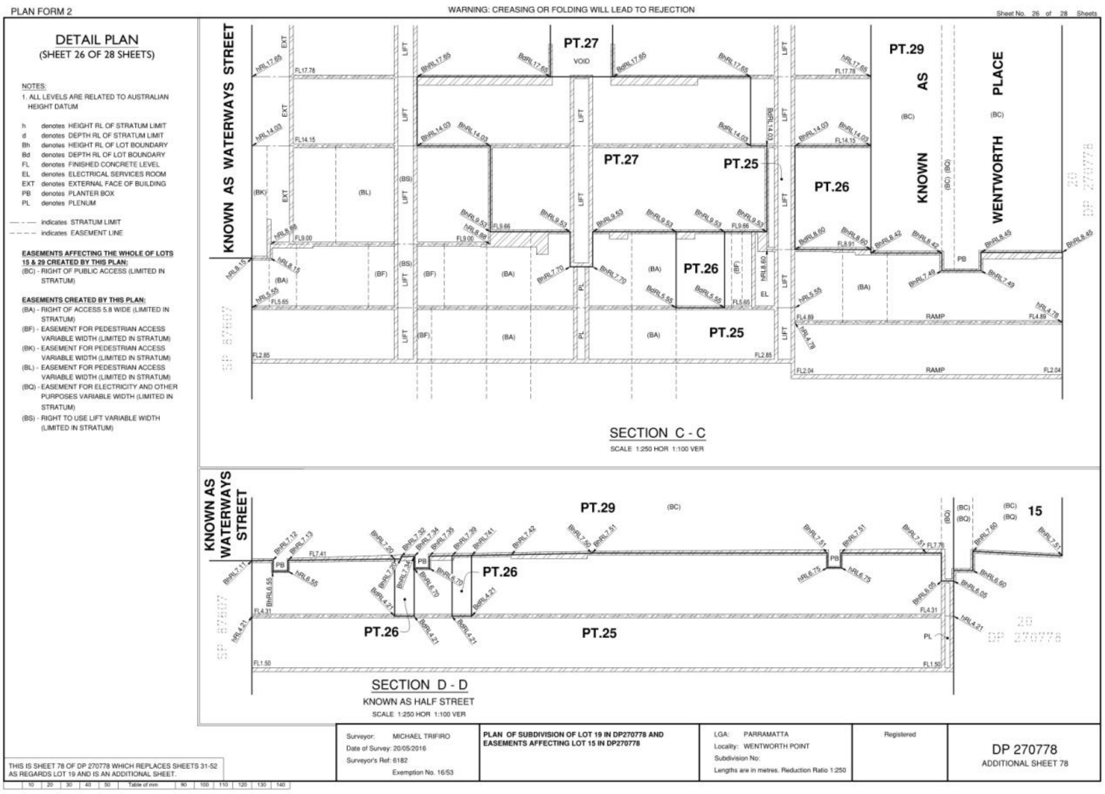

Figure C.26 Block B - Sections (Trifiro 2016).

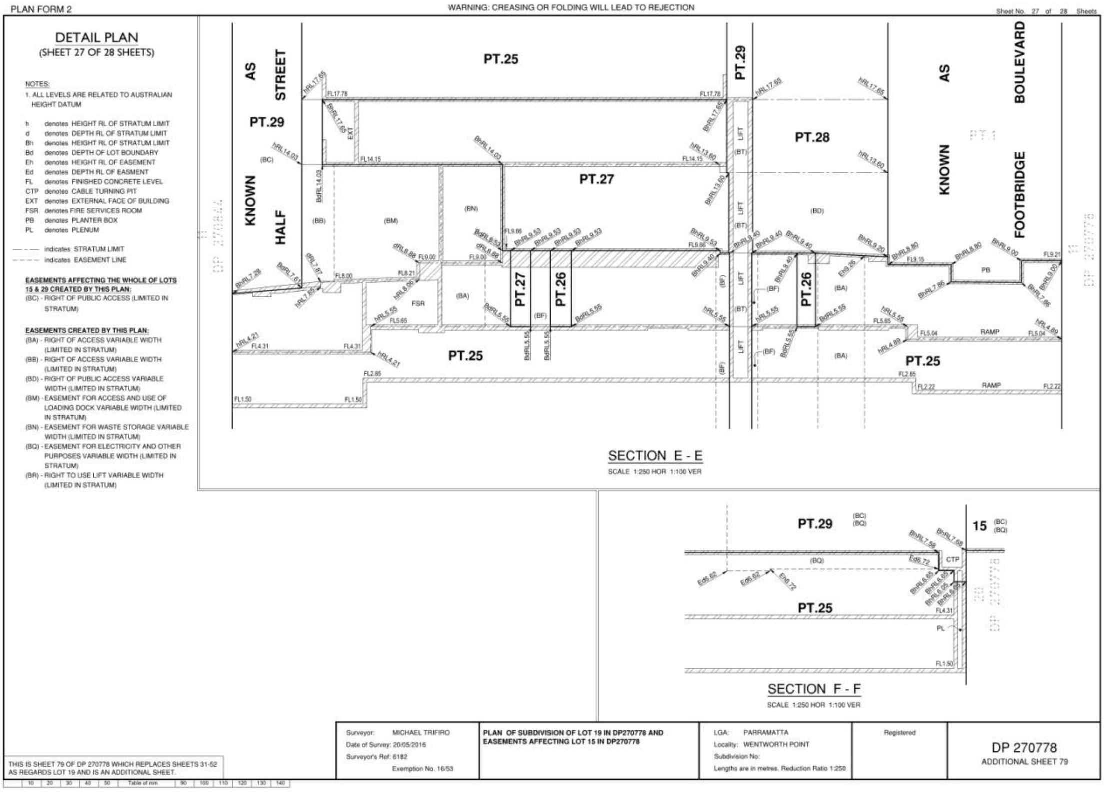

Figure C.27 Block B - Sections (Trifiro 2016).

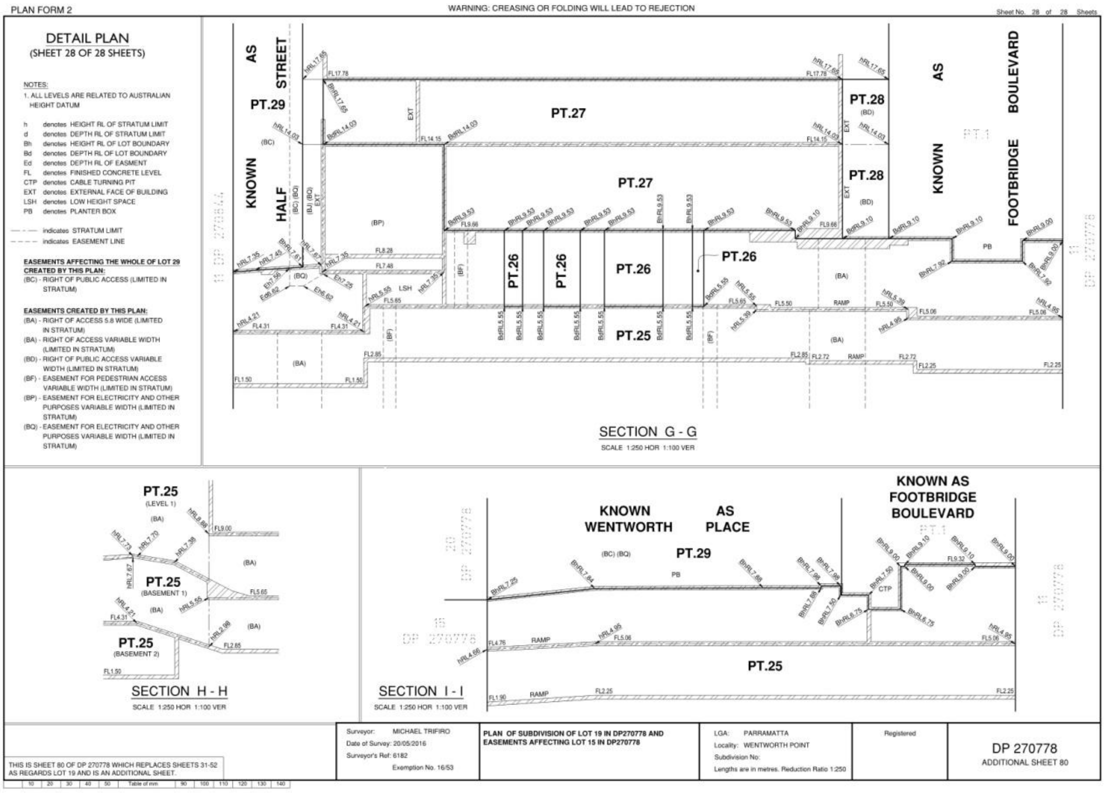

Figure C.28 Block B - Sections (Trifiro 2016).

Deposited Plan 1177634

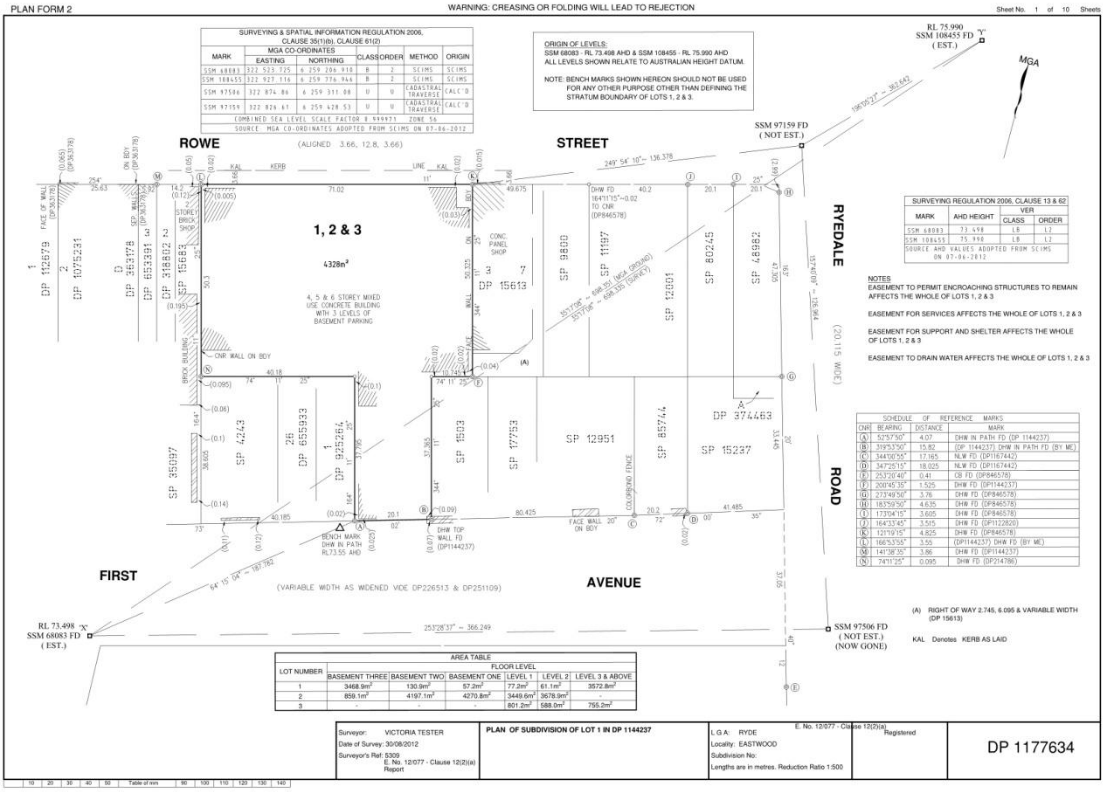

Figure C.29 Location Plan (Tester 2012).

