University of Southern Queensland

Faculty of Health, Engineering and Sciences

Visualisation of a 3D Cadastre using Terrestrial Laser Scanning

A dissertation submitted by

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Abstract

Urban Environments are becoming increasingly more populated which is causing a change in society's lifestyles, modes of transport and ways of living into more vertical forms. This is resulting in the transcending of the cadastre from traditional and historic 2D land parcels into 3D spaces to which are attached complex rights, restrictions and responsibilities. Often the visualisation of these 3D spaces is unclear using archaic two mediums such as survey plans. Given the capability of terrestrial laser scanners to deliver information rich point clouds and 3D datasets, the aim of this dissertation is to investigate the feasibility of using a terrestrial laser scanner to visualise a 3D cadastre.

Firstly, the chosen topic of the dissertation is introduced and discussed, including the definition of the subject problem of the project, justification of the project and the research aims of the project. The second chapter entails the literature review concerning the chosen topic of the dissertation. 3D cadastres are introduced and the legal and administrative aspects of the topic are reviewed. The visualisation side of 3D cadastres is discussed and a review of terrestrial laser scanning and 3D building modelling is entailed. The third chapter outlines the methodology of the project concerning the site selection, resources required and the laser scanning and control surveys.

Chapter four discusses in depth the process of data processing and 3D modelling of the collected point cloud, along with the steps to produce a visualisation of a 3D cadastre using a 3D PDF. Chapter Five discusses and analyses the results of the visualisation of the 3D cadastre using a 3D PDF as well as the accuracy and application implications for this project. Finally the dissertation is wrapped up in Chapter 6 with a review of objectives and some concluding remarks.

Keywords: 3D CADASTRE, VISUALISATION, TERRESTRIAL LASER SCANNER, 3D PDF.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

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.

Nicholas Gann

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Signed:

Date: 13th October 2016

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Glossary of Terms

3D Cadastre	is a system of land administration that purports to represent 3D property and information
AHD	Height Datum defined through geometrical levelling relative to mean sea level around Australia.
Feature Extraction	is the process of retrieving and modelling objects from 3D point cloud data.
Georeference	the process of aligning point clouds to a real world coordinate system and height datum.
Map Grid of Australia	A defined plane coordinate system based on the map projection of the Geodetic Datum of Australia
Point Cloud	an array of points collected through laser scanning applications that has defined coordinate information
Registration	The process of coalescing multiple point clouds into one model
Strata Plan	A plan of subdivision that subdivides a building in accordance to a strata scheme
Terrestrial Laser Scanner	An instrument that is ground based and collects 3D coordinate information of the prevailing environment.
Total Station	A measuring device that is capable of recording bearing and distances through electronic distance measurement
Visualisation	the presentation of data in a graphic form

Nomenclature

2D	Two Dimensional
3D	Three Dimensional
AHD	Australian Height Datum
B&W	Black and White Target
CAD	Computer Aided Drafting
MGA	Map Grid of Australia
PDF	Portable Document Format
RL	Reduced Level
RRR	Rights, Restrictions and Responsibilities
TLS	Terrestrial Laser Scanner

Chapter 1 - Introduction

1.1 Background

The increasing densification of our cities and urban environments into high-density residential structures to cater for an ever-growing population are generating numerous data, legal and information challenges to the present cadastral system. Real property is becoming more and more that of three-dimensional spaces as opposed to traditional land parcels, with land use extending above and below ground and beyond the traditional topographic land parcel.

The cadastre is the system that encompasses and administers land and property information such as boundaries, ownership and other interests. The cadastre forms the basis of transacting land and real property with surety of ownership through the indefeasibility of title, whereby once the title of a parcel is issued, the ownership of the subject parcel or real property is guaranteed by the state.

Presently in New South Wales, and broadly across many other jurisdictions, the current cadastre predominately caters for two dimensional information, with the cadastre being largely represented and visualised in a two dimensional format through topographical plans and other media such as digital cadastral databases, which map and define the cadastre specified within in a 2D format.

The present cadastral system framework is deficient in managing the associated land property rights, restrictions and responsibilities in terms of those 3D spaces that are typically associated with high-density residential structures. With improvements to technology and more sophisticated equipment such as Terrestrial Laser Scanners, Geographic Information Systems and other software becoming increasingly available and more affordable for mapping and visualisation of complex 3D structures.

These types of technology are capable of displaying complex cadastres in a 3D medium that provides greater clarity for landowners, professionals, administrators and other end users. A 3D visualisation of a 3D cadastre will result in a more informative cadastre and allow for greater capabilities in decision-making through a greater understanding of the subsequent RRR's associated with 3D land parcels and real property.

1.2 Problem Definition

The appropriate administration of the cadastre is critical for ensuring that land and property tenure will continue to serve as a pillar of the economy whereby land holders have their land rights, restrictions and responsibilities unambiguously defined particularly as society moves to increased densification in urban environments.

According to (Shojaei et al., 2013) the present cadastral system is flexible enough to cater for the registration of 3D property and the subsequent RRR's attached to the 3D property through use of isometric diagrams, cross sectional drawings and textual descriptions. However, a significant benefit of a 3D cadastre should be the capacity for the visualisation of the legal RRR's and of the parcels themselves.

Shojaei et al. (2013) lists the limitations of the prevailing cadastral system in terms of catering for 3D property information as

- Lack of capability to visualise and display geographical, textual and geometric information of a 3D nature
- Lack of data to enable query, analysis and interactivity with the present cadastral system to unambiguously view and understand 3D cadastral information.

Furthermore, the authors state that there are multiple drivers for a better methodology for visualising such information, including the increased availability and capacity of technology, increased demand from end users such as owners, professionals and administrators for more information and to ensure efficiency and sustainability in the land administration system moving forward.

Given the above information, this encouraged me to consider the use of a Terrestrial Laser Scanner (TLS) to visualise a 3D cadastre in order to better conceptualise and understand 3D cadastres across a range of end users.

TLS is capable of providing sub centimetre accuracy when mapping buildings and their inner features such as facades, walls and other furniture through the collection of vast arrays of point cloud data of the prevailing environment; and from which the scanned surfaces and prevailing environment the and subsequent data can be modelled. According to the Leica C10 Technical Datasheet, this particular instrument has accuracy in terms of scan resolution from 0-50mm proportional to range from 0.1-300m, and is capable of recording 360 field of view as a part of the scan resolution. There are also multiple software packages such as CAD and other programs that are presently available, which are capable of providing 3D visualisation of an unlimited number of features.

As such, it is worth due consideration as to whether a TLS can be used to scan a building that embodies 3D property information in reality, but represented in the cadastre by a 2D strata plan. It is aimed for that the scan could be used to visualise the land titles within the building that are laid out in the plan from the subsequent modelling of the scan. From the modelling of the scan, it is aimed to produce a visualised 3D interactive model that enables people to interact with the data collected and enable viewing of the 3D cadastre.

1.3 Research Objectives

The research aims of this project are to investigate the capability of being able to visualise a 3D cadastre using a TLS and evaluate the best methods for the graphic display of this information to end users.

As a part of the research project, a literature review will be undertaken to review the academic literature associated 3D cadastres in order to gain a sound understanding of the fundamentals of a 3D cadastre. It is then targeted to review the means to visualise a 3D cadastre and what processes and data are involved in producing an effective 3D cadastre that depicts the necessary and appropriate information to visualise a 3D cadastre. The visualisation of will also be considered in line with the current guidelines and frameworks for presenting cadastral information.

The literature of using TLS in similar applications will also be reviewed with the aim to understand the processes involved with collecting modelling, extracting and visualising the data for a 3D cadastre. It is aimed to the evaluate the best methods discussed within the literature to achieve a visualisation of the data modelled and extracted in the context of 3D cadastre.

The ultimate objective is produce a model that successfully visualises a 3D cadastre through the use of a TLS that is unambiguous and easy to understand for all end users.

1.4 Justification of Dissertation

This dissertation is a valuable undertaking considering the points made out above. The topic is highly relevant given the increasingly urbanised environments that society inhabits and also that it is considering relatively new and increasingly used technology of TLS and an emerging field of 3D cadastres. It is aimed that regardless of the outcomes or the results of the dissertation, that it will provide a useful insight to the surveying and spatial sciences profession and associated industries as to the feasibility of representing 3D cadastres using a TLS.

This statement is consistent with the course objectives of ENG4111 and ENG4112; whereby the dissertation is targeted to contribute to the literature concerning the topic and to surveying and spatial sciences profession, as well as the final product being of a professional standard.

1.5 Research Scope and Limitations

This project is focussed on the consideration of using a TLS to visualise a 3D cadastre. The research will encompass the literature broadly associated with 3D cadastres, but with emphasis particularly that which is associated with the visual display of such systems. It will only investigate the means for using a TLS for achieving the visualisation of the 3D cadastre, and the subsequent use of the 3D extracted model to produce a 3D cadastre. The means used to visualise the end product will be reviewed also in the literature review but it is not anticipated to involve the fields of Geographic Information Systems or the development of web databases such as Digital Cadastral Database (DCDB).

1.6 Conclusion

In this chapter the background of the chosen topic of Visualisation of 3D cadastres using TLS is introduced along with the problem justifying the dissertation. The research aims and objectives are then outlined, as is finally the research scope and limitations of this project.

Chapter 2 - Literature Review

2.1 Introduction

To understand and appreciate the current insights to visualising 3D cadastres and the applications of terrestrial laser scanners; a literature review has been undertaken as a part of the project. The literature entails five sections, including a review of 3D cadastres, the legal aspects of 3D cadastres, visualisation requirements of 3D cadastres, Terrestrial Laser Scanners and finally 3D building models and the cadastre.

2.2 3D Cadastres

The expansion of our urban environments and the construction and inhabitation of multi storey structures above to the creation of transport infrastructure is creating the physical and irregular geometrical property components which extend beyond the traditional 2D medium of the horizontal land boundaries which existing cadastres are orientated towards. Governments, planners, and engineers are increasingly creating more and more complex solutions to cater for an increasing population through extension of real property and infrastructure both above and below the ground.

These developments demand the separation of land parcels and the subsequent rights, restrictions and responsibilities to allow for landowners and other stakeholders to manage their property rights. It is critical for governments, regulatory bodies, corporations and professionals to have a clear understanding and conceptualisation as to the full extent of the cadastre in these urban environments for asset management, service location information, lease and contractual arrangements, disaster response management, navigation, infrastructure expansion and for future planning policy (Jazayeri et al., 2014), (Navratil and Unger, 2013).

The cadastre is considered as an intangible repository of land and real property information that is defined through traceable records such as land surveys that entails land ownership, tenure, economic value and other interests attached to a particular land parcel. The cadastre allows for landholders to own and transact their property for personal and economic interests, protects other landholders and society against adverse affects and allows for government and regulatory authorities to administer their jurisdictions and citizens with confidence

The 3D cadastre is the extension of the cadastre beyond typical 2D land parcels and into 3D spaces above and below ground, As such the 3D cadastre is defined as the vertical separation and registration of 3D space as land parcels and the management of technology, databases and information used to and create, administer and visualise these 3D spaces and the real property comprised within (Guo et al., 2013), (Ho et al., 2013)

Typically the cadastre has focused on the 2D aspects of land parcels. 2D cadastres have created and administered land parcels through the processes of defining boundary lines through physical and anecdotal evidence in relation to the surrounding cadastre from previous land surveys. These plans depict the geometrical nature of the boundaries as determined through survey and the relationship that these boundaries have to improvements (houses, structures etc.) and other monuments such as natural features. Once the plan of survey as become registered with the state, the land parcels within have legal status and being with the titles issued for the subject land parcels..

The 3D cadastre and the associated RRR's are developed through using the existing 2D parcel as a base to create 3D property entities. For the realisation of a 3D cadastre, the vertical component (height) of the cadastre must be clearly defined and uniformly adopted in order to realise the 3D cadastre.

Height is defined as the vertical distance from a datum; and can be ellipsoidal or geometrical depending on the instruments and techniques used to ascertain it. In the case of the Australian Height Datum (AHD) geometric levelling has been used to establish a vertical datum whereby mean sea level is considered as coincident with the geoid, being the equipotential surface of the earth's gravity field. This definition serves as the origin of the datum and heights of supplementary points are defined as relative to mean sea level and as such the geoid (Navratil and Unger, 2013)

The adoption of AHD as a vertical datum and the subsequent definition of heights of relative objects to mean seal level, is the common practice in Australia. These AHD heights are derived from documented permanent survey marks that have AHD values, assigned to them, which details can be retrieved from databases such as Survey Control and Information Management System (SCIMS) and the Survey Control Database (SCDB). From these documented permanent survey marks, subsequent heights to other objects and features can be determined relatively to these marks through methods such as conventional geometrical levelling or trigonometrical heighting (Registrar Generals Directions 2015).

The definition of the vertical datum and its origin allows for determination of where the vertical limits of the 3D parcel would lie. Often the determination of the separating boundary between 3D parcels is done so through bounding planes such as ceiling or floors of each level in the case of multi storey buildings. (Navratil and Unger, 2013).

Once defined, these planes serving as monuments for boundary definition and the subsequent determined heights attached as a characteristic of the planes and hence the monuments. This allows for the creation of a 3D cadastre and provides assurances and legal certainty as to the origin of the heights within the cadastre and they have been accurately determined from a common and uniform datum. (Navratil and Unger, 2013)

2.3 Legal and Regulatory Aspects of 3D cadastres

Legislation is a foundation of 3D property. Without proper legislation and the subsequent regulation associated with it, 3D properties cannot be formed. As such it is critical that the legal underpinnings of 3D property are established before the application of 3D cadastral system can be discussed.

According to the paper published by Paulson and Paasch entitled “3D property research from a legal perspective”; there exists several different types of 3D property ownership models.

The most common forms of 3D property are through the condominium concept, which in principle is the ownership of a defined part of a building such as an apartment, and the sharing of common parts of that building with other adjoining landowners in the complex such as apartment gardens entrances and community spaces. Management of these areas extends to an owners corporation, whereby each all owners of the parcels with the building complex are participants in this body by default upon ownership.

The independent 3D model of property ownership is the subdivision of a 3D space from other parts of the building or the alienation of 3D space relative to 2D parcels above or below the subject lot. This form of subdivision is commonly used in the context of building infrastructure such as tunnels or for the separation of different land use types like commercial and residential buildings that are within the same building. This type of segregation of 3D property caters for different stakeholder interests existing in the same condominium complex, and ensures that the property RRR’s are outlined adequately for each type of land use within the apartment building.

Other forms of 3D property ownership include a tenant ownership model, whereby a tenant ownership body owns the apartment building and the tenants contribute funds to the ownership body for the use of their apartment and the condominium rights model, where all owners of the apartments within a building have joint ownership of the common areas and gardens of the complex.

This allows for the economical transacting, purchasing and transferring these rights, as the landowner desires within their rights; but not outside of their restrictions or responsibilities or at the expense of adjoining landowners. It is also required to cater for the different land use types in a building, an example of this is commercial and residential parts of a building, which have different rights, restrictions and responsibilities due to the nature of their use. The benefits of establishing 3D property rights discussed by Paulsson and Paasch in their article include:

- The securement of tenure through legal definition of the property in 3D
- Increasing the capabilities of the landowner to make changes to the property as needed
- Improve revenue and taxable capabilities through clearly defined mapping of the property
- Increased control for landowners over their land or space
- Better land development, planning and urban design from authorities
- Registration of Title and of differing land uses within one complex

Strata is a form of vertical land subdivision that involves the segregation of land parcels in terms of height and bounding surfaces within a structure or building. The Strata Scheme Freehold Development Act 1973 and the Strata Scheme Leasehold Development Act (1986) are the two pieces of legislation in NSW that enable strata subdivision within a structure to occur (Deal, 2015). This form of subdivision is akin to the condominium concept outlined above in the article by Paulsson and Paasch. A stratum subdivision is the segregation of parts of a building or structure through limiting a lot in terms of its height in relation to a defined surface.

Presently 3D property information is depicted through strata and stratum plans, whereby key requirements of stratum subdivision in NSW include (Registrar Generals Directions 2016):

- All lots are shown as a cubic space
- A building or structure must be located within the plan
- Lots defined by building structure or other permanent features
- Stratum Statements establish a lots limits in terms of height
- Everything that doesn't form part of a lot is common/ owners corporation property

In NSW, 3D property is created when the plan of strata subdivision is submitted and registered with the Land and Property Information. Each plan has a unique identifier through the plan number, and titles are created in reference to the parcel notated within the floor plans, this results in the creation of 3D property and the subsequent RRR's by which owners and other stakeholders can transact such property. Each plan generally consists of a location plan that outline the buildings location to its external boundaries, individual floor plans that outline lot boundaries on each floor and administration sheets.

The limitation in depth for a stratum boundary is in relation to a survey control mark of known AHD height, which is used to define the vertical planes to limit the lot, a bounding vertical plane is often assigned an RL and statements as to where this RL lies such as within the centre of a concrete slab. This in effect creates 3D land parcel. Horizontal Boundaries can be defined through the permanent features such as walls, columns and other building objects or through square distances of the face of these structures (Registrar Generals Directions 2016).

2.4 Visualisation of 3D Cadastres

The visualisation of 3D cadastral information is inherently tied to the legal foundation of 3D property rights, which governs how 3D spaces are subdivided and thus how the property rights, restrictions and responsibilities of those created parcels are created and displayed.