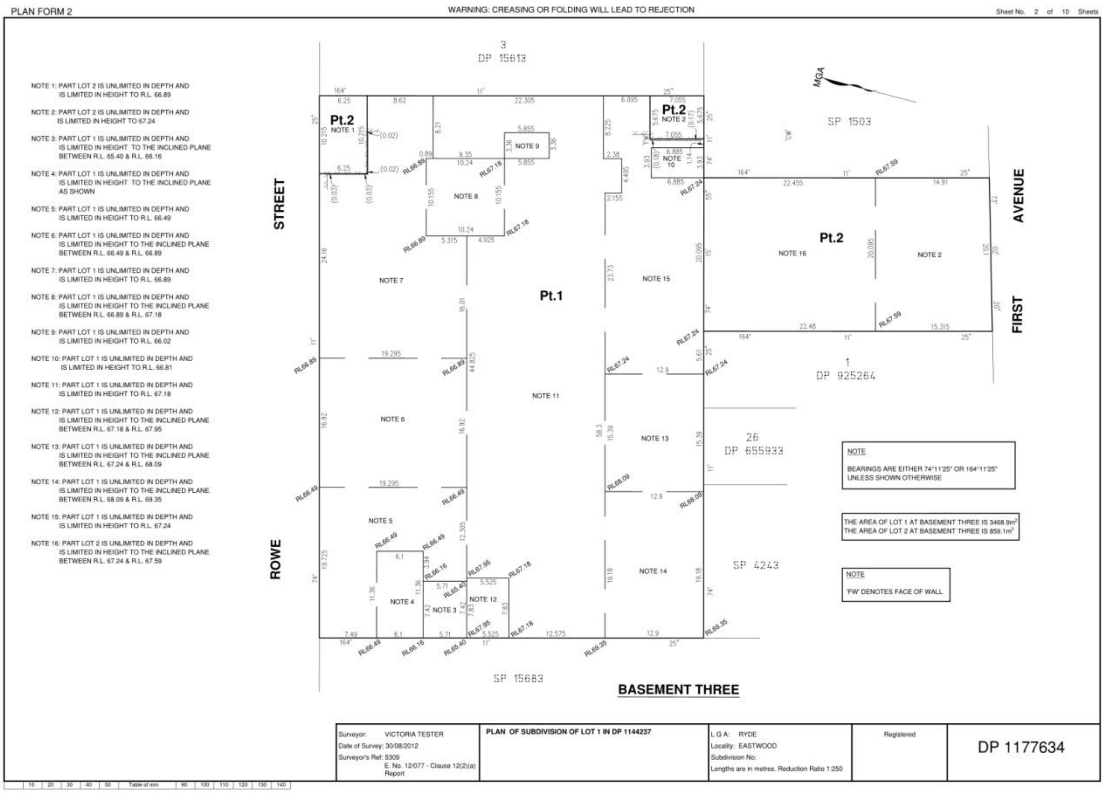

Figure C.30 Basement 3 & Below (Tester 2012).

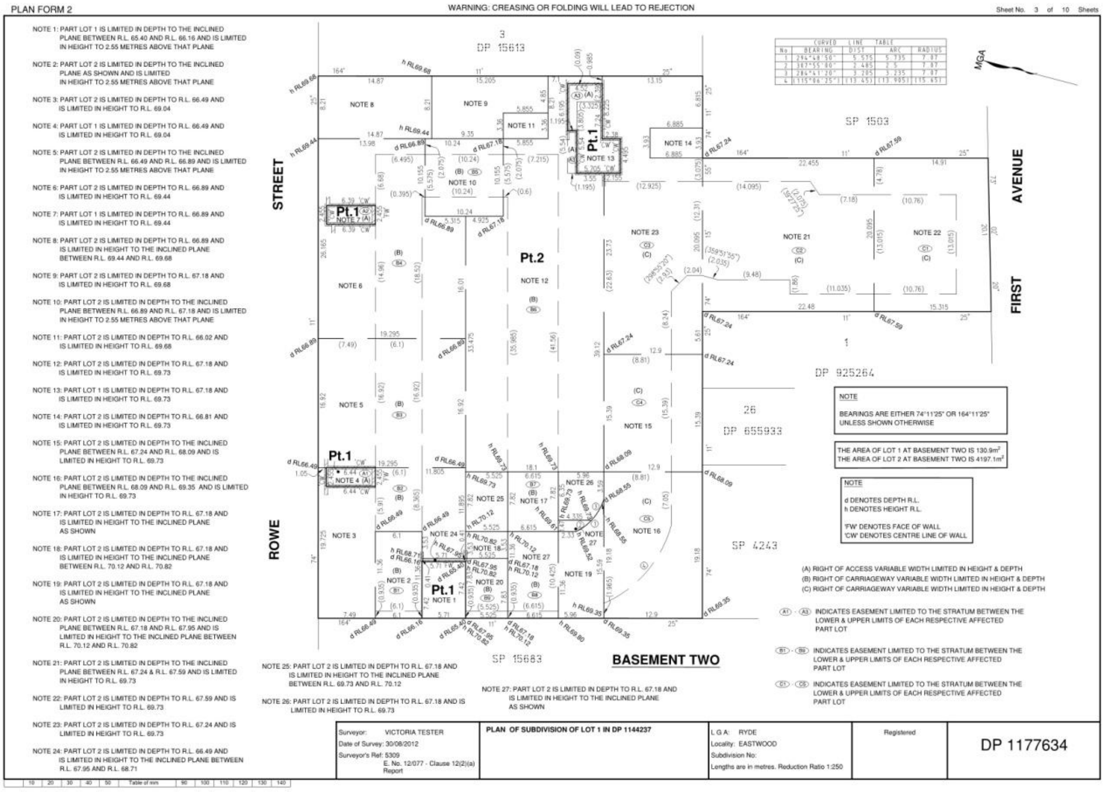

Figure C.31 Basement 2 (Tester 2012).

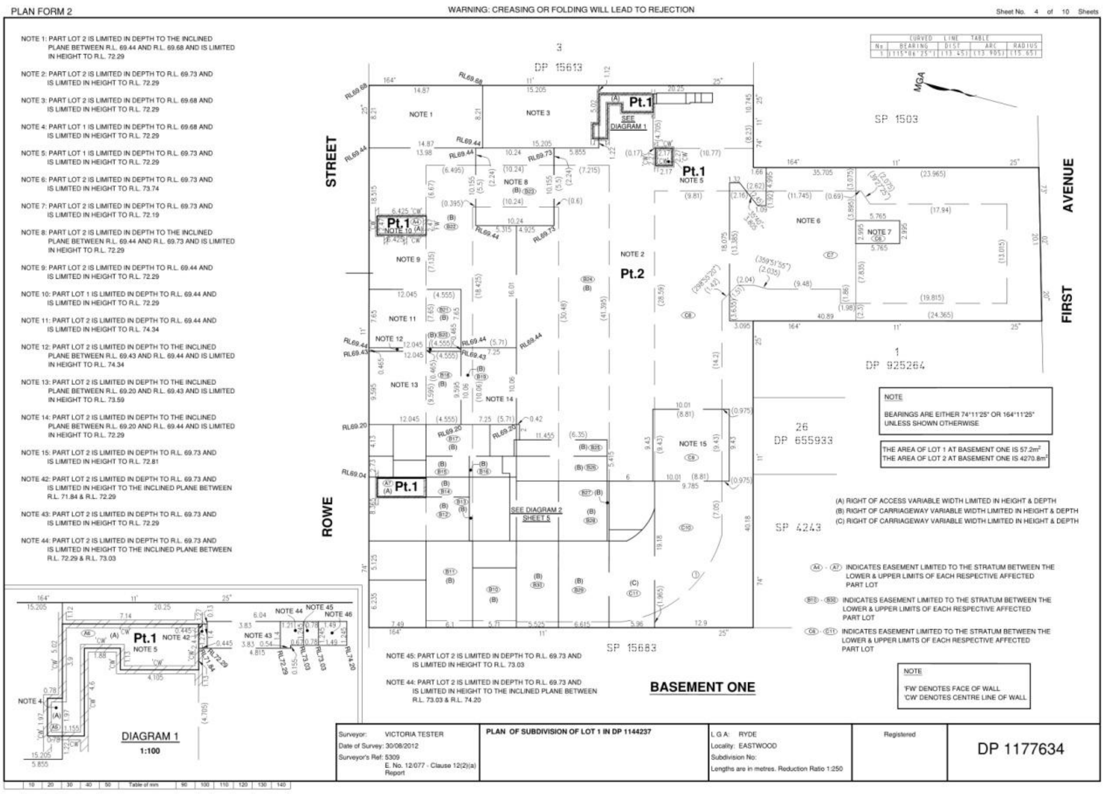

Figure C.32 Basement 1 (Tester 2012).

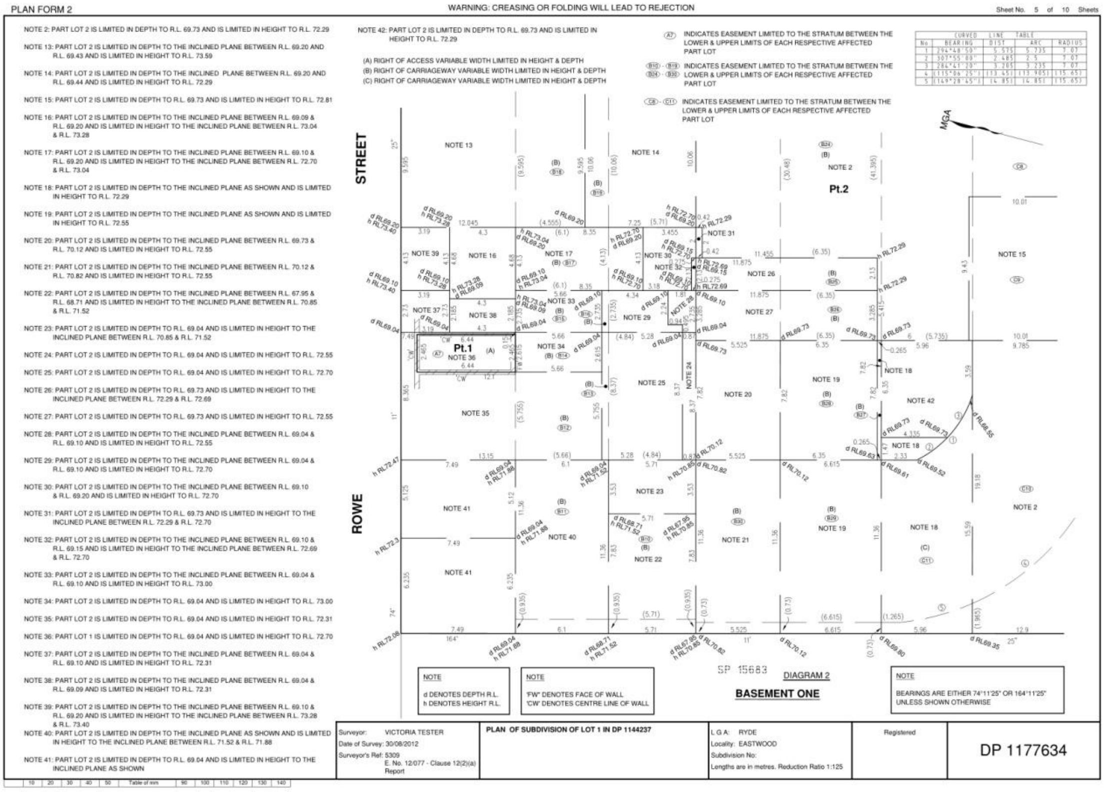

Figure C.33 Basement 1 Diagrams (Tester 2012).

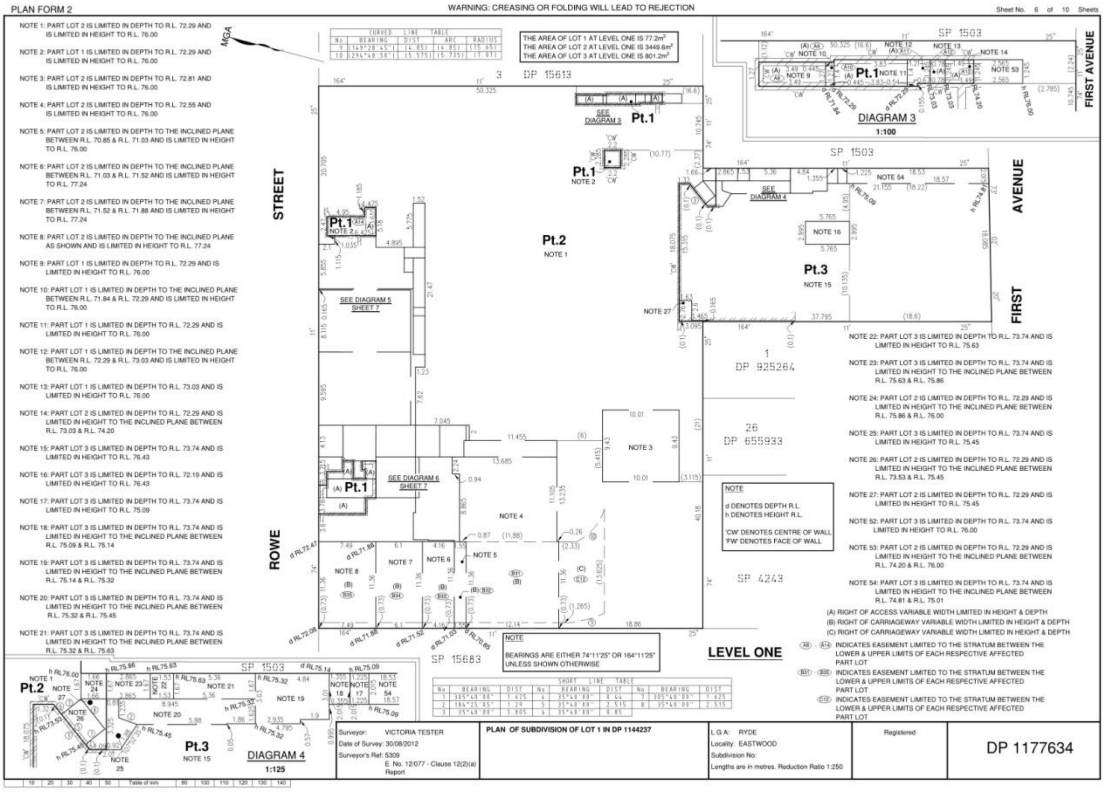

Figure C.34 Level 1 (Tester 2012).

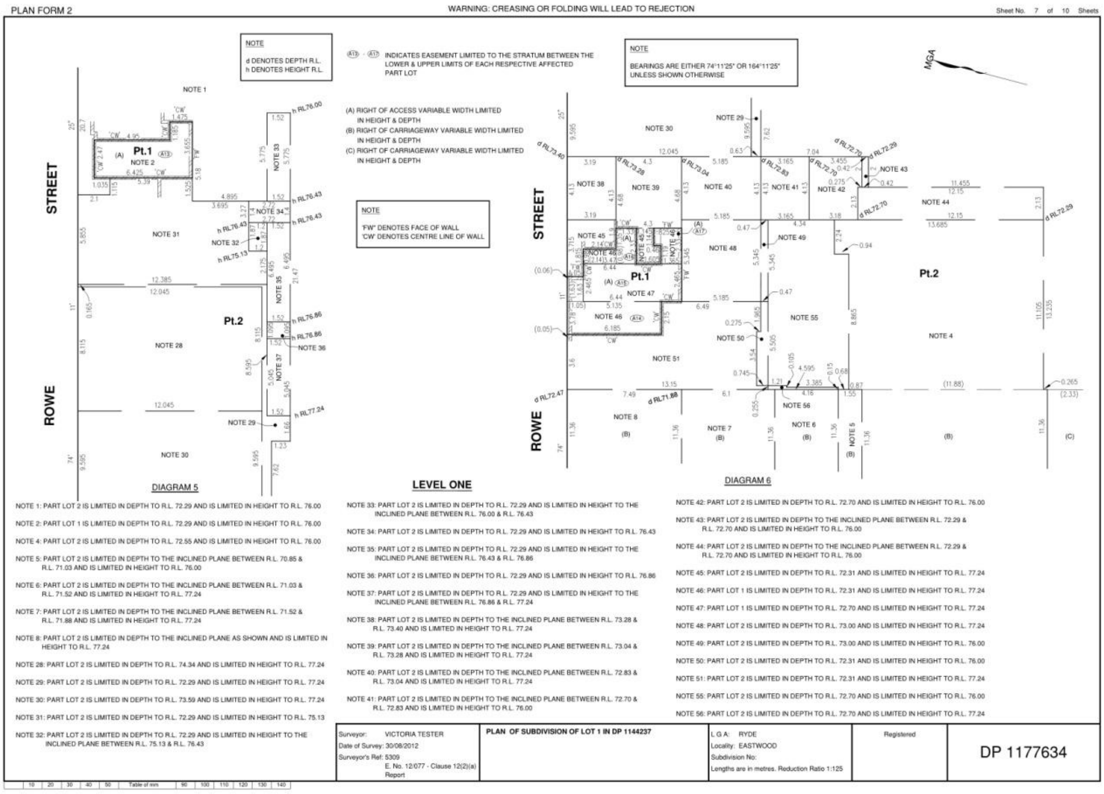

Figure C.35 Level 1 Diagrams (Tester 2012).

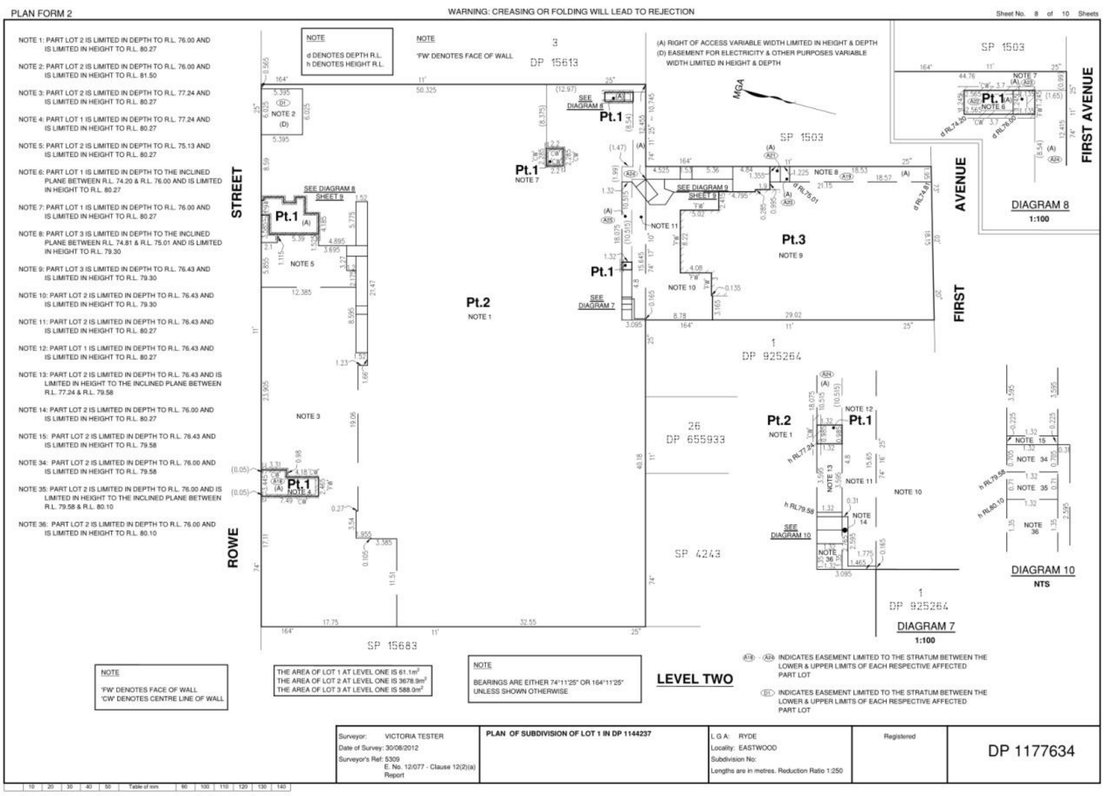

Figure C.36 Level 2 (Tester 2012).

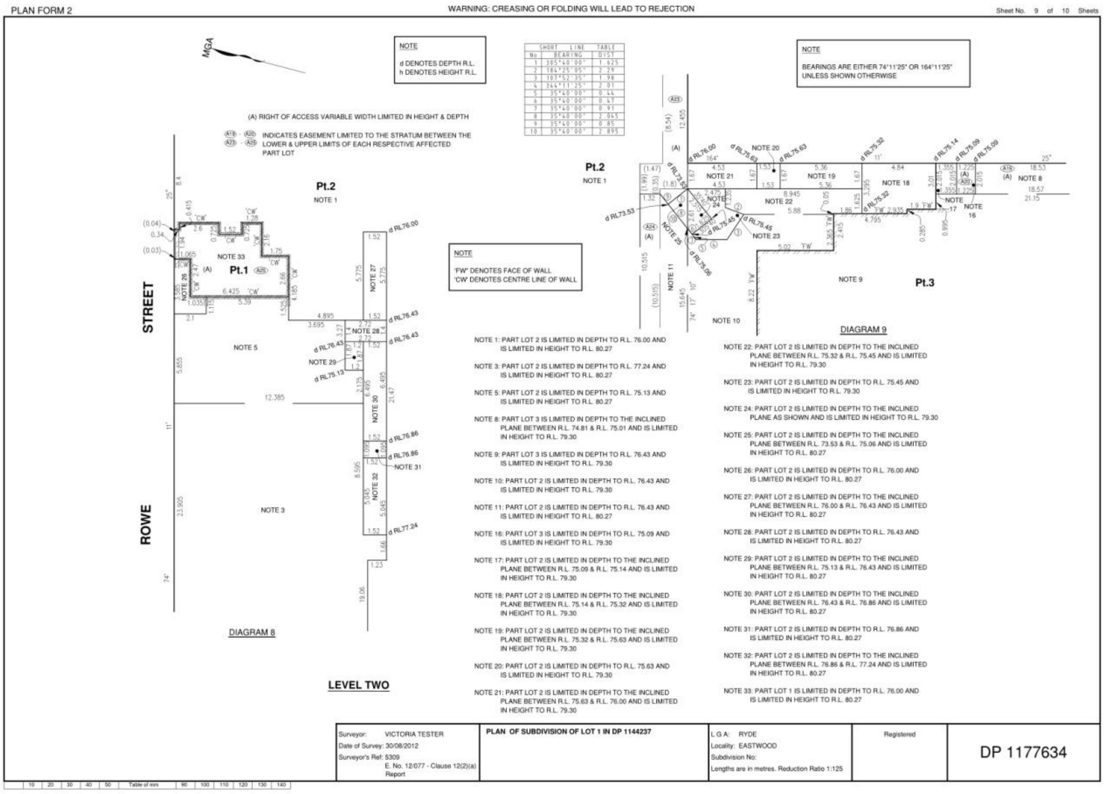

Figure C.37 Level 2 Diagrams (Tester 2012).

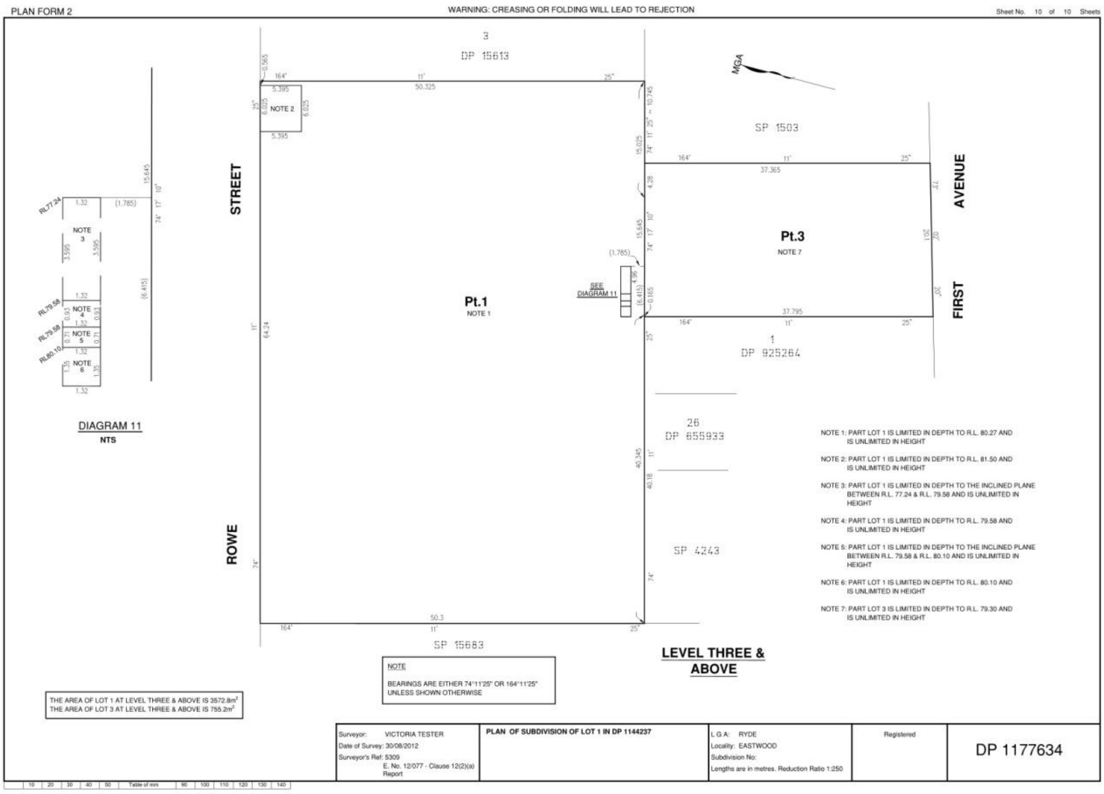

Figure C.38 Level 3 & Above (Tester 2012).