Visualisation of a 3D Cadastre requires consideration of numerous data types given cadastral information requires it has a physical and legal facet, whereby the physical entities are tangible such as walls, roofs and other physical components of a structure and the legal aspects are intangible in terms of boundaries, rights and restrictions. This gives weight to considering other possible mediums for representing 3D cadastral information and parcels; particularly in the light of advancements in technology catering for advancements in 3D visualisation. Applications which have the capacity for the 3D visualisation of data could include Computer Aided Drafting (CAD), Geographic Information Systems

(GIS), Land Administration Domain Models (LADM) being current platforms of visualisation for 3D cadastres and 3D data sets. (Shojaei et al., 2013)

A critical factor of visualising a 3D cadastre understands what aspects of data are required to be shown as a part of the cadastral model. Data associated with 3D cadastres can be classified as the following according to (Shojaei et al., 2013)

- Geometric – information associated with the parcel shape and dimensions such as survey plans, floor plans and other schematic drawings.
- Semantic – the physical characteristics of the building attached to the parcel or property, such as walls, columns and other structural features
- Land Use – information concerning the nature of land use of the land parcel and its zoning under appropriate planning legislation
- Legal – data associated with the legal aspects of the cadastre such as boundaries, common property, easements
- Temporal – data associated with the property and how its use and features have changed over time

The current standards for displaying the different types of data associated with 3D property and cadastre is through two-dimensional formats such as topographic, isometric and cross-sectional plans and diagrams. These different types of drawings are used to conceptualise the vertical limits of 3D property and as to what defines the extent of a vertical boundary. The use of these diagrams is not prescribed in terms of a set format, and how 3D information is displayed is established through personal preferences within the prescribed guidelines as outlined by governing authorities such as The Land and Property Information in NSW. Examples of how these types of drawings are used to conceptualise 3D property and cadastres is shown as follows:

Figure 2.1 Plan View of Strata Subdivision (Registrar Generals Directions 2016)

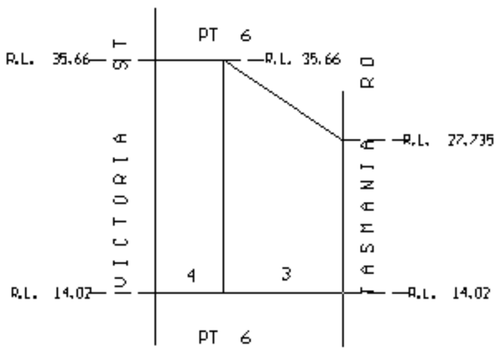


Figure 2.2 Cross Sectional View of Strata Subdivision (Registrar Generals Directions 2016)

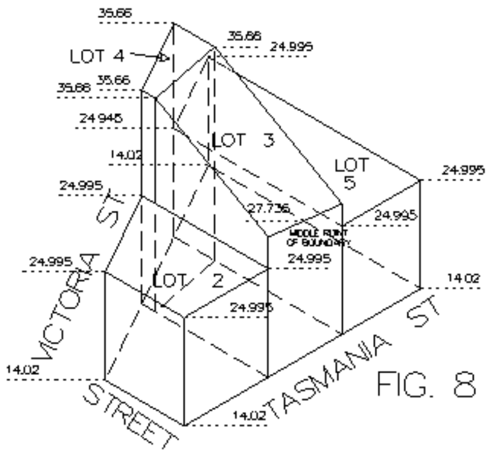


Figure 2.3 Isometric View of Stratum Subdivision (Registrar Generals Directions 2016)

Textual descriptions accompanying drafting conventions such as thick and thin lines to denote boundaries that are features and boundaries that are incorporeal the information are used to describe boundary information contained within two-dimensional plans of 3D property (Deal 2015). These textual descriptions aim to convey and assist through dictation as to where boundaries lie in relation to structural entities within the building complex, such as the face of a wall or through the centre of a column and through. There is a no set nomenclature or methods associated with compiling these descriptions that could result in misinterpretation by end users and as such not having an informed view of their 3D RRR's (AIen, 2011).

Shoejaei et al. (2013) deem such a two dimensional medium as inefficient due to:

- The lack of interactivity associated with plans
- The difficulty in interpretability
- Archival storage of these plans once they are registered, and as such can not be easily changed or modified if changes to RRR's occur due to subsequent development.

- Manual search methods needed to find the particular parcel of interest and the rights, restrictions and responsibilities that are attached to such a parcel.

AIen (2011) further highlights the limitation of the existing institutional frameworks in which they presently convey the 3D cadastre using the example of the cadastral system of the state of Victoria as a case study, with key limitations including:

- Vertical Information is lacking, being only present in cross sectional diagrams, if provided at all
- Plans are paper based and archival in nature, and do not truly depict 3D cadastral information and support 3D information such as colour, texture, shapes and orientation for concise visualisation
- Determinations of dimensions, volumes and other measurements are not always straightforward.
- Plan interpretation is complex and often requires professional experience to interpret.
- Lack of continuity and integration with the surrounding cadastre, resulting in a disjoint of information
- Some RRR's are not capable of being displayed in present formats, resulting in an incomplete 3D cadastral model.

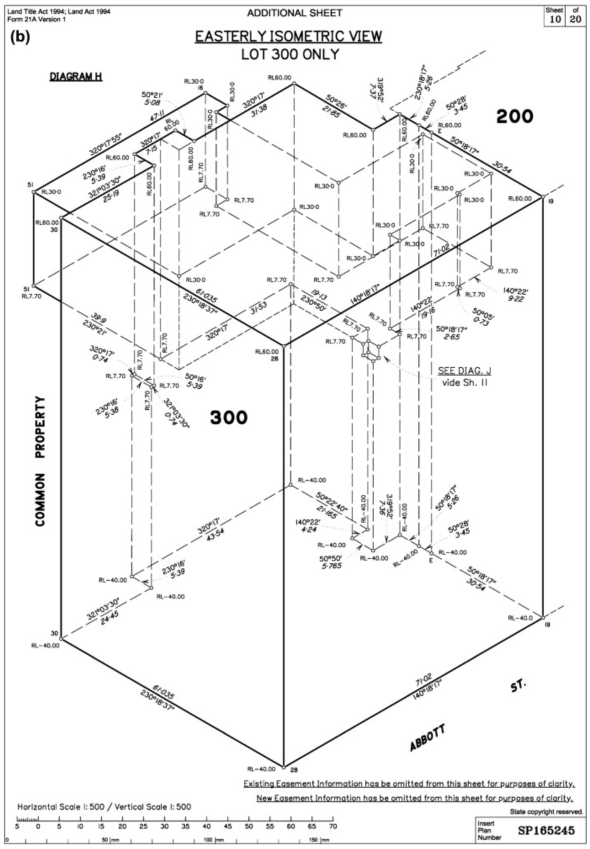


Figure 2.4 Complex and Archival Nature of Present Day Survey Plans (source: Shoejaei et al 2014)

These issues pose several problems to professionals, landowners and stakeholders of the 3D cadastre and the attached 3D RRR's is costly to landowners, governing and regulatory authorities caused by inefficiencies, lack of dynamism and lack of interpretability in the cadastre. A more effective way of convey the 3D cadastre and its associated information should be considered to convey the information comprised within a 3D cadastre, order to avoid ambiguity associated within interpreting the RRR's attached to the cadastre and to fully visualise the 3D parcels, their extents and their attributes within.

In order to completely and adequately conceptualise a 3D cadastre, an understanding of the medium of display is necessary. That is to understand what techniques can be used to achieve better visualisation of objects and how can these be applied to the conceptualisation of a 3D cadastre.

3D models comprise of several key visual variables in order to provide meaningful visualisation for the user, these are outlined by (Wang et al, 2012):

- Shape – the geometric spacing and nature of an object
- Size – modification of the size of an object, such as a line thickness
- Orientation – direction of an object relative to those around it
- Texture – the pattern or grain associated with an object
- Colour – change in an objects hue without changing its colour
- Position – location of an object in relation to others
- Value – the colour of an object

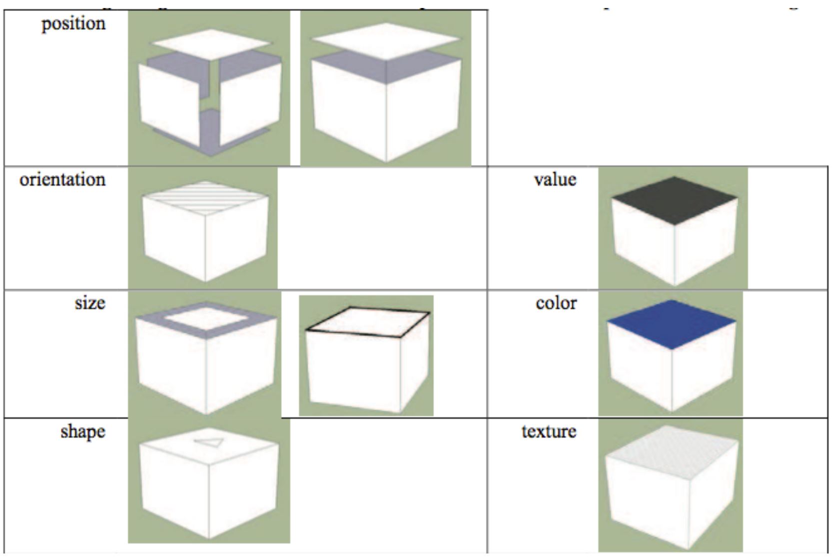


Figure 2.5 Visualisation Variables (Source Wang et al. 2012)

The key to the effectiveness of the 3D cadastre is ensuring that the appropriate information is visualised in a way that is unambiguous and easily interpretable. Wang et al. again elaborates on the appropriate information that should be incorporated into the visualisation component of a 3D cadastre;

These include:

- Representation of Partial and Bounded Property Units – display of the nature and extent of 3D property units
- Interrelationships between 3D parcels and 2D parcels clearly shown –
- Visualisation of spatial relationships between legal and physical objects - how 3D parcels relate to objects around them such as walls, columns and ceilings

- Visualisation of interrelationships between legal entities – the nature of where one 3D property unit lies in relation to other 3D property parcels surrounding it
- Labelling with dimensions and measurements – display of official dimensions and volumes of 3D property units within the visualisation

The article by (Shojaei et al., 2013) reinforces some of the visualisation requirements of 3D cadastres above including dimensioning of parcels and the relationship between 3D entities. The authors elaborate on the use of lines styles and thicknesses, object transparency and use of symbols as tools to enhance visualisation of a 3D cadastre.

They also state another key consideration as to the visualisation of the 3D cadastre are query and analysis functionality within the medium of display of the 3D cadastre to allow for traceability of infrastructure networks, to find adjacent 3D property objects to analyse 3D property RRR's and the topological relation of 3D property with other objects. The capability of the 3D cadastre to provide a multitude of views such as cross sectional, topographical and isometric views through interactivity with the 3D cadastre.

The capture of 3D data is also critical to the visualisation of a 3D cadastre; this data can arise in many forms such as 3D vector and raster data within GIS, point clouds derived form laser scanning as well as digital photography. These techniques and methods can be implemented to achieve results through the use a range of prevalent technologies such as virtual globe technologies such as Google Earth, software suites such as Google SketchUp and CAD packages, GIS software and other interactive software like 3D PDF viewers that allow for visual manipulation of the 3D cadastre to achieve the optimal and dynamic visualisation

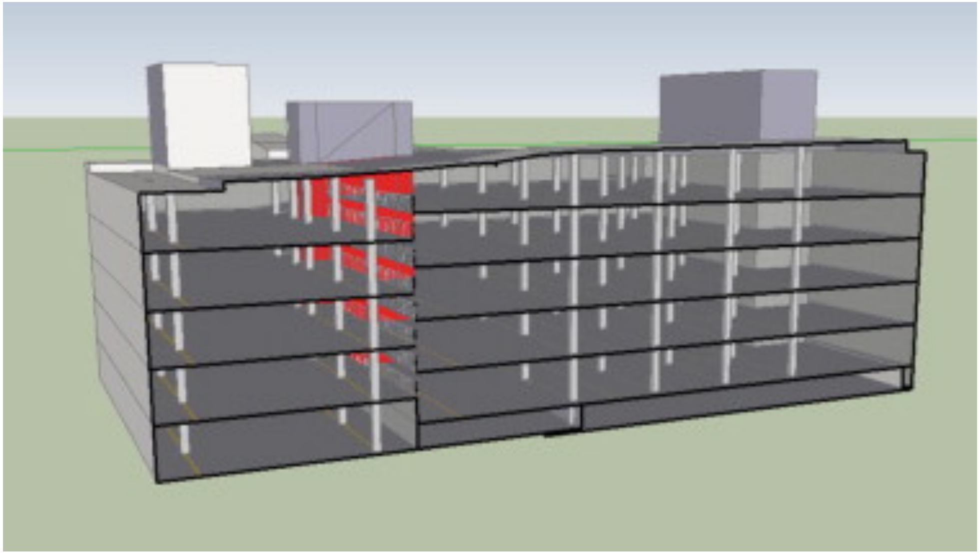


Figure 2.6 Visualisation of 3D structure using 3D PDF (Source Shoejaei et al. 2014)

2.5 Terrestrial Laser Scanning

Terrestrial Laser Scanning (TLS) are survey instruments capable of high volume and high precision data acquisition in the form of point clouds. TLS have a wide range of applications, including the capability of high accuracy of external and internal building feature mapping (Jazayeri et al., 2014)

TLS utilise lasers that measure points on the surfaces of the prevailing environment within a field of view and at a specified density as determined by the operator to collect an unordered array of points. The result is an unordered arrays of points have coordinates (X, Y, Z) that determined from the subsequent scans and collectively these points form a point cloud (Bosché (2012).

Figure 2.7 Image of Registered Point Cloud (Bosche 2012)

To achieve a holistic and concise suite of data of the features being scanned, multiple scans of the scene from different locations within the site must be congealed together. Scan Registration is the process orientating, aligning and conjoining multiple scans obtained from different locations of the prevailing environment to one and other to a common coordinate system and datum. The registration methods can vary and are outlined as follows:

- Manual point selection - iterative selection of corresponding points within a scan such as a corner of a building to mesh together consecutive point clouds.
- Target based matching - the manual selection of a defined target within a scan to align multiple scans together, with these points serving a tie point between the scans.
- Feature Based Matching involves the matching of congruent lines, surfaces and shapes such as walls, roofs, columns and other structures common within scans.

For further refinement of the collected point clouds, a scan to scan registration can be used to refine the combined point clouds, this involves the alignment of common planar surfaces and other geometric shapes (Bosché, 2012).

A further critical process of the procurement of data from a point cloud is the georeferencing of the point cloud. Georeferencing is discusses in the article by (Fan et al., 2015) as the process of transforming the point cloud from an arbitrary coordinate system to a real world coordinate system and datum for representation of real world environments. This transformation is achieved most commonly through the target-based method, whereby total stations or GNSS is used to survey the targets and is subsequently connected to survey marks with known real world coordinate values. Other processes of georeferencing discussed by Fan et al. include surface matching whereby common arbitrary and real world surfaces are aligned together and direct georeferencing, whereby the TLS is integrated with survey devices such as GNSS simultaneously, resulting in the scan being produced directly with real world coordinates.

The transformation process between arbitrary and real world coordinate systems is conducted within software such as Leica Cyclone and involves the selection of points (targets) which are present in both the arbitrary and real world coordinate systems, from which a rotation matrix is determined from the selected arbitrary points in relation to the real world points as well as a translation vector between the coordinate sets (Fan et al 2015).

The point cloud is subsequently transformed from the arbitrary coordinate system to a real world coordinate system. Least squares processes are used to verify the quality of the transformation with residual coordinates generated from the adjustment in terms of the point cloud in its entirety and the target constraints of the point cloud.

The article by (Hong et al., 2015) describes the process of reducing the point cloud into extracted model which displays the captured scene as a reduced 3D model. The RANSAC (RANdom SAmple Concencus) is a commonly used mathematical algorithm within processing software that extracts geometrical planes out of point clouds.

This process involves the selection of a of a minimum number of three points within the point cloud with defined parameters set in terms of the deviation the points away from the planar surfaces. The algorithm is iteratively run and generates planes through the points selected and from the other points that fit within the specifications of the parameters set. The algorithm is continually run until a confidence interval of 95% is achieved for all points lying within the same plane, with errors determined as the measured normal distance of the other outlying points in relation to the generated plane through the selected and iterated points.