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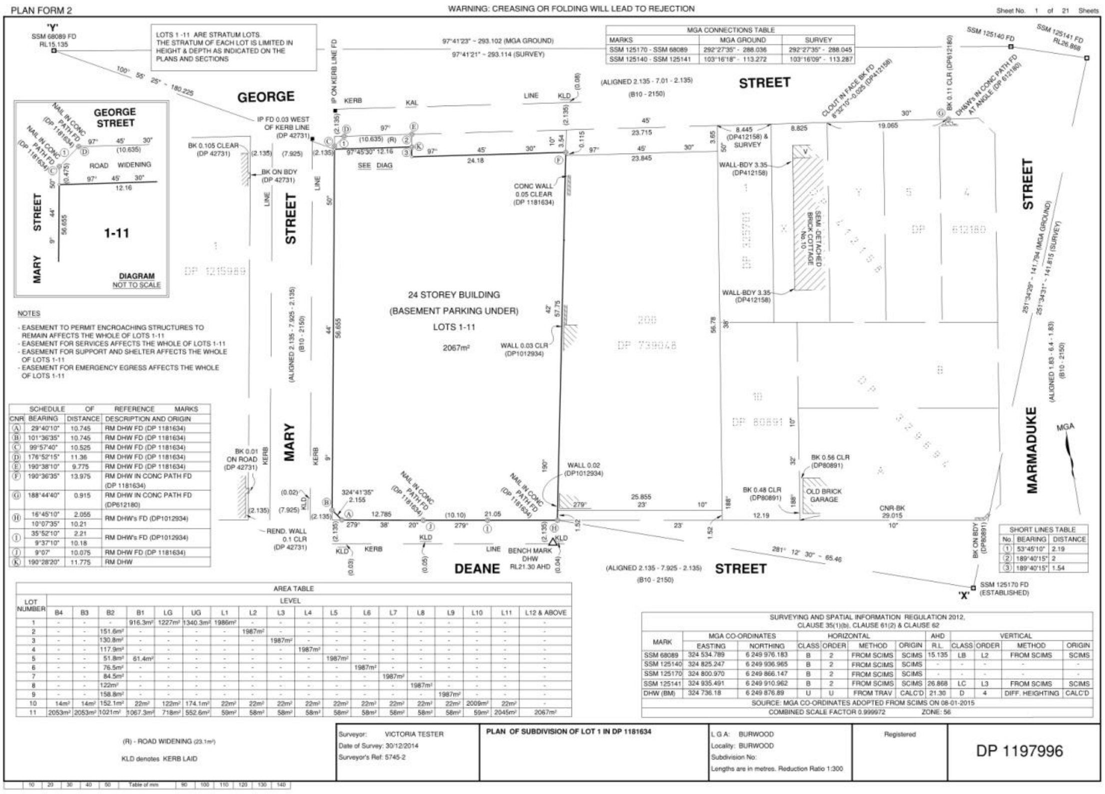

Figure C.39 Location Plan (Tester 2016a).

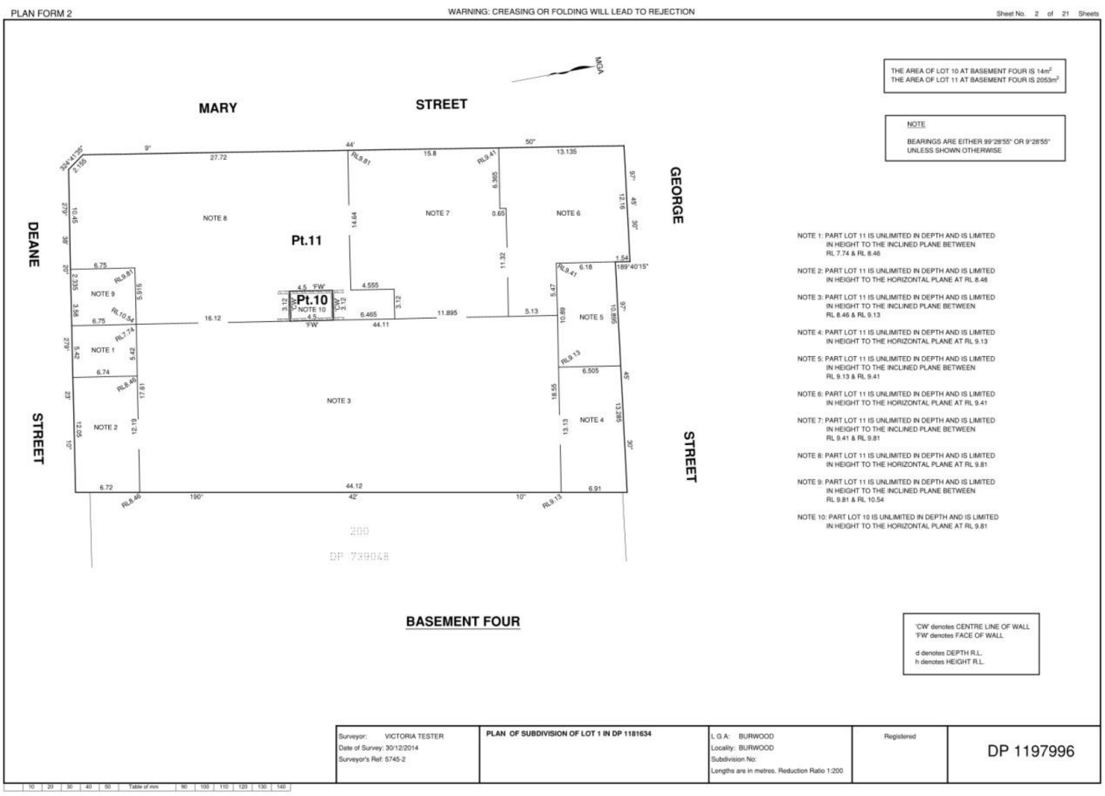

Figure C.40 Basement 4 & Below (Tester 2016a).

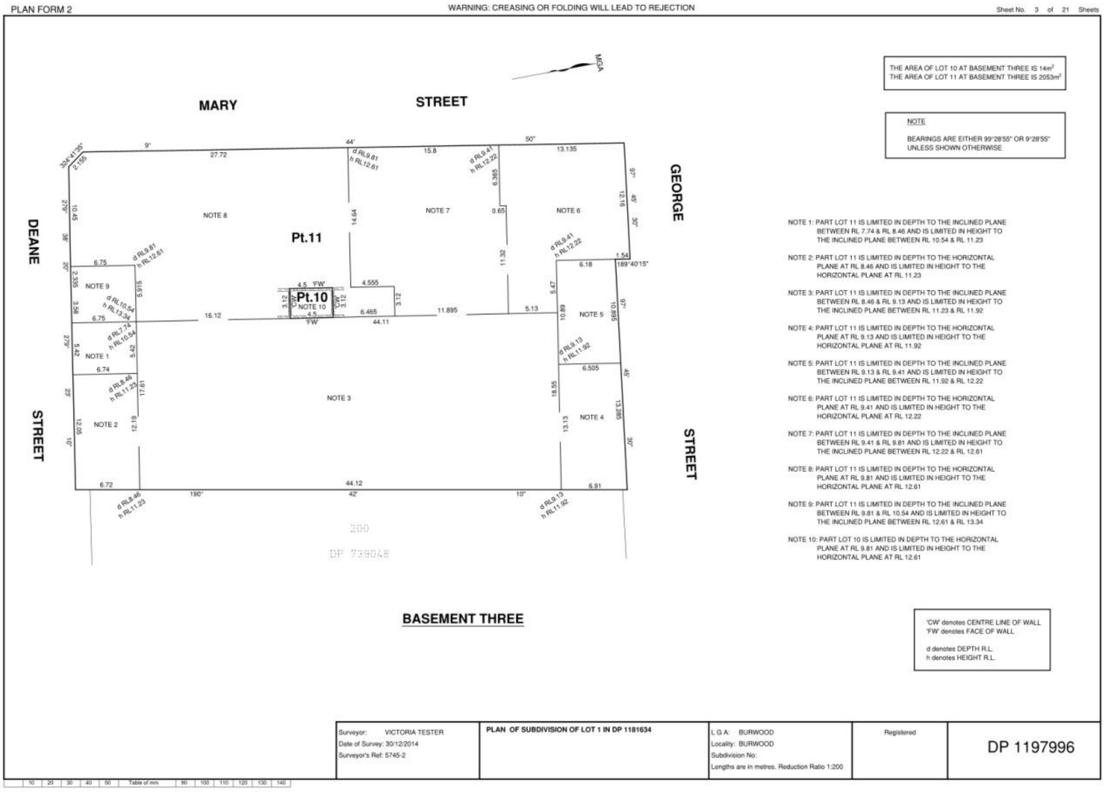

Figure C.41 Basement 3 (Tester 2016a).

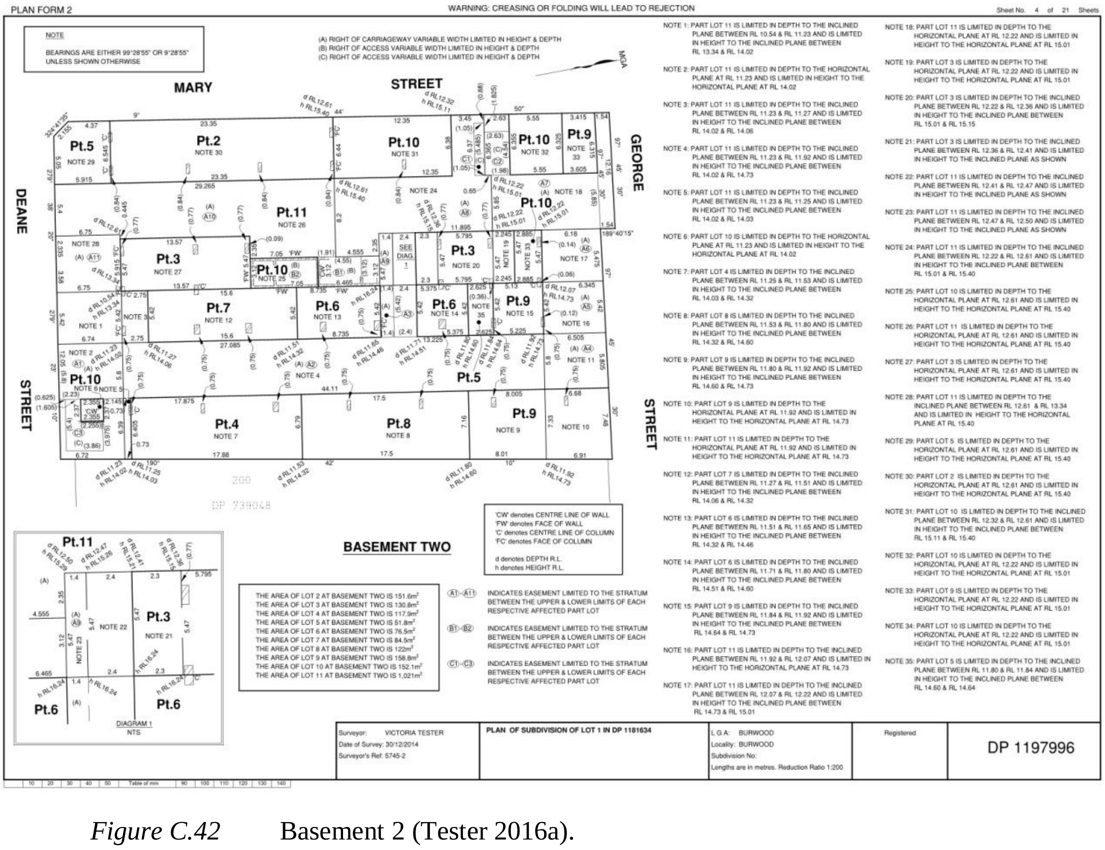

Figure C.42 Basement 2 (Tester 2016a).

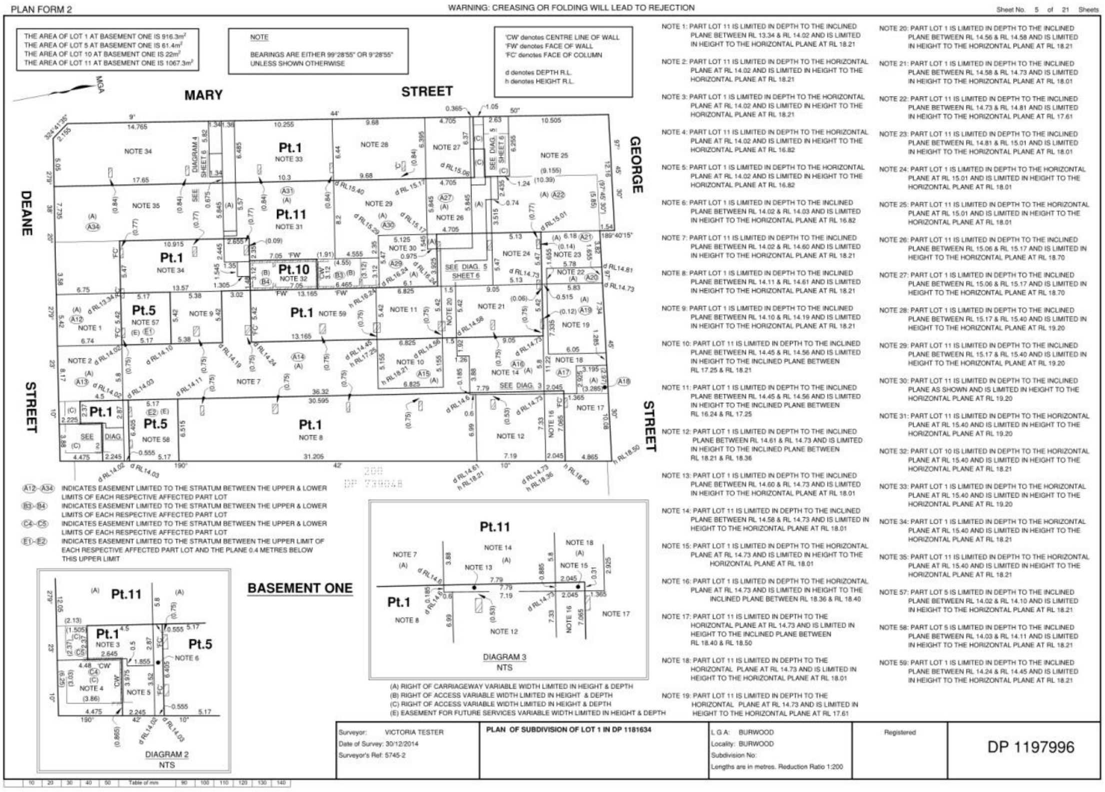

Figure C.43 Basement 1 (Tester 2016a).

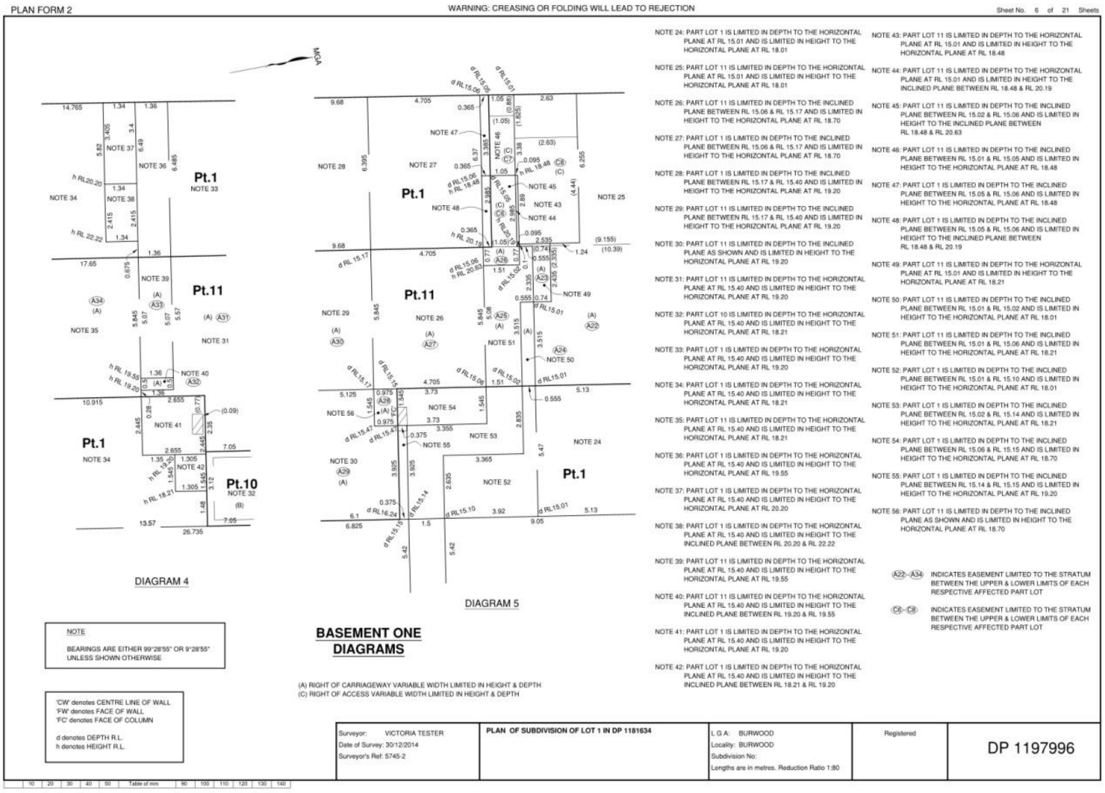

Figure C.44 Basement 1 Diagrams (Tester 2016a).

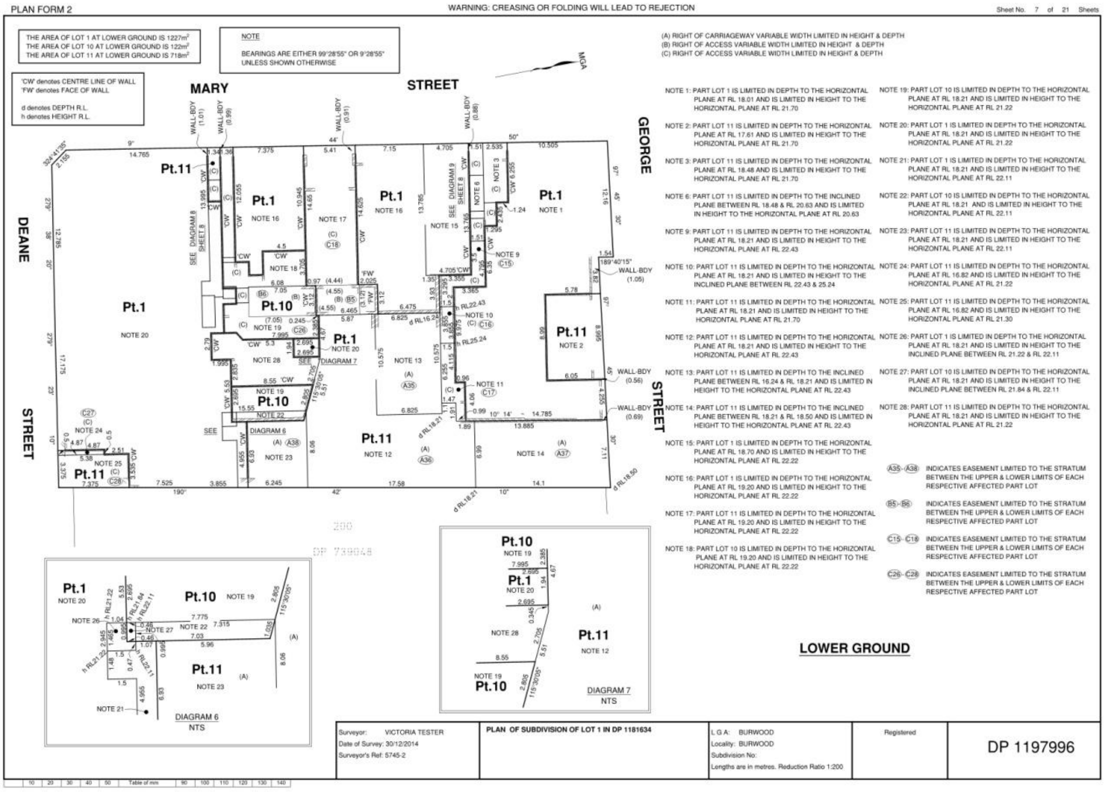

Figure C.45 Lower Ground (Tester 2016a).

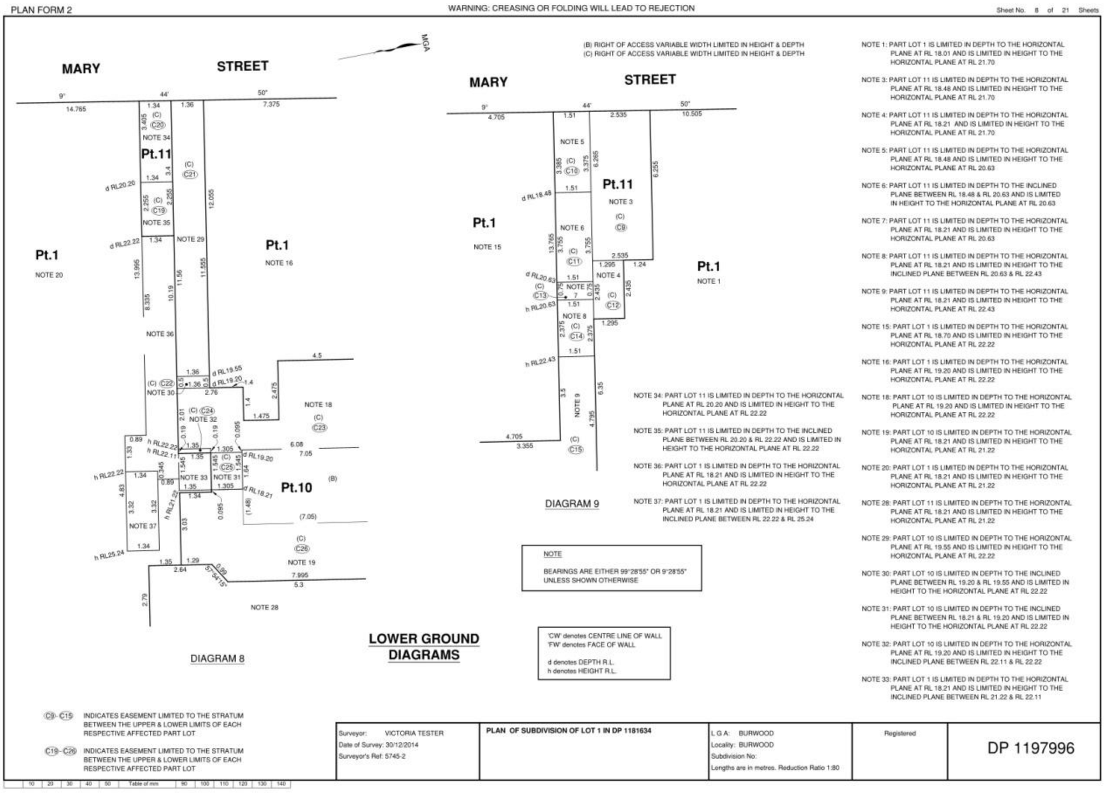

Figure C.46 Lower Ground Diagrams (Tester 2016a).