This process filters out noisy data; that is data that is generated from the laser scanning that doesn't form part of the prevailing environment and its generated from backscatter from reflective surfaces or other interruptions that occurred throughout the data collection phase (Bosché, 2012)

This leads to the generation of planar surfaces, from which a surface's or planes 3D geometry can be created through extruding the developed plane through the selection of minimum and maximum points for the value range of the Z (height value) of the surface from the point cloud or by a known value if stated. This in effect creates a 3D wireframe of the subject surface and as such serves as the basis of the 3D model (Hong et al., 2015)

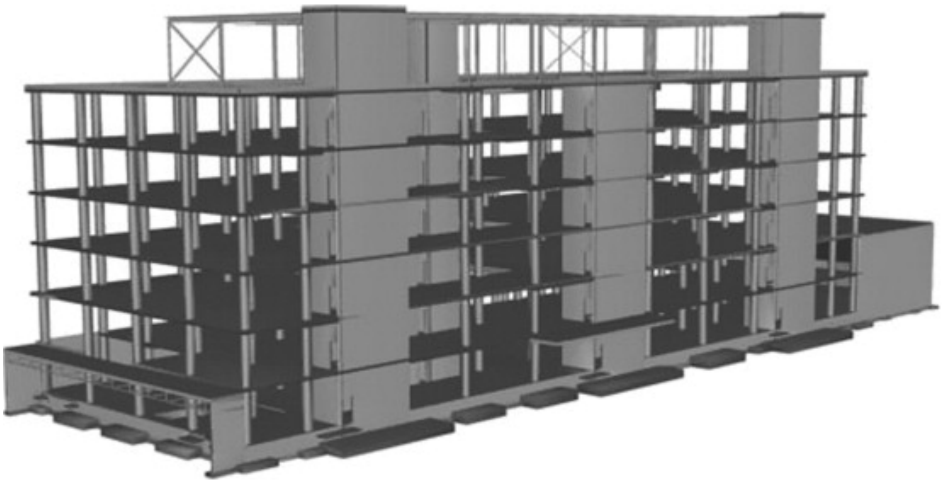


Figure 2.8 Extracted Feature Model from Point Cloud (Bosche 2012)

2.6 3D Building Models

Building Information Models (BIM) are an increasingly common form of building and facilities management. BIM is an information tool in the form of a fully interactive 3D model that enables the management of a building and its subsequent components over the course of its lifetime. The BIM is a tool that and enables interactivity, graphical interpretation and informed decision making to occur about the management of a building or structure over the course of its lifetime (Jazayeri et al., 2014)

The BIM form as a 3D model provides greater understanding to complex spatial relationships between various components of the model and hence the building, particularly in the context of dense and heavily populated urban environments. It provides rich geometrical and spatial datasets that allow for informed decision through the provision of a 3D model that provides visualisation of all internal and external building components. 3D models and BIM are highly suited to managing and displaying the internals of a building, with datasets acquired through the use of terrestrial laser scanners which provide large datasets concerning the geometric internals of the building. The collection of the data allows for the production of 3D as-built information of the internals of the building, including information such as ceiling heights, wall dimensions, room volumes and other structural information; all of which can be processed and integrated into a 3D model (Hong et al., 2015)

A key component of a building is its 3D property and land information. Given the aim of a BIM is to provide holistic building and structural management; there has been an effort to gauge the usefulness of integrating 3D property rights into a BIM as to how effective this is in administering the cadastre. Methods to visualise and represent the cadastre could incorporate techniques such as using transparency on the parcel and modifying line styles, thicknesses, colours and shapes within the 3D model (Jazayeri et al., 2014)

BIM’s can be a useful application for visualising, managing and applying the 3D property rights and the 3D cadastre during and after the completion of construction of a building or structure. The use of building information models to manage 3D property RRR's of a building or structure can be applied in such in the contexts of definition the limits of excavation spaces underneath other property for access to services or for underground construction for infrastructure such as tunnels to prevent encroachment or damage to the adjoining properties and to enforce buffer distances of these kinds of projects (El-Mekawy et al., 2014)

The same authors also discuss the use of BIM to display 3D property boundaries to illustrate the full extent of 3D boundaries above and below the ground to inform users of the full extent of the 3D cadastre and prevent encroachment onto neighbouring properties. The case of using BIM models to display common boundaries between two apartments, which may lie within a concrete slab or wall, is a cited example of the application of this principle.

The application of using a TLS to visualise to reinstate legal property boundaries through a point cloud and subsequent 3D model for conceptualisation is discussed in the paper by (Koo et al., 2014) who use a TLS to determine the encroachment of features onto property boundaries. The author's use a TLS to scan the subject improvements located on the property and coordinate the TLS through using Total Stations and GPS to georeference and link the captured scans to the cadastre, which has also been connected to during the survey. The collected scenes are then downloaded from the TLS and geo referenced using the coordinates from the Total Station and GPS, which then allows the cadastral boundaries to be overlayed and extruded upwards, creating vertical planes within the model for efficient visualisation and determination of encroachments on the property boundaries.

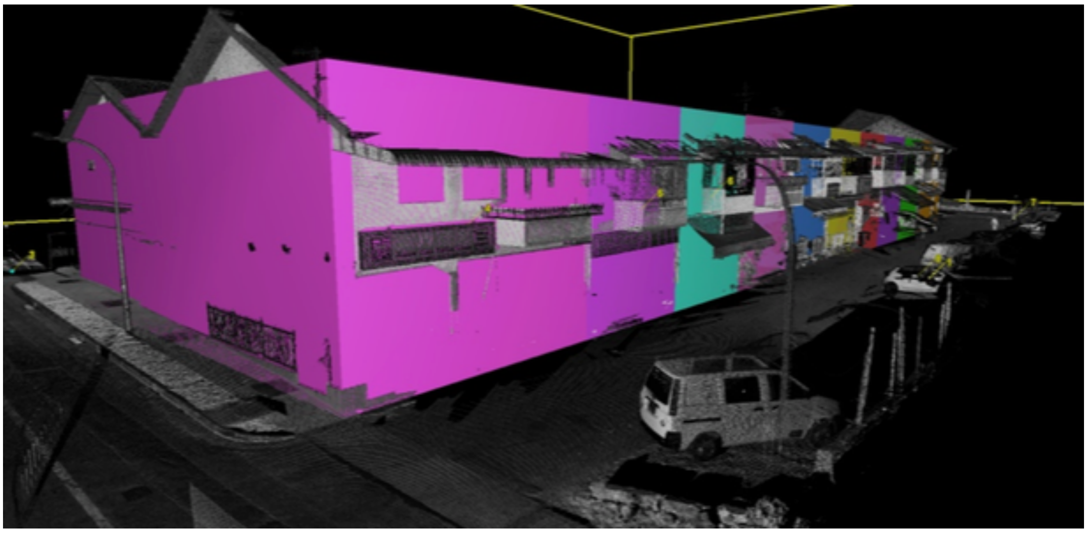


Figure 2.9 Extrusions of Property Boundaries in 3D for Visualisation (Koo et al. 2014)

This concept of using 3D models to visualise a 3D cadastre is reinforced by (Pouliot and Vasser, 2014), whereby the authors use a terrestrial laser scanner to model a 3D cadastre in the form of an apartment building which has elements of private and shared ownership within the apartment complex. The authors endeavour to define the boundaries of the property within the apartment complex using a TLS through conducting a survey of the internal and external features of the building and then manipulating the data into a 3D model to visualise the 3D nature of the land parcels and the attached RRR's through the import of geometric characteristics into the final output. A comparison is made to traditional methods of survey using a distance-meter in the areas of efficiency, cost, time and the processes involved with that involved with the laser scanning of 3D modelling

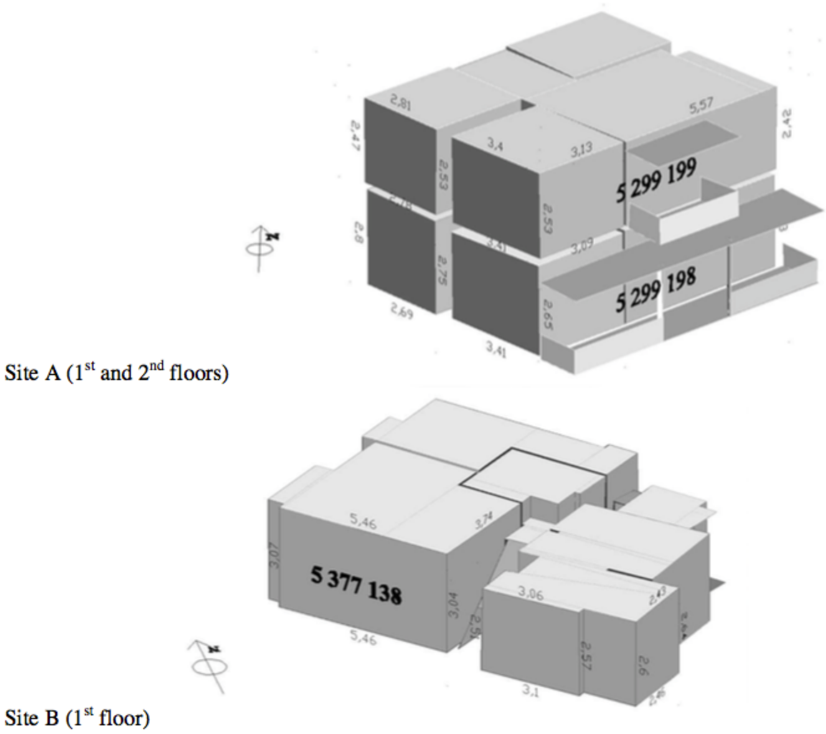


Figure 2.10 3D Model of 3D property (source Poullot and Vasser 2014)

2.7 Conclusion

This chapter has discussed the literature concerning the creation of a 3D cadastre using a Terrestrial Laser Scanner. Firstly, the concept of a 3D cadastre was discussed along with the legal aspects of a 3D cadastre and 3D property. The visualisation requirements of a 3D cadastre were then reviewed. Finally terrestrial laser scanning and the creation of 3D models of buildings were reviewed in the context of 3D cadastre and 3D property rights.

Chapter 3 - Methodology

3.1 Introduction

This chapter discusses the methodology and processes associated with visualising a 3D Cadastre using a Terrestrial Laser Scanner. It is aimed to elaborate on topics such as identifying a suitable site possessing desirable features for the collection of field data for the project, outline the resources and equipment required for the project, as well as the methodology for the field surveys and, briefly, data processing and 3D modelling for visualising a 3D cadastre for the project.

3.2 Site Selection

Of critical importance to developing a visualisation of a 3D cadastre is selecting a site that firstly satisfies the criteria required. A suitable site would ideally possess the following characteristics:

- Readily and freely accessible
- Already in effect has a 3D cadastre and has survey information available
- Possesses multiple land parcels proximate to one and other
- Possesses a range of different cadastre elements such as common property and private titles
- Not requiring access to private property.
- Equipment able to be transported to and used at the site

Considering the above criteria and given the examples discussed in the literature review; it is obvious that an apartment building would be the ideal choice for the field work to occur given it is an embodiment of 3D property itself and has a range of cadastral elements.

Furthermore, an apartment basement car park is highly desirable as it has a 3D property boundaries on one or multiple floors through the presence of numerous car spaces which form apart of separate land titles. Also a car park basement floor has the capacity to be freely accessed without interference to private property and have equipment freely used on site.

As such, the site chosen is a car park basement located in St. Leonards NSW. The site encompasses numerous car parks and has a registered strata plan (SP90738) that implies the presence of a 3D cadastre and of 3D property units. Images of the chosen site and the part of the registered strata plan are shown as follows:

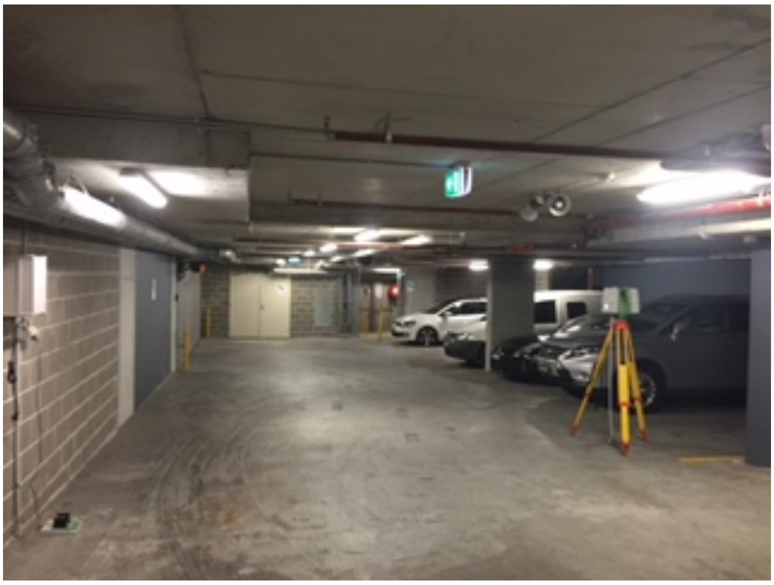


Figure 3.11 - Image of chosen site

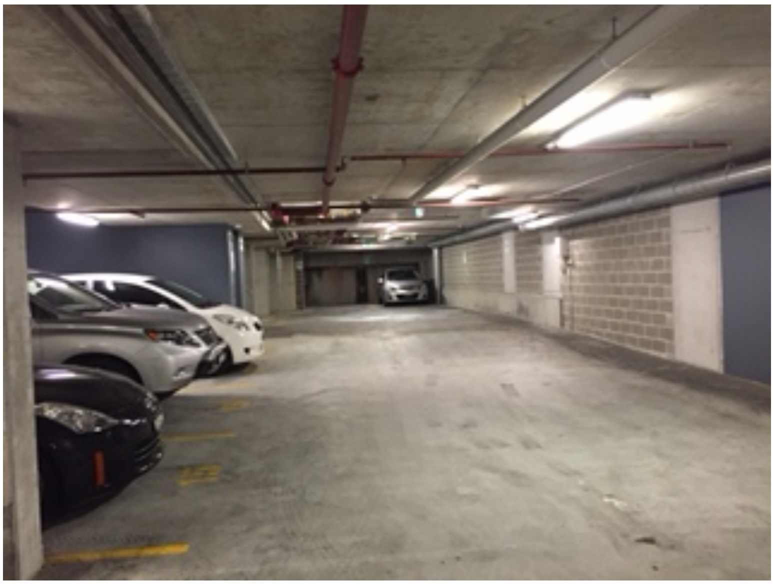


Figure 3.12 - Image of chosen site

3.3 Methodology

The project is comprised of numerous steps and was completed in a staged process given the data that had to be acquired, processed and then manipulated.

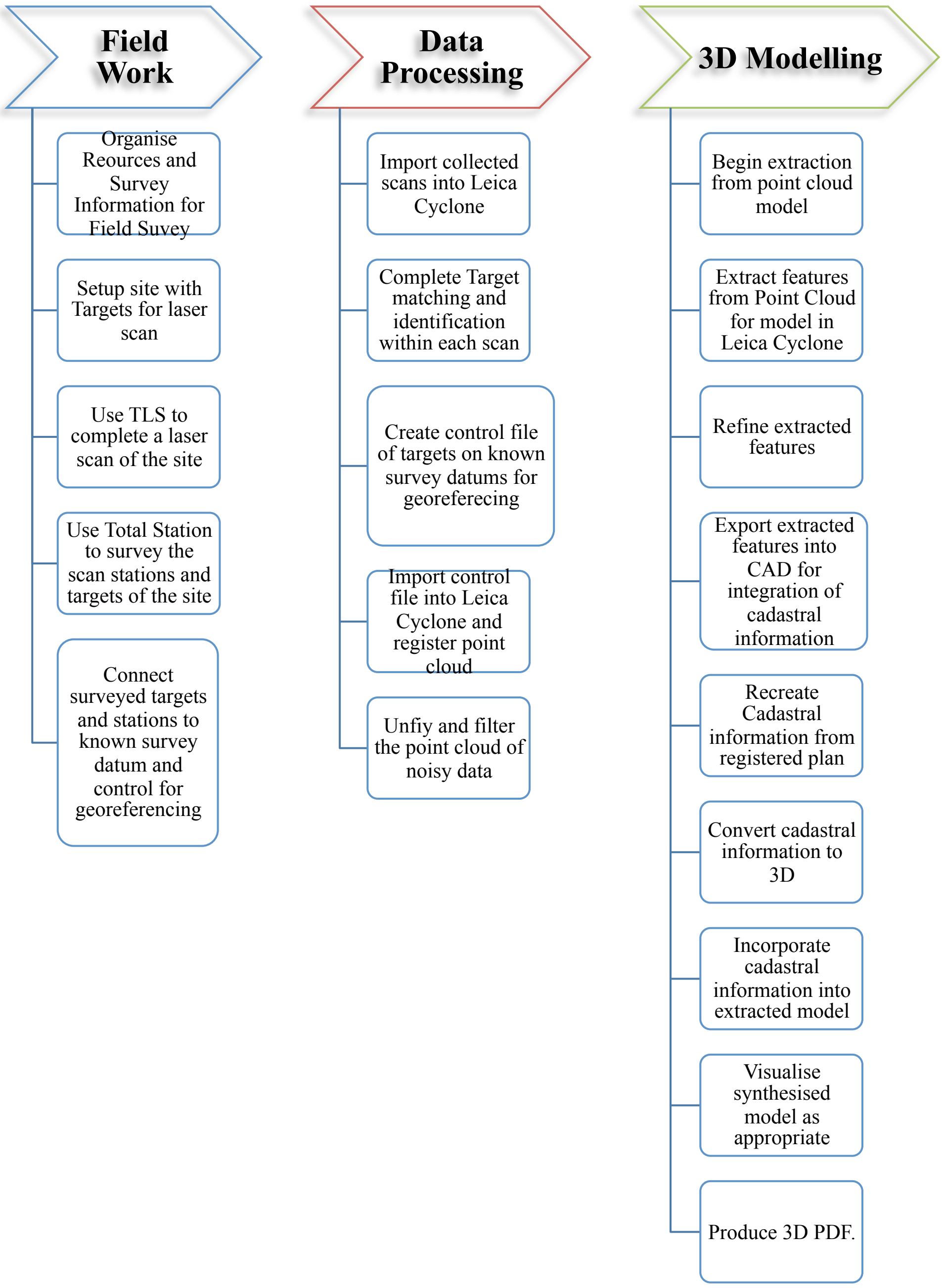


Figure 13.3 Project Workflow

The aim of breaking down the project into a workflow was to enable a clear path of critical tasks that had to be completed in attainment of the objective of visualisation of a 3D cadastre using Terrestrial Laser Scanning.

3.5 Field Survey

3.5.1 Search and Field Survey Planning

Prior to the commencement of the field survey, the necessary resources and search information was required to be gathered before the survey could commence. Firstly, once an appropriate site was identified, a search of the appropriate cadastral information was undertaken through the Spatial Information eXchange (SIX) portal, which is a NSW government database and mapping platform that comprises all survey information in NSW.