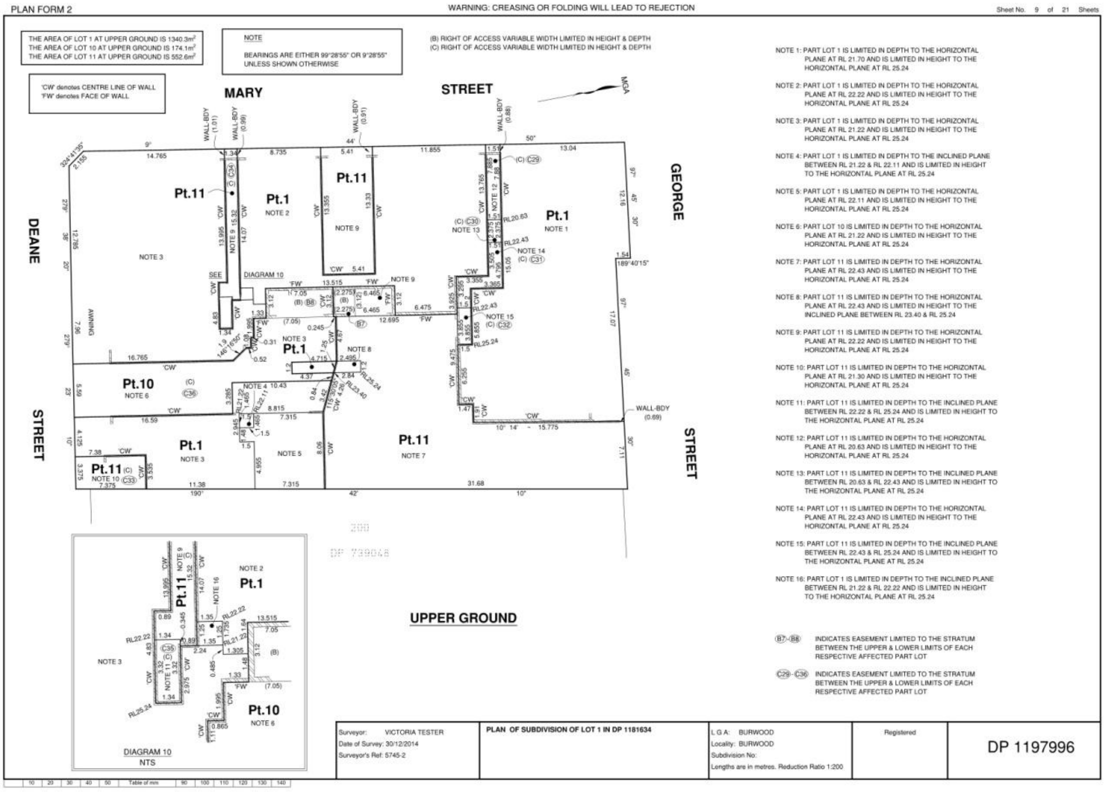

Figure C.47 Upper Ground (Tester 2016a).

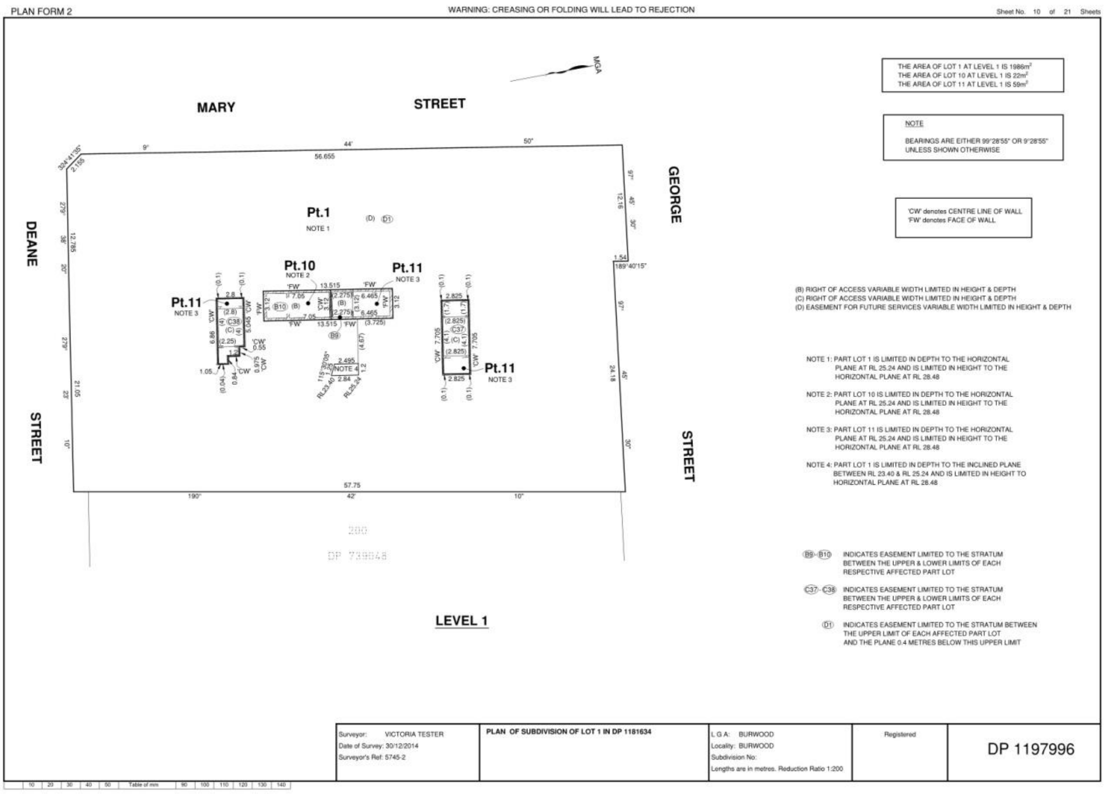

Figure C.48 Level 1 (Tester 2016a).

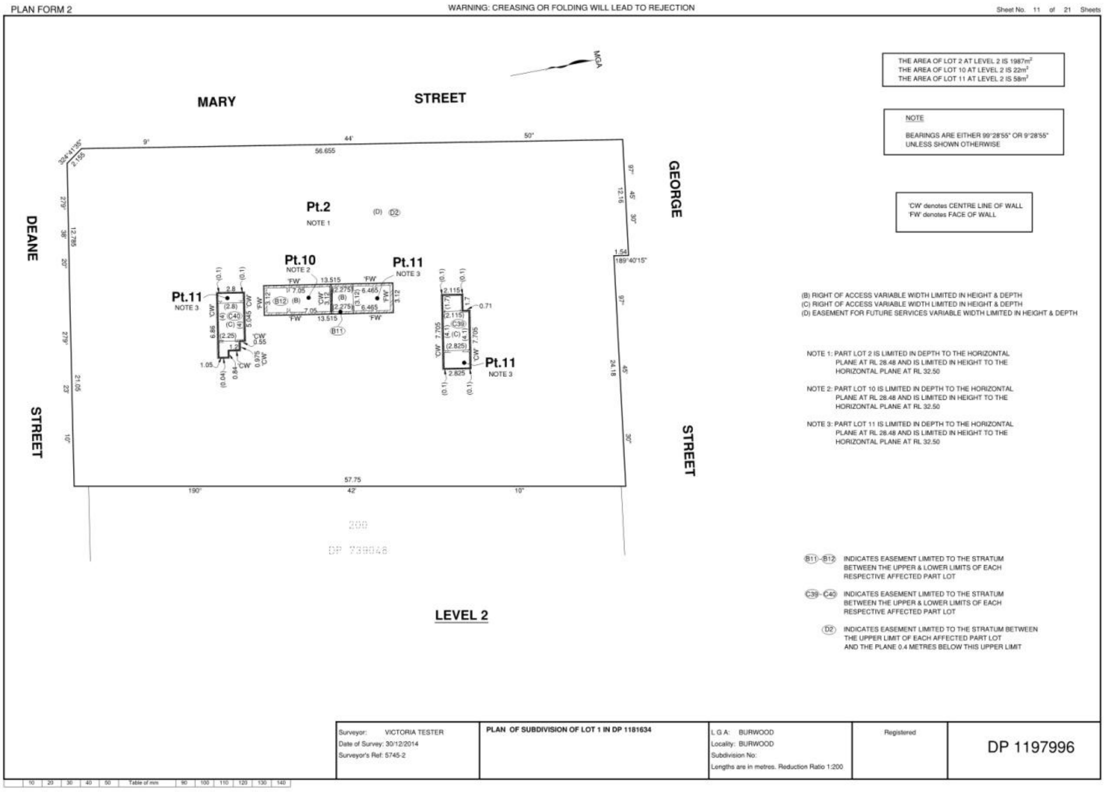

Figure C.49 Level 3 (Tester 2016a).

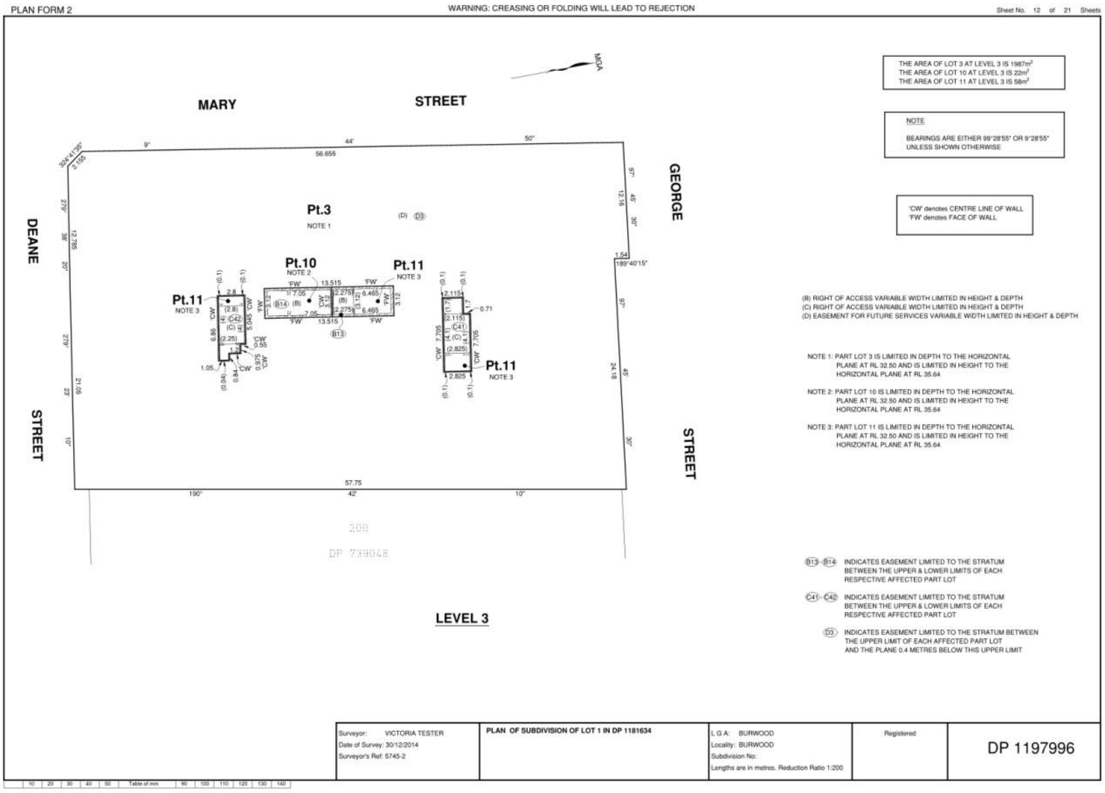

Figure C.50 Level 3 (Tester 2016a).