From this database, the registered Strata Plan (SP) for the site was identified as being SP90738, which contains the land title and survey information for the site. The same portal was also used to retrieve information about permanent survey marks nearby which had known values for MGA coordinates as well as AHD height. The information was then ordered and their location is subsequently shown in the following figure:

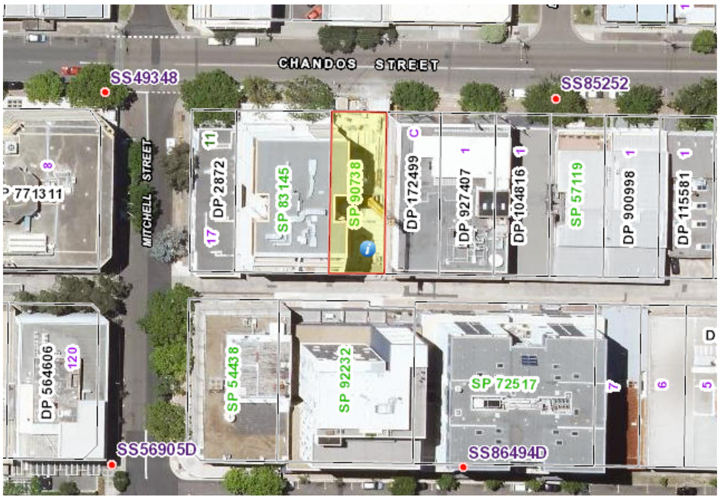


Figure 3.14 - SIX Maps image of selected site

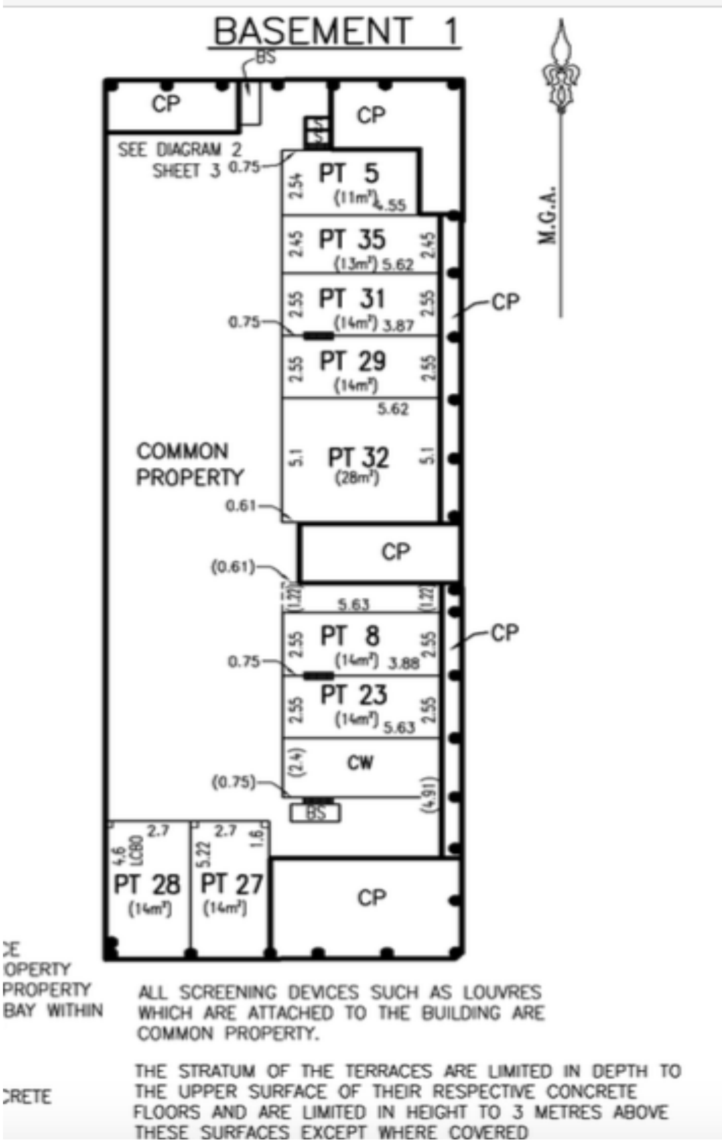


Figure 3.5 Registered Strata Plan for subject site

Once this information was collected, the necessary resources were identified and organised so the field survey could commence. The resources required for the laser scanning survey and the total station field survey respectively is listed as follows:

- Leica C10 Terrestrial Laser Scanner
- 3x Tripods
- Black and White Paper Scanning Targets
- Measuring Tape
- Trimble S8 Total Station
- TSC3 Data Collector

- Mini Prism
- 2 x Traverse Prisms

The Leica C10 Laser scanner is marketed by Leica Geosystems as “An all in one laser scanner for any application” and is described as a compact, easy to use and learn and as a highly versatile scanning station; with a scan rate up 50,000 points per second and positional accuracy of 5mm at 50 meters (Leica HDS Datasheet).

Figure 3.6 C10 Laser Scanner

Given the Leica C10’s specifications as stated by the manufacturer, which can be seen in Appendix C.
It is highly apparent that this instrument is well suited and applicable to the field survey being undertaken.

3.5.2 Risk Analysis and SWMS

As a part of any work activity conducted, there may exist inherent risks posed to individuals and the environment that may realise harm as a consequence of completing the task at hand. A hazard is a source of harm that may pose or cause personal injury or environmental damage as a result of an activity occurring, whilst a risk is the degree of likelihood that such a hazard should eventuate.

A requirement of the of managing these risks is the development, adherence to and implementation of a Safe Work Method Statement (SWMS), which aims to assess work methods involved with work tasks and assess the likely occurrence of these events, with the goal of mitigating or reducing the risks involved with work practices. The risk matrix works by evaluating the task at hand and identifying the associated risk factors with those tasks, to which a rating is assigned to that task.

RISK ASSESSMENT MATRIX	LIKELIHOOD: HOW LIKELY IS IT TO HAPPEN AND HOW OFTEN?				
CONSEQUENCES: HOW BAD IS IT LIKELY TO BE?	**A - Very Likely**	**B - Likely**	**C- Possible**	**D - Unlikely:**	**Very Unlikely:**
1 - Extreme: Death or cause permanent injury/damage	**1A**	**1B**	**1C**	**1D**	**1E**
2- Major: Long term injury or major damage	**2A**	**2B**	**2C**	**2D**	**2E**
3 - Moderate: Moderate Injury or damage	**3A**	**3B**	**3C**	**3D**	**3E**
4- Minor: Minor first aid required or minor/no damage.	**4A**	**4B**	**4C**	**4D**	**4E**

Figure 3.7 Risk Matrix

Once hazard identification and a risk assessment has taken place, a hierarchy of controls can then be applied to moderate the risks associated with the tasks and then a mitigated risk rating can be applied to the controlled situation. Some of the potential hazards that were identified in association with this task are identified in the following table.

Job Safety and Health Analysis				
Task	**Hazard**	**Grade**	**Controls**	**Mitigated Risk Rating**

Conduct Field Survey on/adjacent to roadways and Field Site	Live Traffic	1C	Wear High Visibility Clothing Use, Traffic Control Devices (Cones, signs), Do not walk on roadway	3D
	Pedestrians	3D	Use traffic Control Devices to segregate Instrument and work zone	4E
	Slips, Trips and Falls	3C	Be Aware of surroundings	4D
	Poor Lighting (Carpark Basement)	4D	Wear High Visibility Clothing	4E
Use of Laser Scanner and Total Station	Class 3R Lasers	2E	Don't set instrument at eye height to prevent damage, Display warning signs.	2E

Figure 3.8 SWMS for Project

3.5.3 TLS Field Survey

The field survey utilising the Leica C10 TLS was then able to be commence once the preceding steps had been completed. Firstly, before any scanning could commence, Leica Black and White (B&W) paper targets were strategically placed around the site. These specific targets chosen for this particular survey as the preferred target type to provide control for the TLS field survey given their ease of setting up and essentially being able to have as many unique targets as possible available for the survey as required. The B&W targets are circular in shape and have contrasting black and white sectors within the circle, and are specifically designed so that the algorithms within the scanner and Leica Cyclone software can identify them automatically within a certain range of the scan station.

The process of placing targets around the site that is being scanned is a crucial part of both the TLS field survey and the subsequent data processing that occurs after the field survey, as it provides an efficient and effective means of incorporating control into the point cloud. The targets can then be surveyed through conventional means to allow the point cloud to be geo-referenced and to facilitate the registration process of joining multiple clouds together. As such, it was an objective during the survey that each scan would have at least four B&W targets visible within each scan to ensure that sufficient control was present within each scan to enable accurate registration. At least two targets are required to be present within each scan for it to be able to be coordinated through the use of the B&W targets and to facilitate the registration of individual scan worlds to on and other.

Given the relatively small and enclosed nature of the site, 10 B&W targets were placed across the site on walls using masking tape. The main considerations to placing these B&W around the site was to ensure that as many as possible would be visible from the chosen scan stations. The field notes denotes in appendix B show the placement of these black and white targets around the site along with the target identifiers.

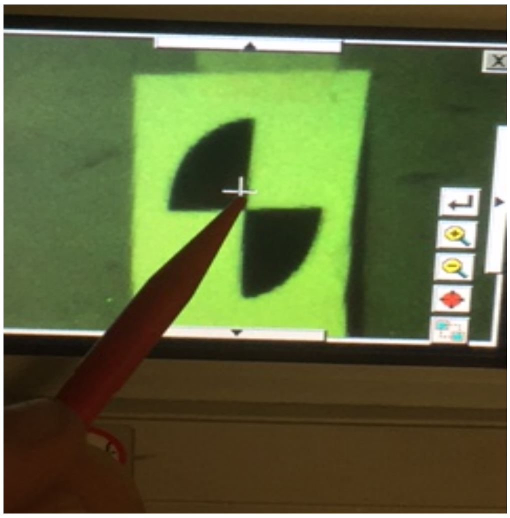
Once the targets were placed around the site; the TLS field survey of the site can begin. The scanner was first step up and a new job within the scanner was created. This will store the entire collection of scan worlds into that job which can be then downloaded off the scanner when the TLS field survey is completed. The scanning of the site could now be commenced.

Figure 3.9 and 3.10 - Images of TLS set up at selected site

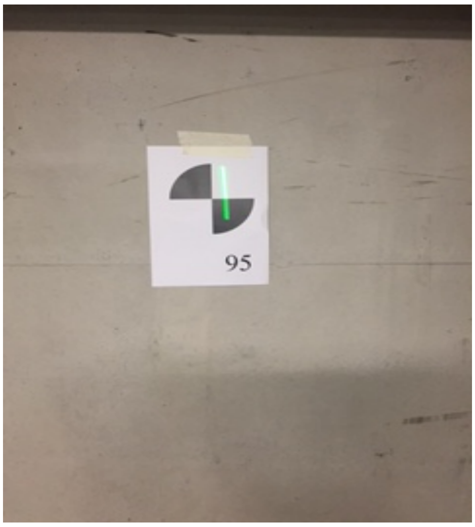
Another important consideration prior to the commencement of any scanning for any project is the selection of a scan resolution. For this TLS application, the medium resolution was chosen which scans a point at a ratio of a grid pattern of 100mm at a 100m range and each scan has a duration of six minutes which was deemed more than sufficient for this application. Other options available to the operator for scanning resolution are a low resolution which has a ratio of 200mm grid at a 100m range for a duration of about two minutes, whilst a high scan resolution option has a scan ratio of 50mm grid at a 100 metre range for a duration of approximately 25 minutes per scan.

At the scan resolution chosen, all B&W targets within 15m of the scan station are capable of being automatically detected within each of the scan worlds, and therefore not requiring target identification. The targets can also be specifically recorded from each scan station the scanner occupies through the scan target function located within the interface of the scanner menu. This process was repeated numerous times to tie targets further away from the scanner and the steps of the process are outlined below in the following figure.

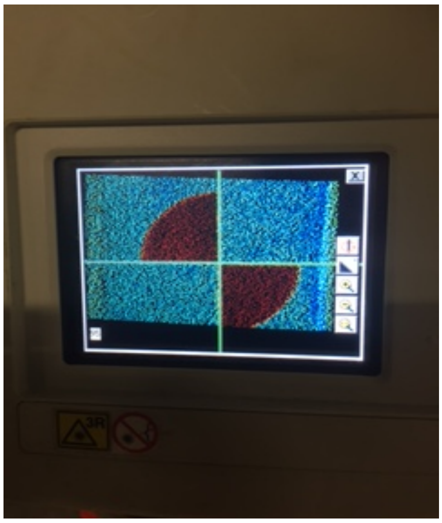
a) Creating



b) Locating



c) Scanning



d) Definition

Figure 3.11 Process of Target Definition (Creation, Locating, Scanning, Definition)

Once the targets have been defined from the scan station, the scanner can then be engaged and the scanning was commenced. This process is repeated at each scanning station until sufficient scans have been completed of the site. The result is a point cloud of the scanned environment, termed a scan-world by the instrument. All up, 9 scans were completed at this site, as this was deemed more than sufficient for the application given the enclosed and relatively small nature of the site. These scans were than exported from the TLS onto a USB using the transfer function within the menu interface from the scanner.

It should also be noted that the two common property areas being service cupboards at the southern and northern ends of the basements were not surveyed as a part of this project, as they were inaccessible at the time of survey.

3.5.4 Field Survey using Total Station

The next step of the process would be to conduct the field survey using the Trimble S8 Total station. This field survey is aimed at connecting to survey marks that have defined Map Grid Australia (MGA) and AHD heights in order to geo-reference the scanned scenes. The survey control for the project was obtained from the survey marks SS49348 and SS85252, both of which have known MGA coordinates and AHD height.

Figure 3.12 Total Station surveying B&W targets

This part of the project first commenced in the basement where the B&W targets and terrestrial laser scanning stations were located. An arbitrary azimuth was set to a backsight and each target was subsequently measured in face left (FL) and face right (FR) using the measure rounds function within the Trimble TSC3 controller, with some scanning stations surveyed for additional control coordinates for the terrestrial laser scanning survey.

A conventional survey traverse was commenced out of the basement to connect to the permanent survey marks mentioned above. All up 7 survey stations were required to connect to these permanent survey marks and Comma Separated Values (CSV) of all the data was exported which contains each points name, easting northing and height. This will enable the arbitrary data to be rotated and translated to the datum's of MGA and AHD in the CAD program Terramodel in the data processing stage of the project.

3.6 Data Processing

The next phase would involve the reduction of the point clouds through using the Leica Cyclone software. According to the Leica Cyclone datasheet, the software program comprises of numerous modules which include as Register, Survey, Model, Viewer, Importer, Publisher and Basic. There are also other modules such as Cloudworx, which is a plug in for AutoCAD, Microstation and other software packages to allow for data processing of point clouds within the familiarity of the widely these widely used suites. Each of these modules are licensed and available for purchase individually.

Firstly a database and project were established which then enabled the collected scans to be imported into Cyclone, with each scan appearing within the program as its own scan world. This allowed for the viewing of each of the scan worlds individually where the data can be interactively through the model space of each scan world. The viewing of the scan world individually allows for identification of individual features and targets, this can be clearly seen in the following figures where the targets are annotated with their respective identifier as picked during the target definition process previously discussed.

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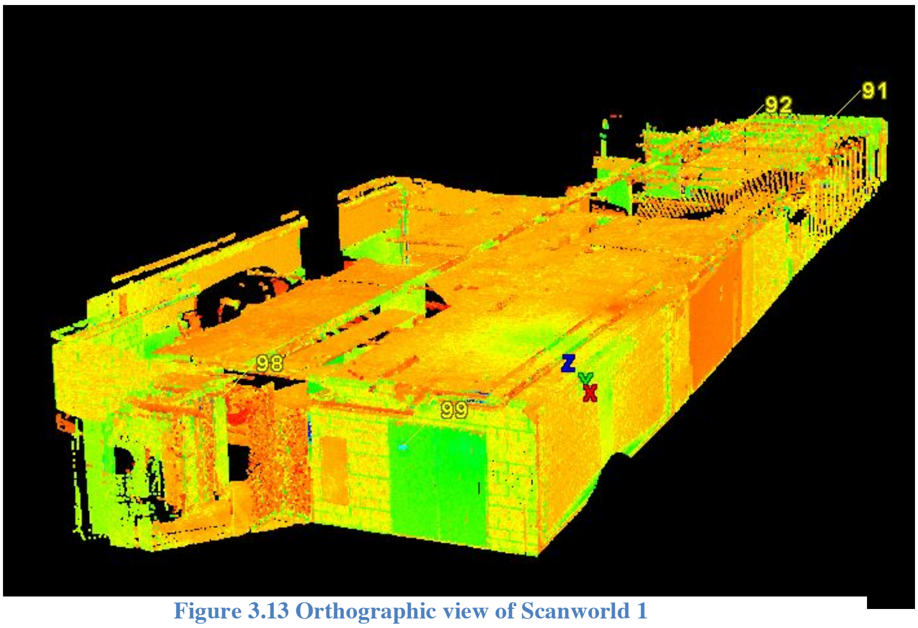


Figure 3.13 Orthographic view of Scanworld 1

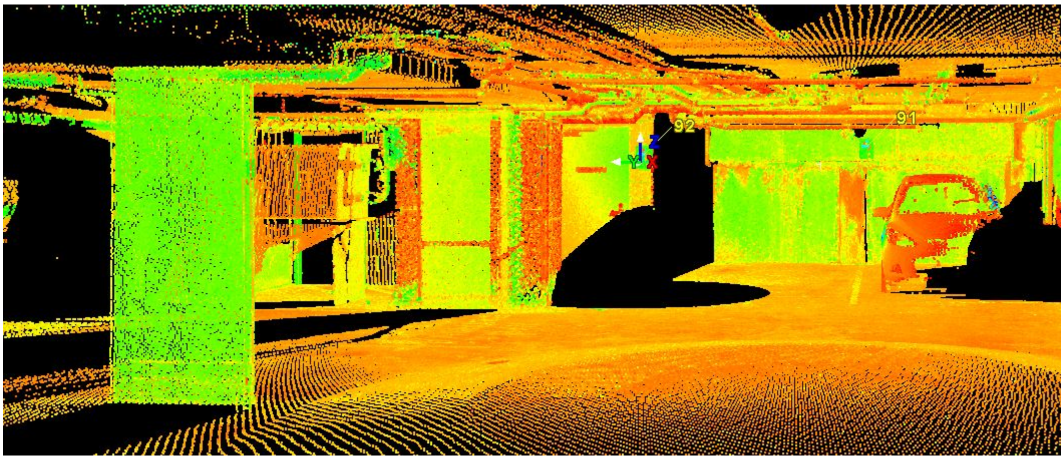


Figure 3.14 Scanworld 1 Import

Once each Scanworld is imported, it is necessary that all the targets be appropriately identified within each scan in order to facilitate the registration process. Each identified target that was not picked and defined within a name during the scan has a blue crosshair attached to it, but can be named through clicking on the crosshair.