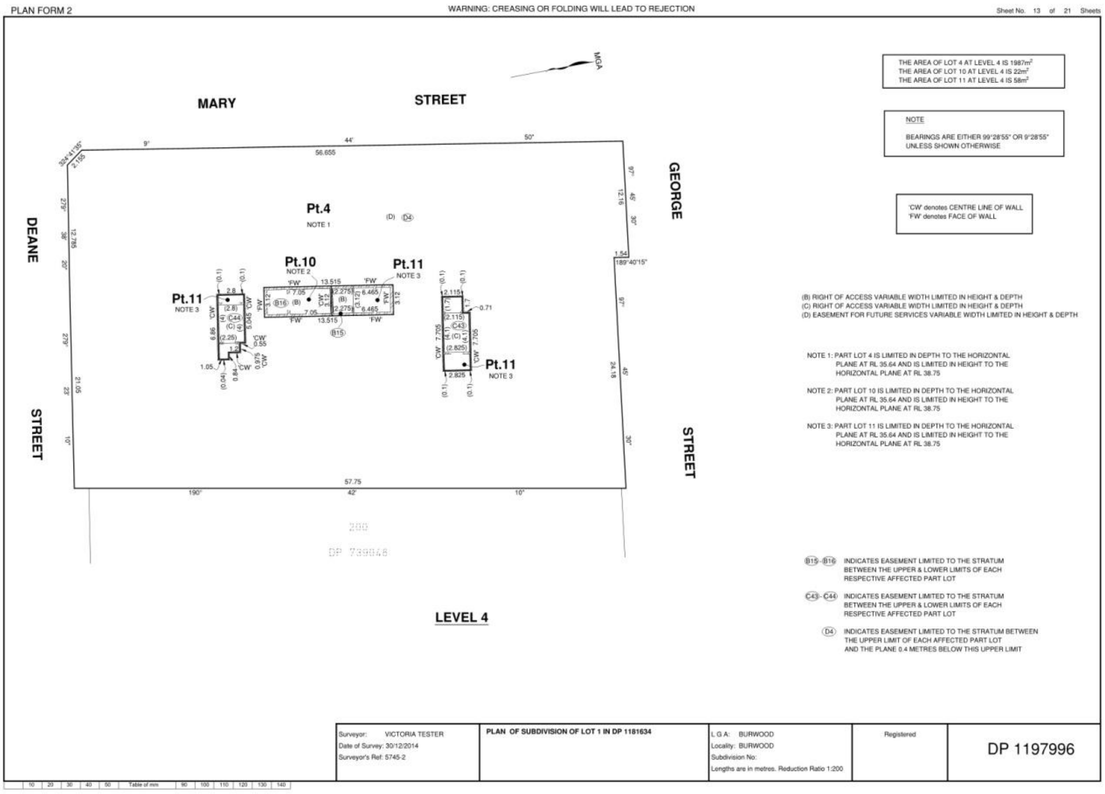

Figure C.51 Level 4 (Tester 2016a).

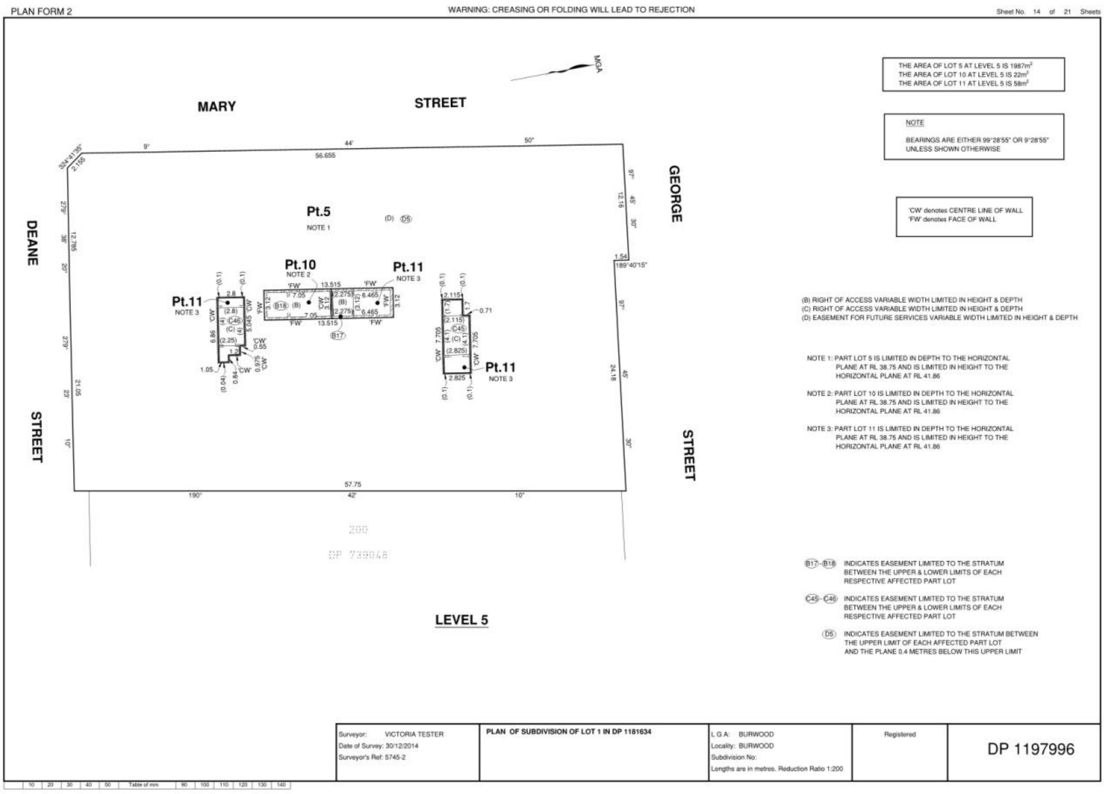

Figure C.52 Level 5 (Tester 2016a).

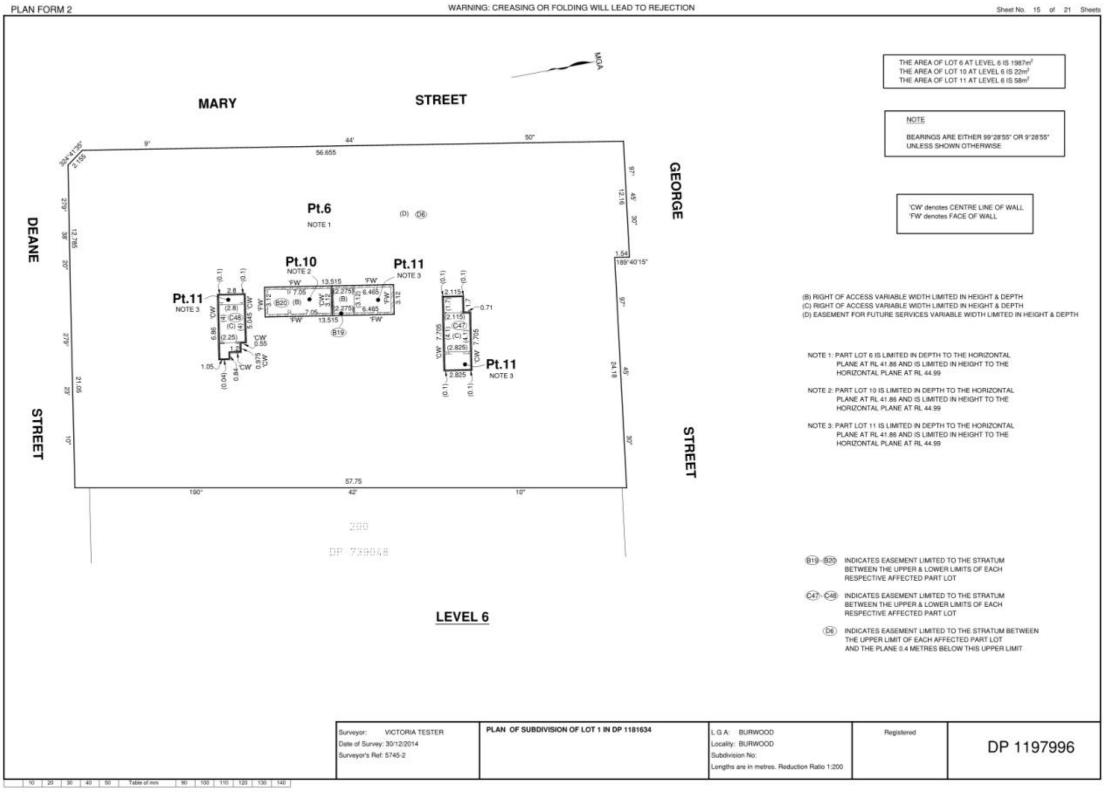

Figure C.53 Level 6 (Tester 2016a).

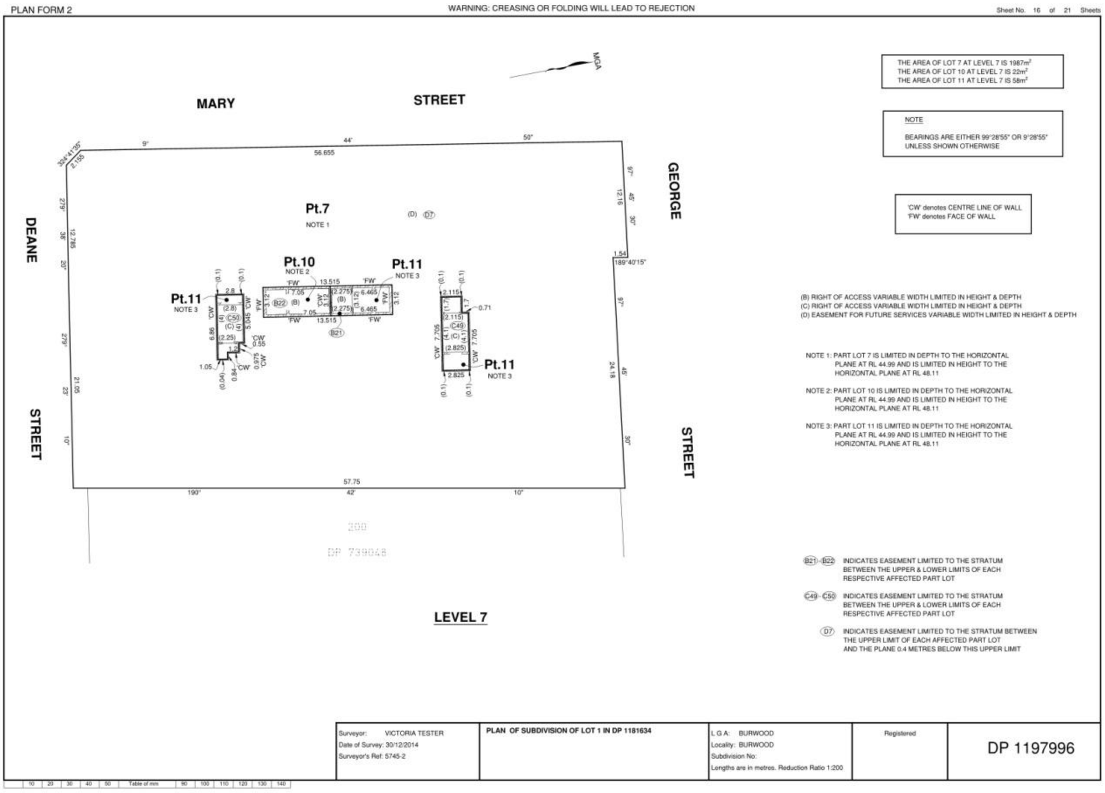

Figure C.54 Level 7 (Tester 2016a).

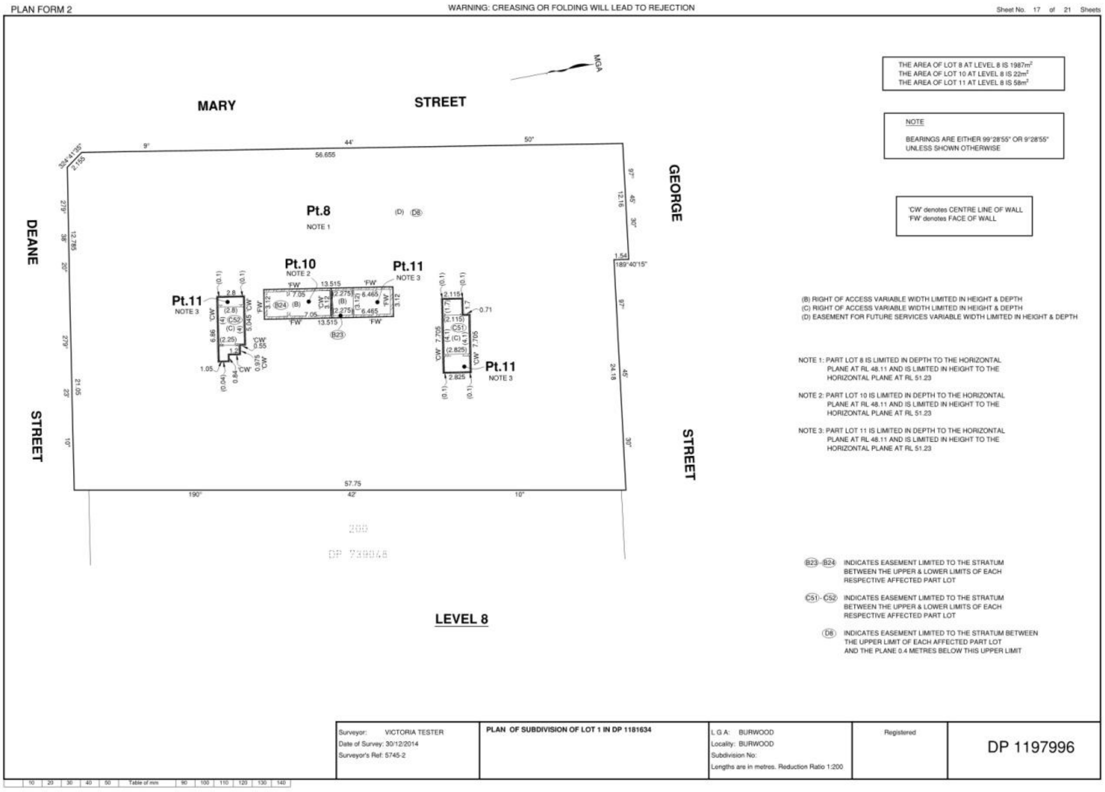

Figure C.55 Level 8 (Tester 2016a).