The targets facilitate the registration and the geo referencing processes which both occur simultaneously as a part of the registration process. The geo referencing occurs through the importation of a .txt file that is generated from the translating the arbitrary total station onto the real world datums of MGA and AHD within Terramodel.

The registration process works through constraints that are accessed through the register menu of Cyclone. The types of constraints that can be selected include cloud-to-cloud constraint, Target ID only constraints and the visual registration which involves the iterative selection of points that are common to one and other within differing point clouds. Residuals for errors are provided during the registration process in terms of how matching targets within a scan world, which is indicative of the errors involved in the congealing process of the individual point clouds. Finally, the point cloud can then be unified and filtered of noisy and unwanted data to allow for modelling of the registered point cloud and creation of a 3D model.

3.6 3D Modelling

The process of 3D modelling can commence once the final unified point cloud is produced. The aim of the 3D modelling is to create, from the point cloud, all the structural features within a point cloud through extracting the surfaces and shapes of objects.

The process of creating a 3D model is performed within Leica Cyclone which possesses multiple tools to create objects from point clouds such as region grow, create box, create cylinder, extract surface plus a range of other options to cater for the accurate modelling of a broad range of possible objects found in the real world. These processes are generally similar in the way that they are executed within Cyclone, and involves the iterative selection of points on a surface or object, and then the software running an algorithm to extract the geometry of the subject objects from the chosen points of the point cloud.

These process are repetitive in nature and was performed multiple times in order to refine the extracted features to ensure that they were geometrically representative of actual feature in reality and to ensure that it was survey accurate. The extracted features were then edited using tools within Leica Cyclone such as merge, extend patch and align to axis to further develop the 3D model. Again this process was repeated numerous times to ensure a truly representative 3D Model of the site were created.

Once a final model is obtained and satisfactorily created, the objects are exported into AutoCAD Civil 3D in the format of the Cyclone Objects Exchange (COE), which exports the features from Leica Cyclone to either AutoCAD or Microstation in the form of objects classed as meshes, surface, 3D solids or polylines. From here, the imported objects can be classified into layers to control the visualisation and future modelling of the features.

The Cadastral data can now be created in AutoCAD for the incorporation into the 3D model; this is done using the registered cadastral plan of the site SP90738 that contains all the geometric cadastral information for all the parcels. The parcels are created using conventional CAD methods and then extruded using the extrude function to extrude the parcels vertically and by doing so converting them into 3D. The parcels are then aligned to the 3D model of the site to synthesise the two datasets together and the appropriate textual information concerning the cadastral information of the site is also added into the model to enhance the effectiveness of the visualisation.

Once this process is complete, the combined model is then exported to Microstation in the form of a DWG for creating of the 3D PDF. Microstation was chosen as the software to print the 3D PDF as it embodies an inbuilt capability to print 3D PDFs without requiring the purchase or acquisition of additional third party software and information on how to edit and modify the end product is broadly and freely available. This process is the final in a series of the steps of using a TLS to visualise a 3D Cadastre with the output of the final 3D PDF that can be interactively manipulated to view the cadastral data.

3.7 Conclusion

In this chapter, the methodology of the research task has been introduced. The characteristics of a suitable site were discussed and a suitable site was selected which embodies the desired traits for the project. The methodology of the required task was also outlined and briefly discussed through the surmising of the key steps of the project.

Chapter 4 - 3D Modelling and Results

4.1 Introduction

This chapter describes the data processing and 3D modelling phase of the project. The methods of registering the point clouds that were acquired from the field survey and the processes of feature extraction are discussed. The steps of synthesising the extracted model and the 3D cadastre of the site are then described and the visualisation of a 3D cadastre is also presented in this chapter.

4.2 Import into Leica Cyclone

Once all the data is collected by the field survey the phase of processing and modelling the collected data can then commence. Processing of a 3D point cloud is the methods whereby the point clouds are imported in to 3D laser scanning software where the data within the clouds can be interactively manipulated and viewed as well as having the data extracted from the point clouds. The software package chosen for this step is *Leica HDS Cyclone*, which is marketed as an industry leading package for point cloud manipulation, robust model creation and other survey and geographic datasets that are rich in data by nature for a variety of engineering, construction and architectural applications.

Leica Cyclone comprises of several modules being Register, Survey, Basic, Model, Importer and Server for flexible customisation of the software to suit individual requirements. For the application of visualisation of a 3D Cadastre, the modules that will be used are register and model that allow for the registration and data modelling of point clouds respectively.

Figure 4.1 Creating a Database

The first step of any project is the creation of a database within the software. This is done by the process of right clicking on the server icon that is unshared and then on the database icon in the subsequent menu. This opens up a new screen where the name of the database can be entered which results in the creation of the database where the project and all its data including control files, scan worlds and models will be stored within the software as a .imp file, which can be used to import that database into any *Cyclone* package. Once this step is done, the project can then be created through right clicking on the database and then selecting create project, which allows for the entering of the project name in the prompted window.

The scanning project can then be imported from the laser scanner into the project once the preceding steps have occurred. This is done through file > import > import c5/c10 data which prompts a directory to find the files to be imported.

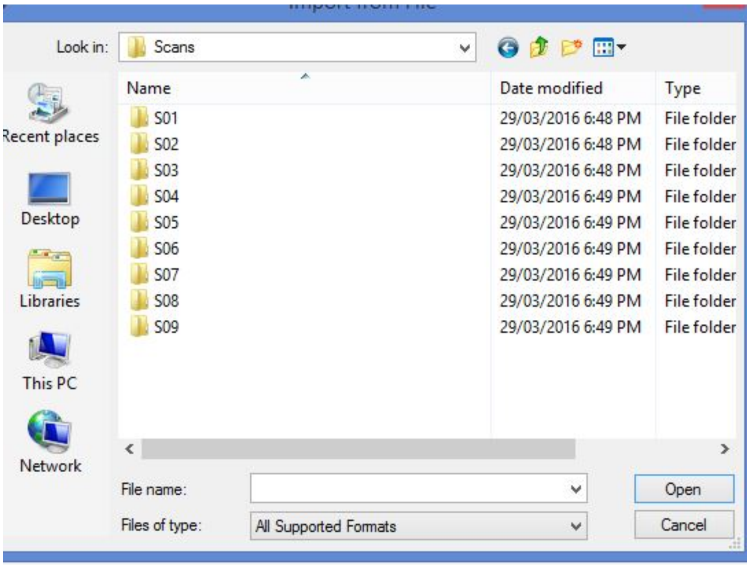


Figure 4.2 Import Menu

Once the files are selected, it prompts with the menu shown in figure 4.3. It is important at this point to have the box find black and white targets ticked, which were used as the targets for survey control during the field survey. This will automate the identification of these targets within each of the scan worlds that are being imported through an algorithm in the software and will help streamline the registration process.

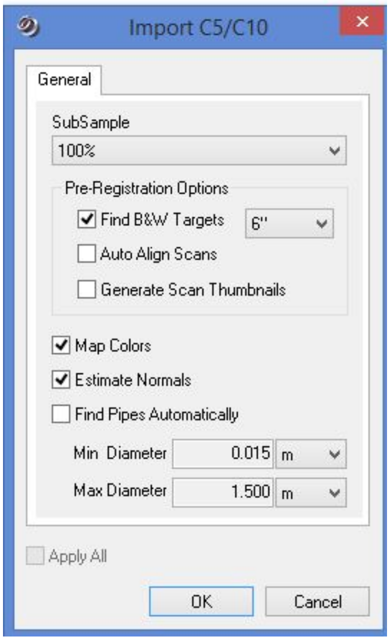


Figure 4.3 C5/C10 Preferences

The resulting scanworlds can then be interactively viewed once the import is complete through the navigation tree of the database and the project, with a total of 9 scanworlds being imported into the project. The navigation tree menu lists the names of all the projects and their scanworlds and the individual files within these scan worlds in the format of hierarchy that is easy to navigate and view individual parts of the project.

Upon expanding a scanworld folder by clicking on any project, there exists four sub levels of the navigation tree hierarchy being the scanworld, control space and model space, which upon selection open up a new window containing specific information. Each scanworld and registration has the same sub menu and the items are described as follows:

- The Control Space contains the targets and control points that have been used in the registration process of the point cloud. The control space is in essence locked from editing to prevent any erroneous data manipulation or loss and can only be updated through editing the model space.
- The Model Space is the workspace where all the data manipulation and feature extraction of the point clouds occurs. It has a sub menu which is the Model Space Viewer which is where an edited or changed point cloud can be viewed and features extracted and where 3D modelling takes place
- The Scan sub menu is where the original scanworld as which has all the data collected in the field by the TLS and contains the original data. It also contains the scans of the targets that were defined within that scan through the scan target process discussed in Chapter 3.

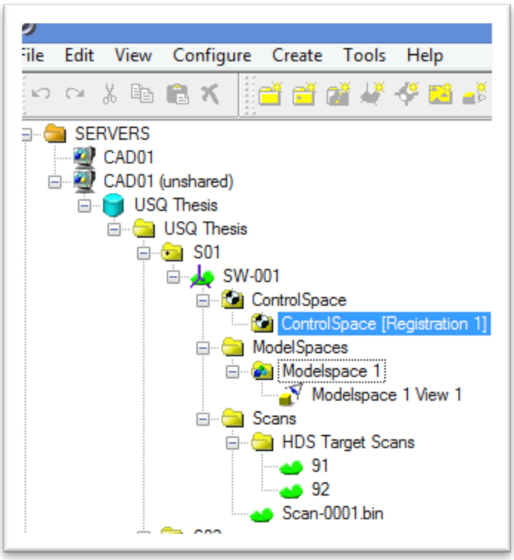


Figure 4.4 Navigation Tree Hierarchy

Once the scanworlds have been imported they can be individually viewed and analysed. This step is useful as helps identify the data contained within each scan. The following images shown below illustrate the raw scan import into Cyclone before any registration or manipulation has occurred.

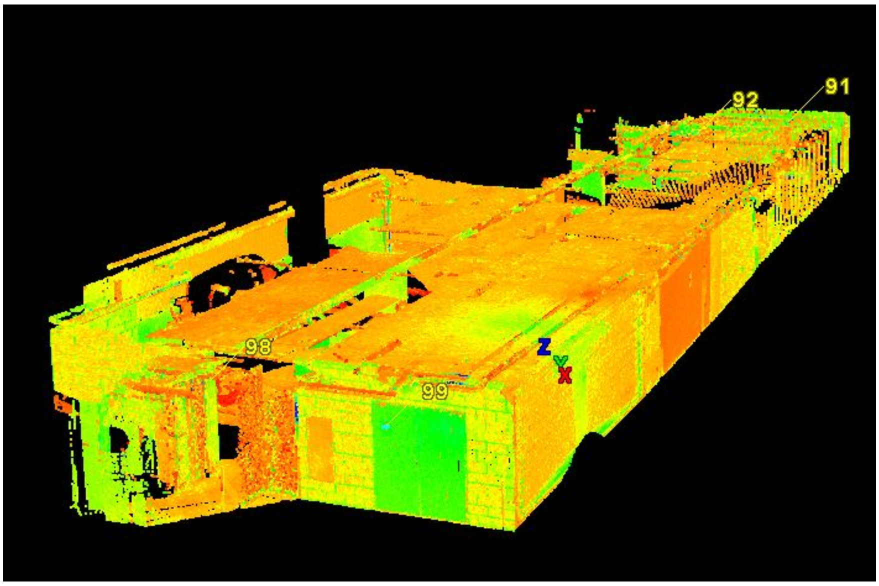


Figure 4.5 Raw ScanWorld 1 Import

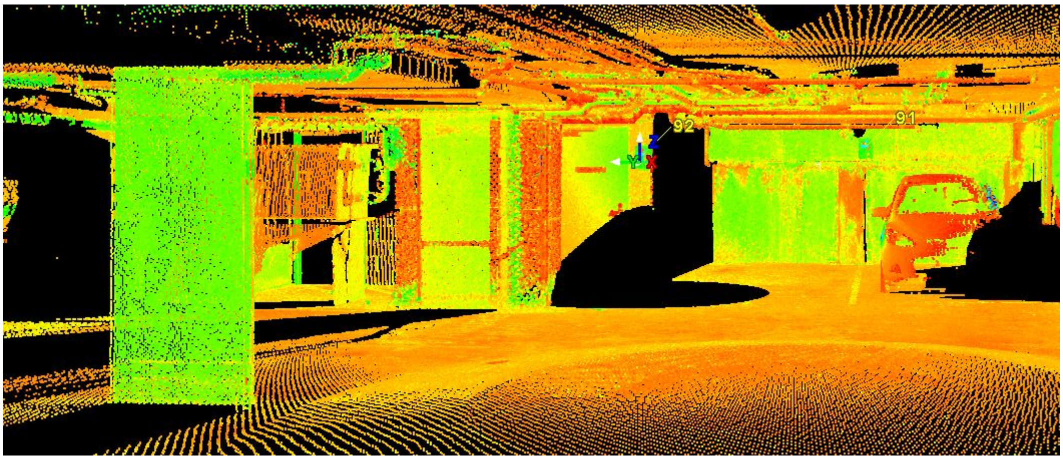


Figure 4.6 Scanworld 8 Raw Import

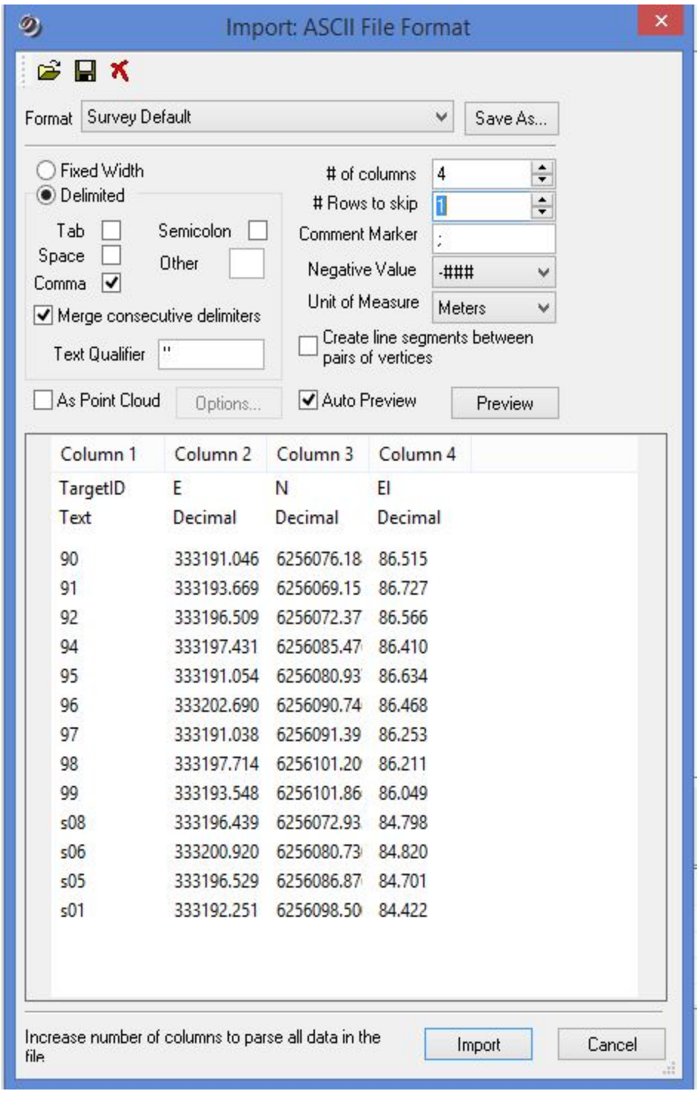


Figure 4.7 Imported Control File

Before proceeding to the registration and georeferencing phase of the project, the control file which was obtained as previously mentioned by using the the total station to survey all the B&W targets at the site and then subsequently connected to permanent survey marks to obtain MGA and AHD values. The control file was reduced and rotated in the TerraModel Survey software and exported as an ASCII .txt fie.

The same file can be imported into *Leica Cyclone* through the same import process used to import the scan worlds, but changing the file type extension to a .txt in the selection box at the bottom of the window and then subsequently selecting the control file. The Imported file can be seen in Figure 4.6 and shows the reduced MGA and AHD values for each of the target points. This will facilitate the registration each of the scan worlds to these real world coordinate and datum values.

4.3 Registration of ScanWorlds

Once the point clouds and the control file have been imported into *Leica Cyclone* through the methods aforementioned above, the registration process and by consequence the geo-referencing of the point clouds and subsequent model can commence. As discussed previously, it was an objective during the field survey that to have where possible at least four B&W targets visible from each scanning station and coincident to at least two scanworlds within the project. This was to ensure adequate redundancies for the registration process whereby matching coincident targets are used to align the overlapping scanworlds to one and other to create a registered point cloud.

The Registration menu can be launched within *Leica Cyclone* through hovering over the *create* icon and moving down to *registration* option which launches a new window where the registration process can commence. It can be seen from this newly launched screen that it has three tabs within it being the scanworld, model space and the constraints respectively. Selecting the constraints tab of this menu, the scanworlds of the project can be added into the project through hovering over the scanworld menu and then clicking on add scanworld item.

This prompts another window whereby the scanworlds that have already been imported to appear on the left side window, and the right hand side window of the menu shows the scanworlds which will form a part of the registered point cloud. The right hand side window can be simply populated through selecting the proposed point cloud on the left hand side and using the arrow icon to move it to the right hand side of the window for registration.

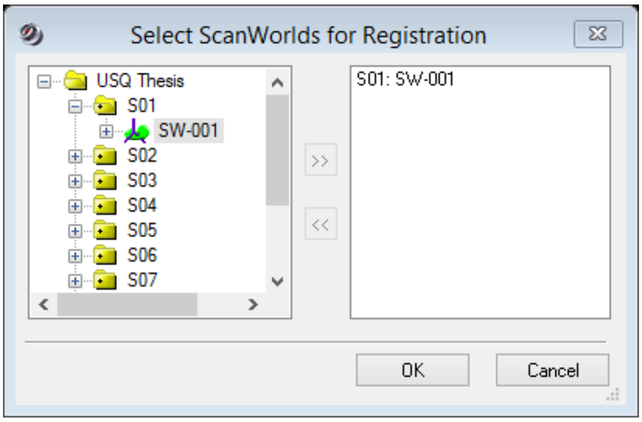


Figure 4.8 Import Scanworlds to Registration

Once all the scanworlds and the control file have been imported into the registration menu and before the actual registration process can be commenced, a home world scan must be set. This is the scan or coordinate system to which all the other scans within the project will be registered to. Given the control file that was imported contains all the MGA and AHD values for all of the B&W targets placed around the site, it is highly appropriate to set this as the home world scan as this will enable the registered point cloud to be geo referenced through the same process.

Once the home world is set, the registration process can commence. For this project, it is intended to use the constraints of the B&W target so using the constraints menu and then selecting the *auto add constraints (target ID only)* which populates the registration menu with the matched target ID's within each of the scanworlds. The selection of *auto add constraints (target ID only)* results in only the addition of the B&W targets which have been assigned an ID within their respective scanworlds being added to the constraints tab of the registration menu.

Once the registration menu is populated, the registration process is enacted through the *file menu* and selecting the *register* command. This results in the alignment and conjoining of the point clouds together. During this process the software is quite ingenious as it prompts if it finds targets that it believers have been mislabelled in error and proposes the correct target ID for a solution. After it has completed its registration process, the results of the registration values are displayed and the computation of the error values and the residuals for each of the coincident targets that have been matched to one and other from the overlapping scans can also be seen within the registration menu. This can be seen below.

Constraint ID	ScanWorld	ScanWorld	Type	Status	Weight	Error	Error Vector	Group Error	Group Error Vector	Group
99	control file MG...	S03: SW-003 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(-0.001, 0.000, -0.001) m	n/a	n/a	Ungrouped
91	S08: SW-008 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(-0.001, 0.000, 0.000) m	n/a	n/a	Ungrouped
91	S06: SW-006 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.000) m	n/a	n/a	Ungrouped
99	S08: SW-008 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(-0.001, -0.001, 0.000) m	n/a	n/a	Ungrouped
91	S06: SW-006 (...	S08: SW-008 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.001, -0.001, 0.000) m	n/a	n/a	Ungrouped
93	S06: SW-006 (...	S07: SW-007 (...	Coincident: Vertex - Vertex	On	1.0000	0.001 m	(0.000, -0.001, 0.000) m	n/a	n/a	Ungrouped
90	S06: SW-006 (...	S07: SW-007 (...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, 0.002, -0.001) m	n/a	n/a	Ungrouped
90	S06: SW-006 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.001, -0.001, 0.000) m	n/a	n/a	Ungrouped
92	S08: SW-008 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.002, 0.000, 0.000) m	n/a	n/a	Ungrouped
91	control file MG...	S06: SW-006 (...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.000, -0.001, -0.002) m	n/a	n/a	Ungrouped
92	control file MG...	S08: SW-008 (...	Coincident: Vertex - Vertex	On	1.0000	0.002 m	(0.001, 0.000, -0.002) m	n/a	n/a	Ungrouped
91	control file MG...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.002, -0.002) m	n/a	n/a	Ungrouped
91	control file MG...	S08: SW-008 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.001, -0.001, -0.002) m	n/a	n/a	Ungrouped
98	control file MG...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.001, 0.002, 0.002) m	n/a	n/a	Ungrouped
90	control file MG...	S06: SW-006 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.003, -0.001, -0.001) m	n/a	n/a	Ungrouped
90	control file MG...	S07: SW-007 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.003, 0.000, -0.002) m	n/a	n/a	Ungrouped
93	S07: SW-007 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.000, -0.003, 0.000) m	n/a	n/a	Ungrouped
90	control file MG...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(-0.001, -0.002, -0.001) m	n/a	n/a	Ungrouped
90	S07: SW-007 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.001, -0.003, 0.000) m	n/a	n/a	Ungrouped
95	control file MG...	S08: SW-008 (...	Coincident: Vertex - Vertex	On	1.0000	0.003 m	(0.003, 0.001, -0.001) m	n/a	n/a	Ungrouped
95	S07: SW-007 (...	S08: SW-008 (...	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(-0.001, -0.003, 0.000) m	n/a	n/a	Ungrouped
92	control file MG...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.003, 0.000, -0.002) m	n/a	n/a	Ungrouped
93	S06: SW-006 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(0.000, -0.004, -0.001) m	n/a	n/a	Ungrouped
94	control file MG...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.004 m	(-0.002, -0.004, 0.002) m	n/a	n/a	Ungrouped
97	control file MG...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(-0.001, 0.003, 0.003) m	n/a	n/a	Ungrouped
95	S06: SW-006 (...	S07: SW-007 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(-0.001, -0.001, 0.005) m	n/a	n/a	Ungrouped
97	S03: SW-003 (...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(0.001, 0.004, -0.002) m	n/a	n/a	Ungrouped
99	S03: SW-003 (...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(-0.002, 0.004, 0.002) m	n/a	n/a	Ungrouped
97	S02: SW-002 (...	S03: SW-003 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(0.004, -0.003, -0.001) m	n/a	n/a	Ungrouped
99	control file MG...	S04: SW-004 (...	Coincident: Vertex - Vertex	On	1.0000	0.005 m	(-0.002, 0.005, 0.002) m	n/a	n/a	Ungrouped
97	control file MG...	S03: SW-003 (...	Coincident: Vertex - Vertex	On	1.0000	0.006 m	(-0.002, -0.001, 0.005) m	n/a	n/a	Ungrouped
91	S04: SW-004 (...	S09: SW-009 (...	Coincident: Vertex - Vertex	On	1.0000	0.006 m	(0.001, 0.005, -0.002) m	n/a	n/a	Ungrouped

Figure 4.9 Residuals for Registration of Point Clouds

It can be seen in the above figure that all of the matching targets within the scanworlds that have been identified with about 120 tie points in total. Once the registration values for the matching targets are computed, each of the targets can be individually selected and viewed and checked. Below in the figure, it can be seen how the registration process has matched the coincident target 93 in scan worlds 6 and 9 to one and other and computed the results for the target.

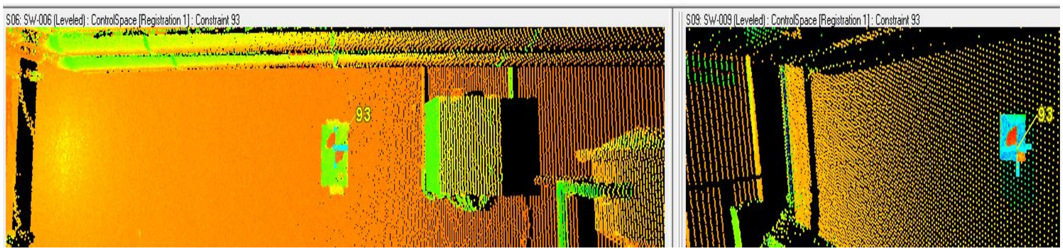


Figure 4.10 Matching Targets in Overlapping Scanworlds

It can be seen from the results of the registration process that the point clouds have been congealed together with a high degree of accuracy. In total, there were approximately 80 control points from the control file and the 9 scan worlds used to produce the registered point cloud, with a total mean error of 0.004m for the entire registration process. This provides a high degree of confidence moving forwards into the modelling phase of the project due to the high quality of the registration.

Once registration process is complete, it is important to then freeze the registration. The freezing of the registration locks the registered point cloud from further editing or changes to the point cloud and ensures that the current registration is maintained. This is done so through the file menu and then selecting on freeze registration. Once this is done the registration menu can be exited. The registered point cloud can now be viewed within the navigation tree under the registration tab. The following figures show the results of the registered point clouds.

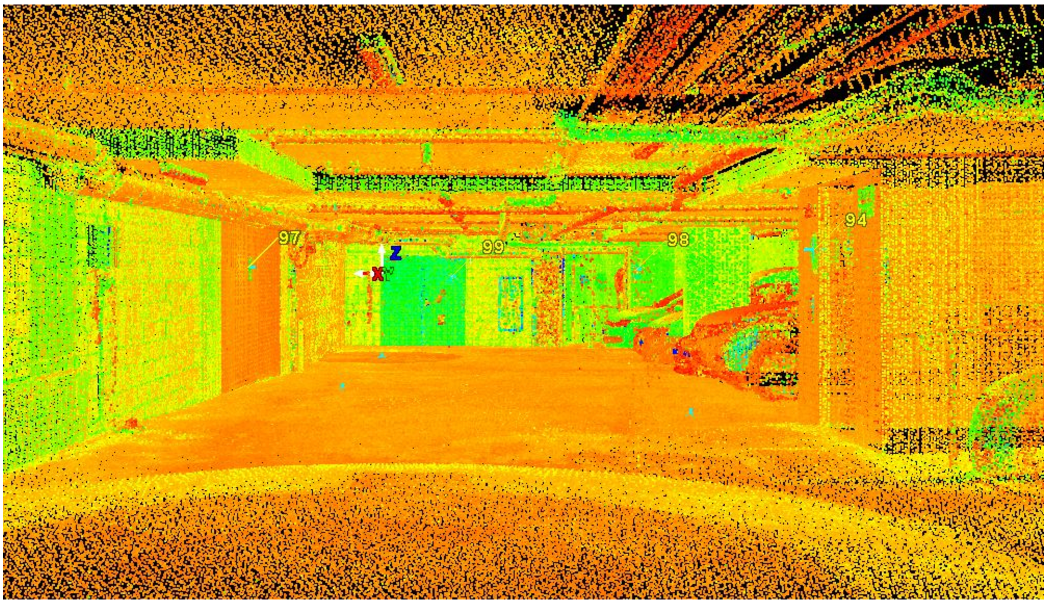


Figure 4.11 Registered Point Cloud

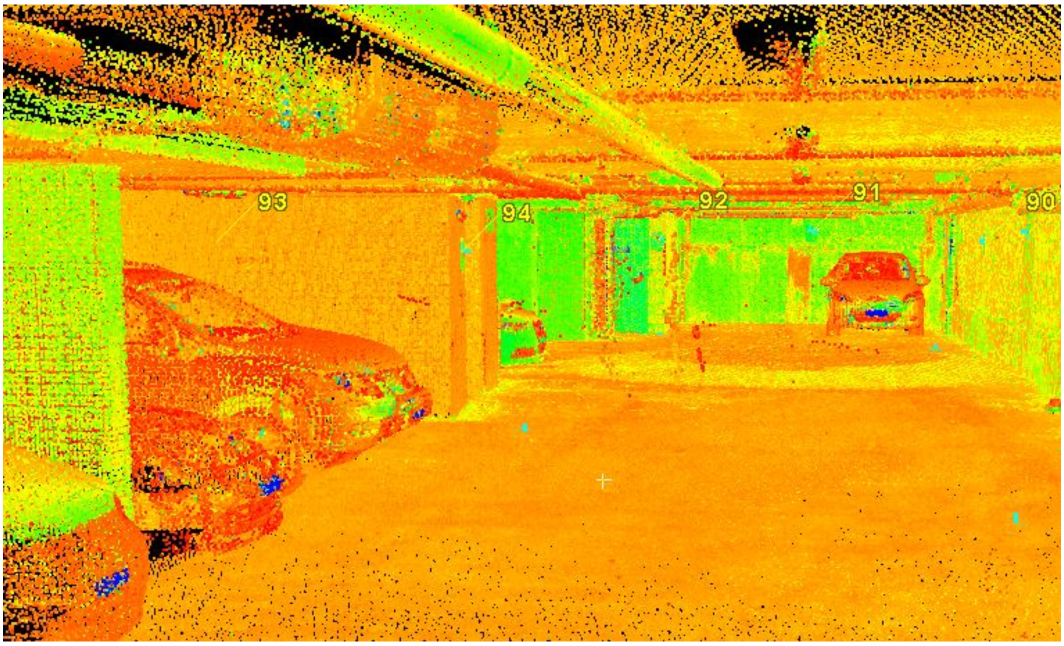


Figure 4.12 Registered Point Cloud

A Final step before the feature extraction can commence is the unifying of the point cloud, which reduces the total amount of points by a specified spacing between points. This makes Leica Cyclone easier to function and process the large amount of points within the registered point cloud. First, it is necessary to copy the registered point cloud through right clicking on the registered cloud in the navigation tree and copying the registered cloud as the unification of the registered point cloud cannot be undone. The unifying can then be done through first launching the copied registered point cloud in a new model space view and then going to the tools menu and selecting the unify cloud option.

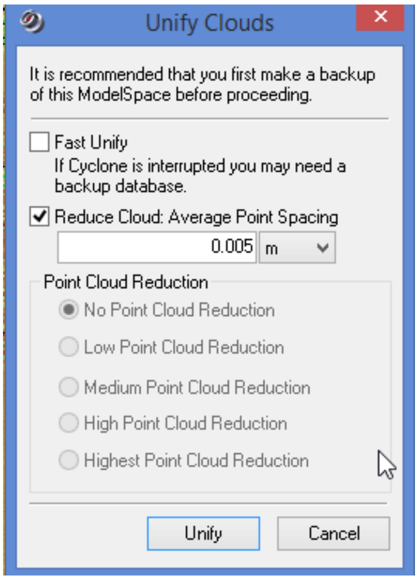


Figure 4.13 Unify Point Cloud

The window shown in figure 4.13 then appears and prompts for the settings for the unification of the point cloud. For this project a unification spacing of 5mm was set. Once this step is complete, the feature extraction phase of the project can commence.

4.4 Feature Extraction

Feature extraction is the process of using the point cloud to create 3D models and shapes of the prevailing environment that was captured during the laser scanning survey within the point cloud. For this application, all the feature extraction and modelling took place within *Leica Cyclone* using the *Cyclone Model* license but there exists numerous other feature extraction and modelling software packages available on the market such as *3D Reshaper*, the *Cloudworx* Plugin for *AutoCAD* and *Microstation* and a host of other options.

To enable the feature extraction within *Leica cyclone*, the Cyclone-Model license must be utilised within the software to enable the extraction and modelling commands within the software to be enabled. The enables the modelling commands such as region grow, fit to fence and fit to cloud all located within the create menu as well as other modelling functions such as create TIN mesh and pipe modelling of the software to be utilised for this process (Payne 2011).

Before the modelling commences however, it is recommended that the point cloud be cleaned of any unwanted shapes of objects that have been captured in error by the TLS which are likely to adversely affect the modelling of features be removed from the point cloud. This can be done in a straightforward approach through using the fence options located in the edit menu to isolate the erroneous points and deleting them from the combined model, however caution should be exercised to not delete excessive amounts of the point cloud. For this application minimal cleaning of the point cloud was undertaken as it was deemed unlikely to affect the extraction and modelling of the point cloud in bad way due to small parts of walls and objects being obscured by cars parked within the site at the time of survey.

The feature extraction process should commence in a sequential way with focus on extracting one particular feature such as the walls first and then moving onto the next feature. The workflow of the feature extraction is outlined as follows:

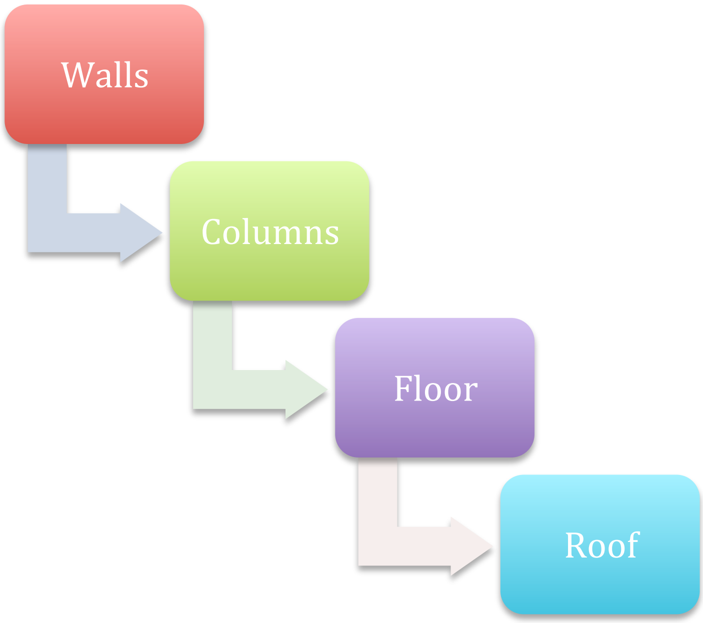


Figure 4.14 Workflow of Feature Extraction and Modelling

The feature extraction process for each of the object types within the project can be further broken down into a series of individual steps each of which must occur before the next can begin. These series of steps are entailed as follows with the focus being applied to a section of wall within the site (Payne 2011):

1. To begin the feature extraction process of a feature, the point cloud should be set to a view that enables the effective isolation of the object through the fencing tool of *Leica Cyclone*. For walls and columns this should be set to a topological view using either the perspective or orthographical view, and for the floor and roof it should be viewed in a cross sectional or longitudinal view. This is done through simply rotating the model to the desired view with the cursor

2. Once the view is set, the fence tool can be used to isolate the feature of interest through either the polygon or rectangle fence mode icons located in the main tool bar of *Leica Cyclone* and then selecting the object of interest.