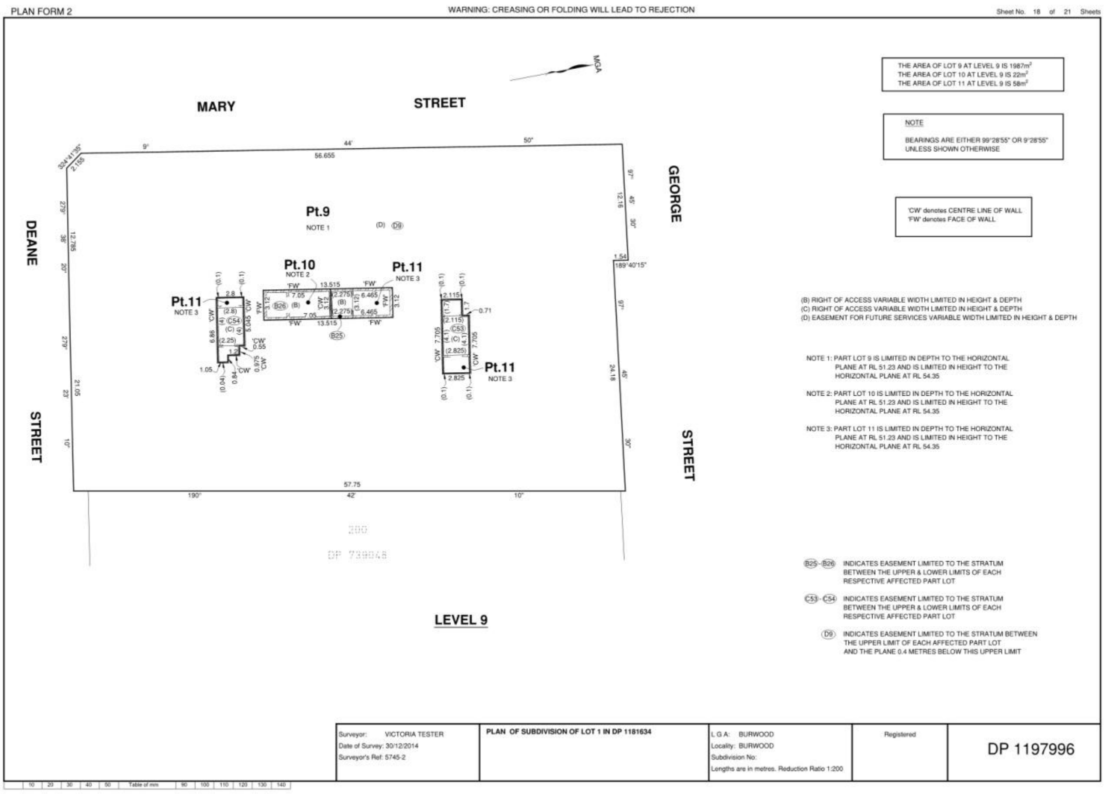

Figure C.56 Level 9 (Tester 2016a).

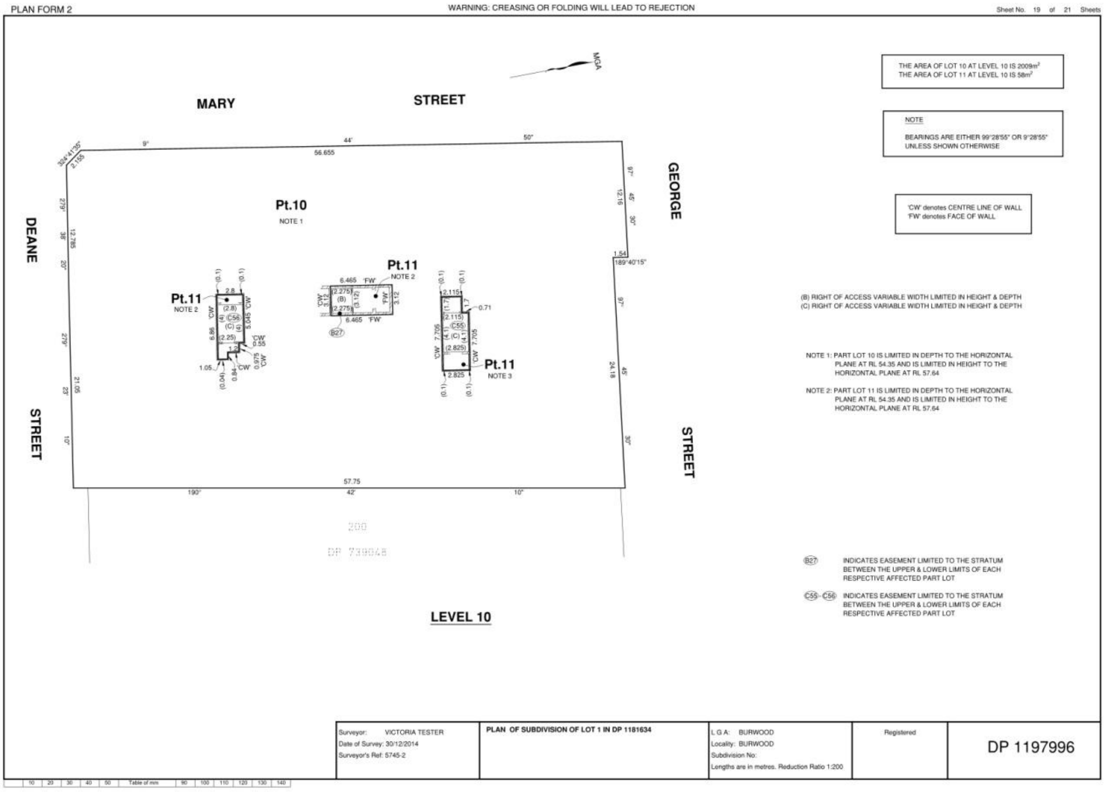

Figure C.57 Level 10 (Tester 2016a).

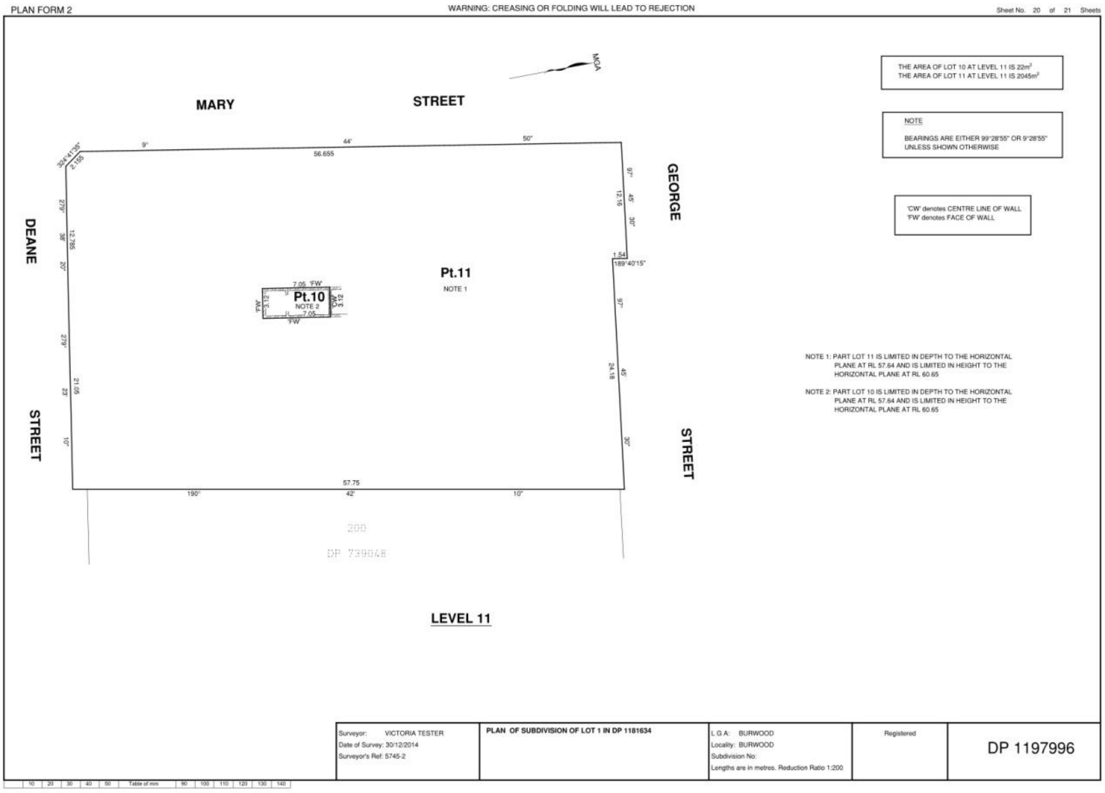

Figure C.58 Level 11 (Tester 2016a).

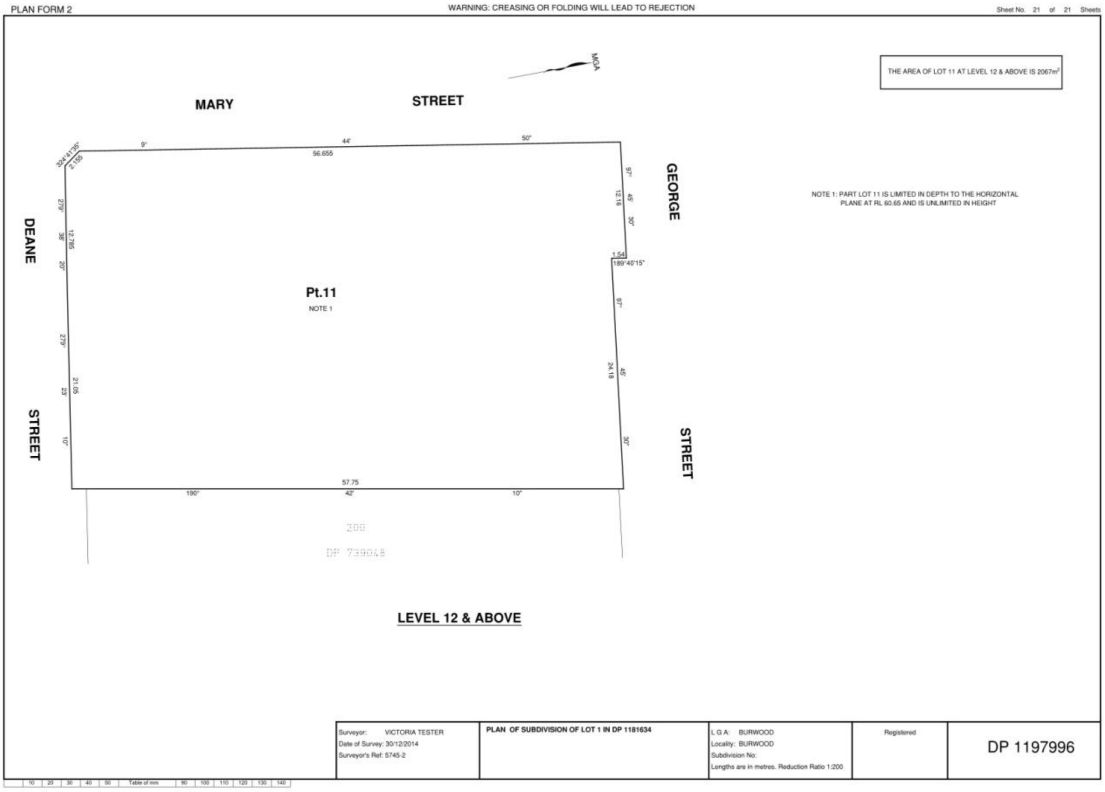

Figure C.59 Level 12 & Above (Tester 2016a).