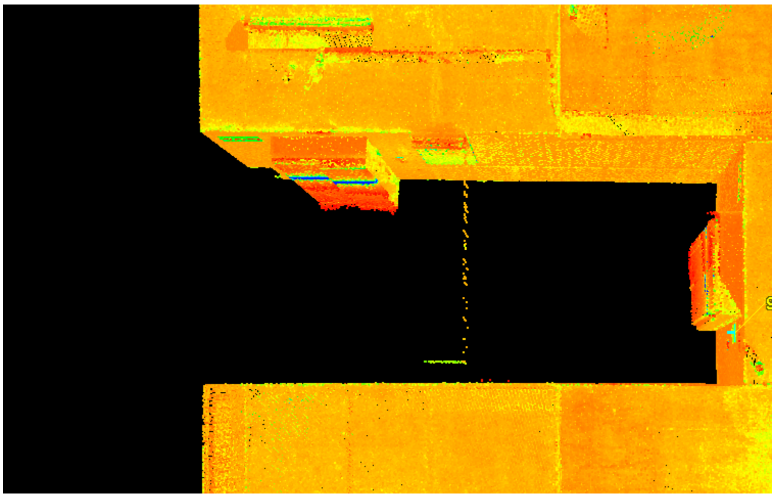


Figure 4.15 Topographic View of Feature of Interest

3. The fenced point cloud selection needs to be added through the *selection* menu and *select fenced* or alternatively right clicking the fenced selection and selecting the *fence* menu and then *select fenced*
4. Then the isolated and selected point cloud is copied to a new modelspace view through again right clicking on the isolated point cloud and the right clicking again and selecting the menu option of *Copy Selection to New modelspace.* This results in the fenced point cloud being copied to a new modelspace where the feature extraction, editing and the modelling can occur without affecting the original point cloud. This can also done

through the file menu and then selecting the launch command

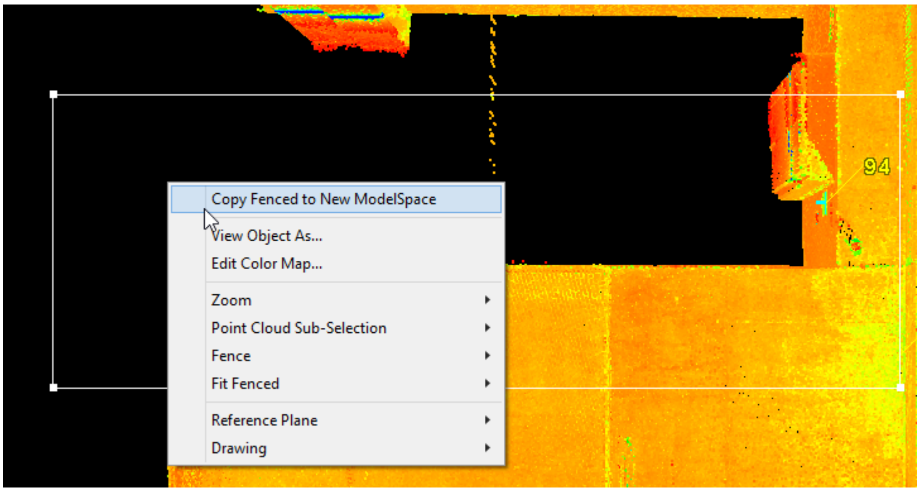


Figure 4.16 Copy fenced selection to new modelspace

5. In the newly created modelspace, the isolated feature should be positioned so that it that its view is square on to the user
6. Now the feature extraction and modelling process can begin. Using the multi pick tool which is located in the main toolbar of *Leica Cyclone*, multiple points can be selected along the face of the wall which is square onto the user in this instance. Caution must be stressed however when using pick points to create the modelled surface of a feature of interest, as incorrect selection of pick points can quite easily result in erroneous patches of the features being modelled in terms of shape, size and orientation. This can result in frustrating results for the modelling process and the re modelling of features many times over due to the surfaces bing created from a poor selection of pick points.

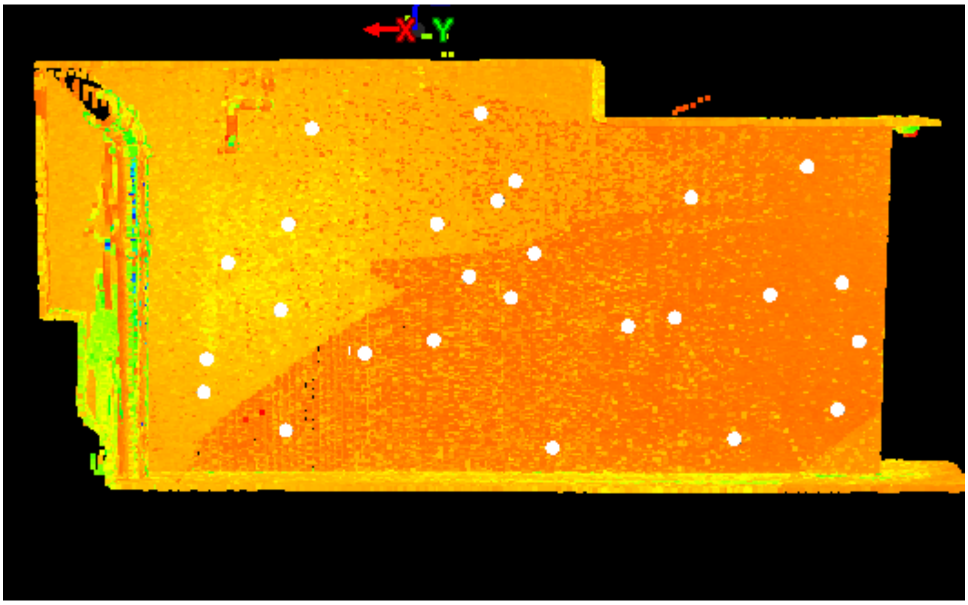


Figure 4.17 Multi Selecting Points for Region Grow

7. Then by going to the create object menu and selecting the region grow and selecting the patch option. This prompts a new window to be launched that contains multiple options for creating the patch. It can be seen in figure 4.18 that the tolerance for the patch thickness is set at 5mm, which means that any points outside that tolerance from the selected points will not be used to create the surface of the patch, whilst the maximum gap to span limits how far the patch will grow through specifying the maximum distance between points used to grow the patch is set at 0.3m. The size of the patch and the statistical details of the patch can also be seen in this window.

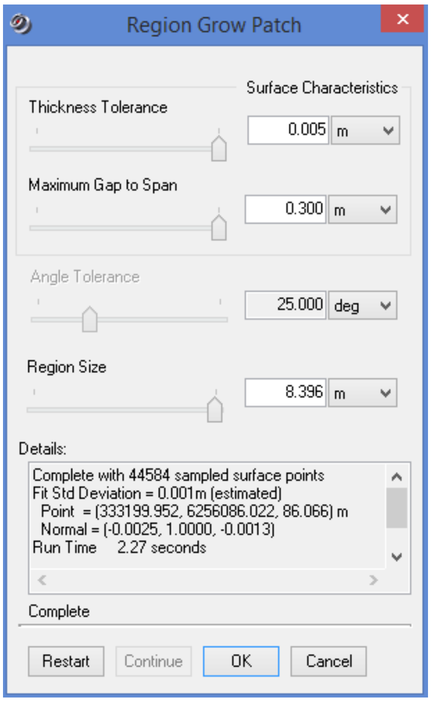


Figure 4.18 Region Grow Statistics

8. Once satisfied with the computed statistics of the patch, the OK icon can be selected and the patch is then grown using the algorithm of the software. Once complete the patch can be viewed within the model space

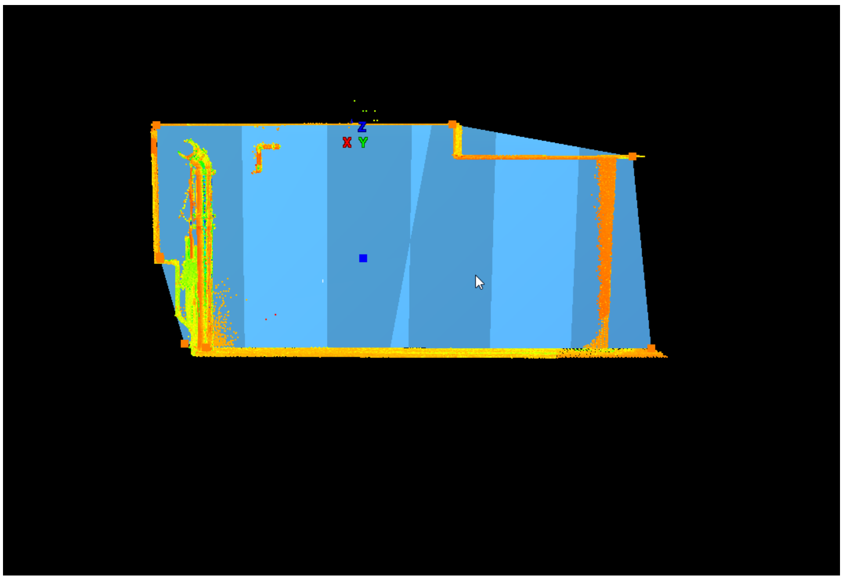


Figure 4.18 Created Patch from Region Grow

9. Once the patch is grown, it is highly probable that the patch will need further editing to truly cover the extents of the object. This can done through using the handles of the object, but it is important to limit the motion in which the patch can be edited otherwise it will not be truly representative of the object it represents. The edit object menu and the handles option can be used to constrain the motion of the handles to a particular axis and in this instance the constrain motion to the Z axis was used.

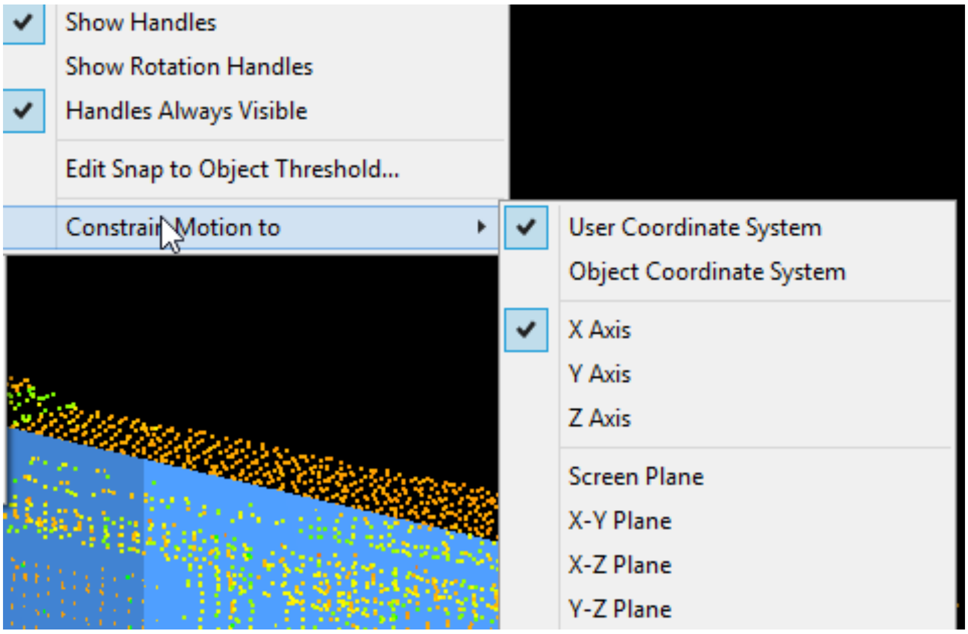


Figure 4.20 Constraning Handle Motion for Patch

10. Once satisfied with the position of the patch, it can be extruded perpendicularly to represent the thickness of the object. For the walls, floor and roof, each of the objects were all extruded by a nominal thickness of 0.2m through going to the edit object menu and the selecting extrude patch and then extruded perpendicularly.

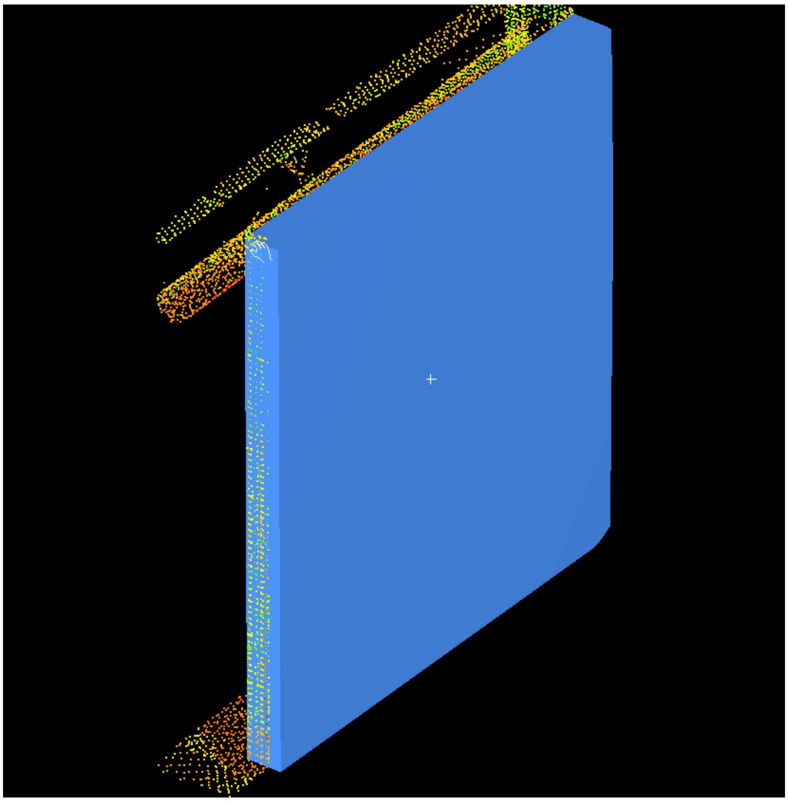


Figure 4.21 Extruded Patch of Wall

11. Once the wall is extruded and the modelling is completed, it can be copied back to the original modelspace through going to *file*, launch and then updated the original modelspace. The copied modelspace can now be exited and the modelled wall now appears in the original modelspace.

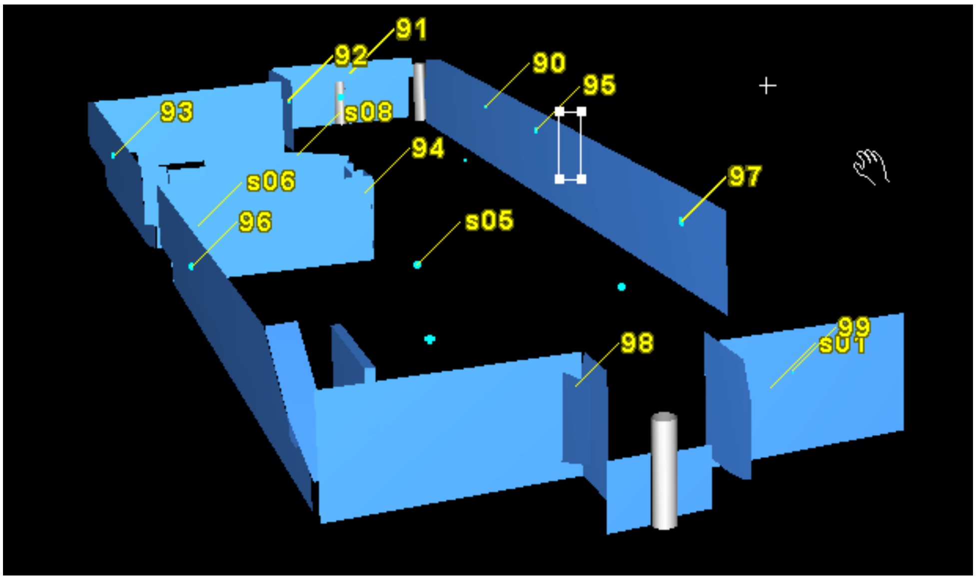


Figure 4.22 Modelling in Progress for Walls

Once a patch was created for the chosen wall of interest, the next was modelled again using the same process described above. Another important function when creating the patches was the use of the extend tool which can be found within the edit object menu. This enabled the walls to be extended to one and other as they are in reality and to ensure no gaps were apparent within the model.

Caution must be stressed however when using pick points to create the modelled surface of a feature of interest, as incorrect selection of pick points can quite easily result in erroneous patches of the features being modelled in terms of shape, size and orientation. This can cause frustrating results for the modelling process and the re modelling of features many times over due to the surfaces bing created from a poor selection of pick points.

Some of the walls and features of the site, the roof in particular, consisted of surfaces that were not rectangular in shape and as such the conventional method used to create the patches was not effective as the patch did not have sufficient handles to model the feature of interest. This difficulty was overcome through using the polyline command that can be found under the drawing options of the tools menu within *Leica Cyclone*. A polyline was used to trace around the edges of the isolated point cloud of the surface of interest, from which a patch could be grown within the point cloud using the from curves command within the create object menu (Payne 2011).

This resulted in a patch being created using the polyline as the constraint for the limits of the surface rather than the picked points on a surface described above in step 6, from which after the patch was created the surface could be edited using the constrain motion principle for the handles described in step 9 of the extraction process described above.

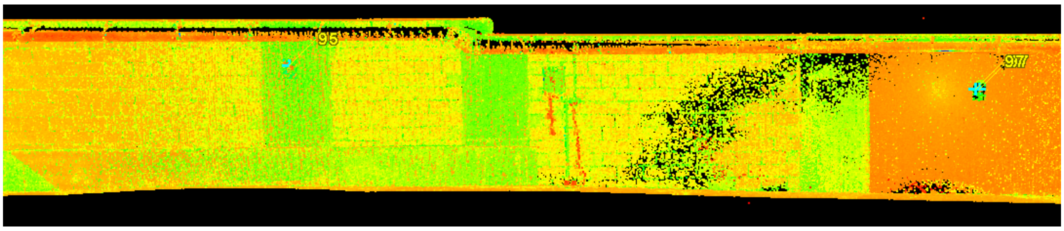


Figure 4.23 Irregular Wall section

Once the walls of the site were modelled, attention was then turned towards the columns of the site. *Leica Cyclone* possesses several different options for the creation of different types of modelled surfaces and solids of an array of features that are straightforward and to learn and then simple to put into practice. Given the columns are rectangular and solid in nature they were modelled using the fit to cloud command within the create object menu.

Firstly the columns were isolated and copied to a new modelspace and then using the multi select tool points were selected on each of the four sides of the column. From this point the fit box to cloud command was initiated and *Cyclone* automatically creates a modelled solid ‘box’ reflective of the column. Once the ‘box’ solid is created it can be extended the floor and roof through using the central blue handle to modify its height or through using the extend command available within the edit object menu of the software.

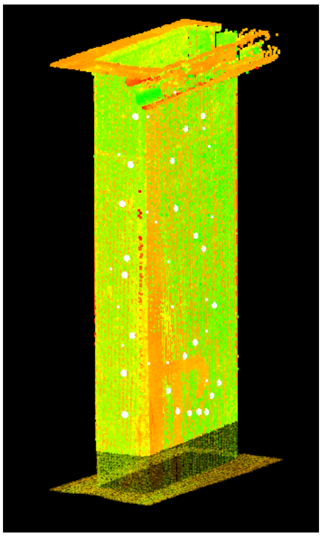


Figure 4.24 Isolated Column Point Cloud

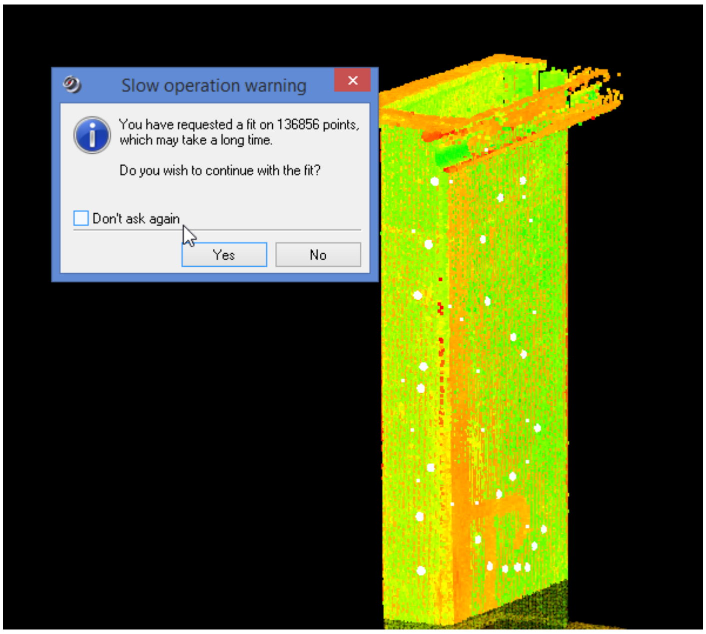


Figure 4.25 Create Box Pick Points

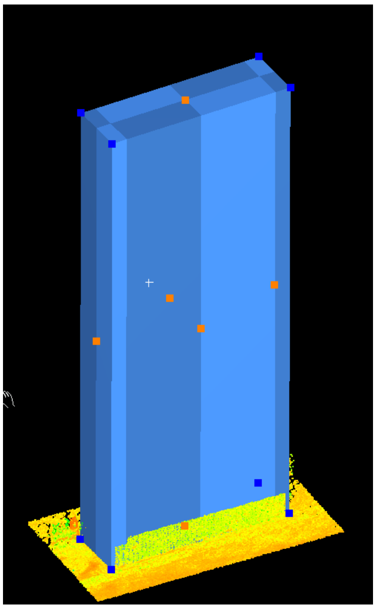


Figure 4.26 Resulting Modelled Column

Once the columns were successfully modelled and added to the primary modelspace, the floor was then modelled using the polyline command to trace its outline and then the from curves command to create its surface. Once the floors surface had been created, it was extruded and then extended to match the surface to tie in within the walls of the model.

Once the floor was completed, attention was focussed on modelling the roof whereby the same process that was used to model the floor were implemented to model each of the sections of the roof. The roof was modelled in a staged approach as it consisted of numerous step-downs in the slab as well has having a beam running across its breadth. Each area of the roof was modelled using a combination of the techniques described previously, and then extruded to one and other and then to the walls of the site.

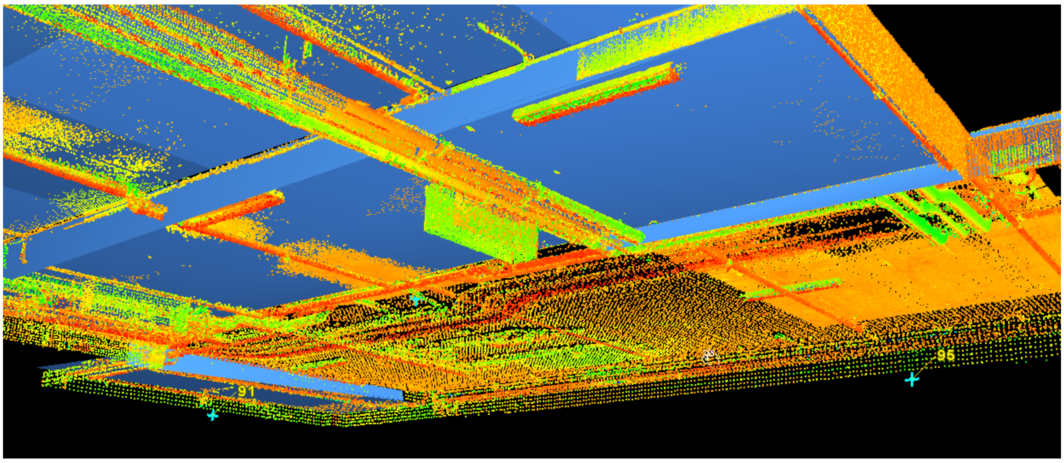


Figure 4.26 Modelling in Progress of the Roof

Overall the modelling process was quite technical and time consuming within its own right not only to ensure the features being modelled were done so correctly but also to ensure that they were accurate and truly representative of the features of the site. The completed modelled was tidied up to ensure there was no gaps within the model using the extend tools and the handles of each of the patches and to make sure no features were modelled in error. The completed model can be seen in the figures 4.28 and 4.29 as well as an image of the actual car park in figure 4.30 for comparison with the model and it can be seen that the created model is very reflective of the actual site.

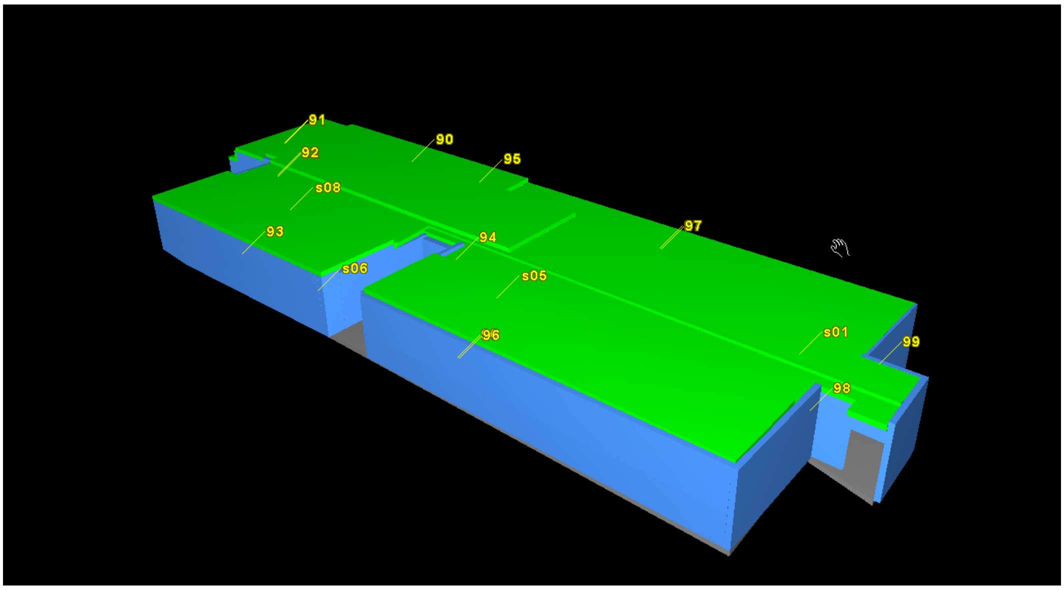


Figure 4.28 Isometric view of completed modelspace

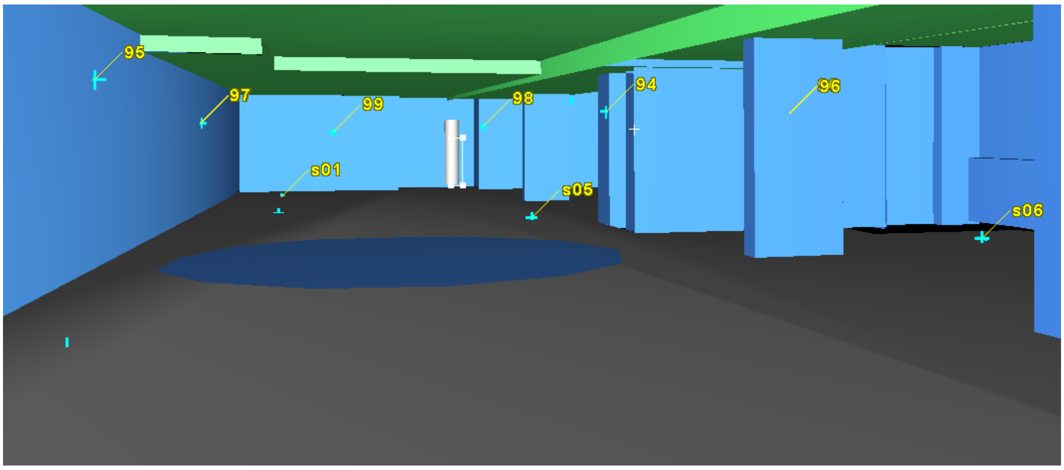


Figure 4.29 Internal view of completed model looking north

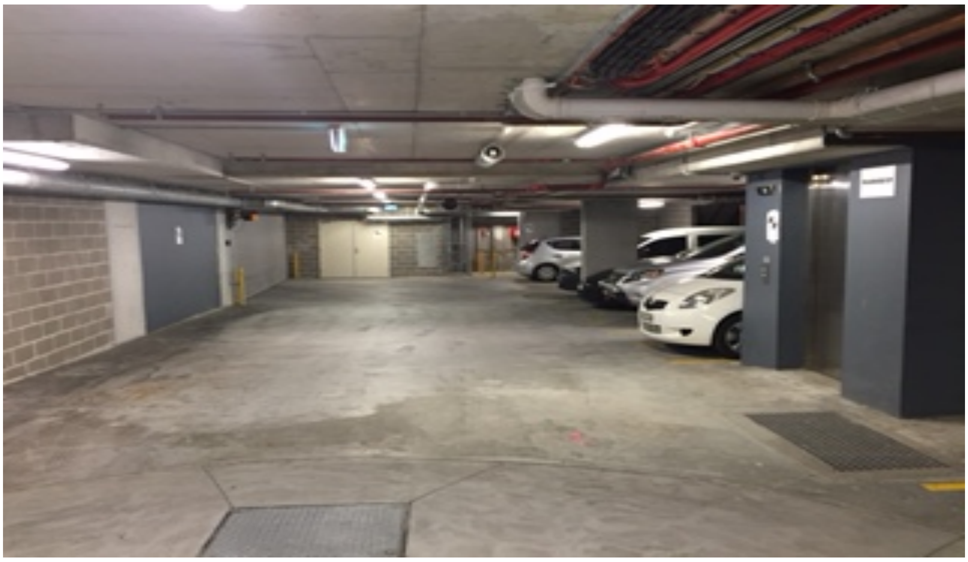


Figure 4.30 Car park Site facing north

4.5 Export Model From Cyclone To AutoCAD

Once the final modelling processes were completed and the final model of the site was produced, it is now ready to be able to incorporate the cadastral information of the site into the produced model. It is a statement of the obvious that boundaries are intangible and as such they can be modelled and created through the commands and tools available within *Leica Cyclone*, nor is it suitable like conventional CAD or survey packages for inputting boundaries into through conventional traverse commands within the software.

Given these points, it is much more straightforward to export the completed model into a conventional CAD package, in this instance being *AutoCAD Civil 3D*. The *Cyclone Objects Exchange* (COE) function is a free plugin that is available to download which allows the straightforward export of objects within *Cyclone* to *AutoCAD* as surfaces, 3D solids and other types of objects.

To export the completed model out of *Cyclone*, the file menu needs to be opened and the export command actioned, which results in a pop up window prompting for a file name. Once a filename is inputted, the dropdown menu below this field can be expanded to select the file type of the export as .COE, clicking on the OK icon and then selecting all that is visible check box that results in the export of the visible model in a .COE format.

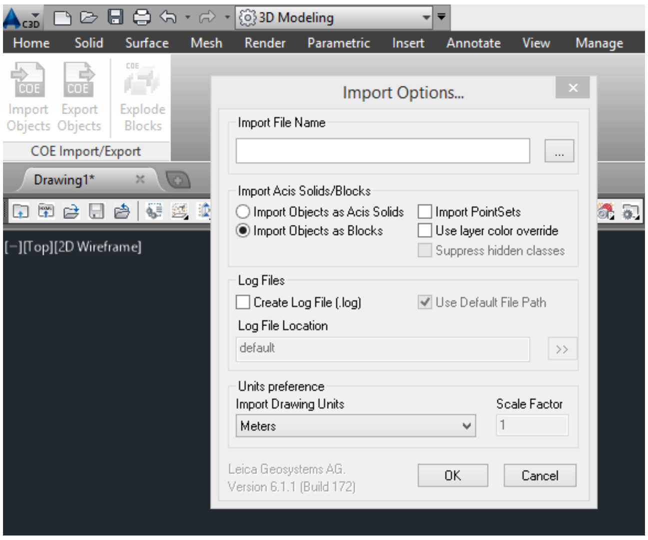


Figure 4.31 COE Import into AutoCAD

Once opening Civil3D, the same file can be easily imported through moving to the COE ribbon and selecting *COEIN* command or by typing *COEIN* into the command field at the bottom of the screen and then finding the file directory of the exported model, leaving the current settings for the import process as they are and then choosing OK. The resulting import can be seen as follows, and it shows the model appearing as wireframes within Civil3D. The appearance of the imported model can be changed through the visual styles command within the view group of commands in the ribbon.

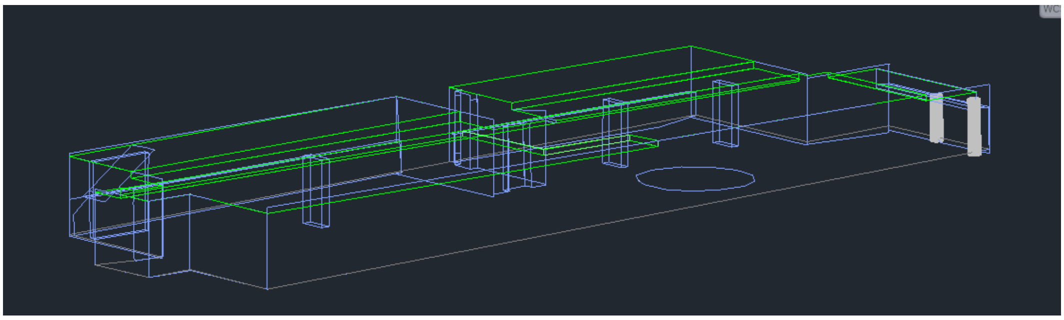


Figure 4.31 Imported Model into Civil3D

4.6 Import of Cadastral Information into Model

One of the most significant challenges of the project was the determination as to how the cadastral information of the site would be incorporated into the extracted 3D model of the chosen site. Given cadastral boundaries are largely intangible and as such cant be directly and physically measured by TLS or any other survey equipment.

To incorporate the cadastral information of the site into the model numerous options were experimented with and considered in order to achieve this task. Firstly it was experimented with trying to recreate the cadastral information directly within *Leica Cyclone* through using polylines to create the cadastral boundaries within the point cloud. This was unsuccessful as there was no way to ensure that the boundaries would be able to put into *Cyclone* accurately as they would be if they were inputted into a typical survey CAD package.

It was then considered with using the created 3D model to produce a two-dimensional floor plan from which the cadastral information could be recreated within and then converting this back into a 3D model. This also proved unsuccessful as it was deemed superfluous and self-defeating of the purpose of creating a 3D model of the site in the first instance. It was also experimented with trying to offset the appropriate walls within the model to incorporate the cadastral information but this also proved unsuccessful as the boundaries are not always coincident with the walls and extend beyond or fall short of the limits of the wall.

It was then considered using the approach adopted by Hao 2011 in the thesis entitled *Assessement of Mobile Laser Scanning in 3D Cadastre*. In this piece of research, the author is evaluating the effectiveness of using mobile laser scanning to create a 3D cadastre, and in the apartment modelling section of the project encounters the same issue of incorporating cadastral information into the point cloud from the laser scanning. The author uses points the façade of the buildings to stitch the outline of the cadastral boundaries of the subject site in order to create a 3D cadastre.

This approach was then applied to this context of recreating the cadastral information of the site separately from the 3D Model of the site and then using common tie points to congeal the two datasets together. The cadastral parcels of the site were recreated using conventional CAD techniques with *AutoCAD*, with the parcels created in three separate blocks of data in accordance with the layout of the boundaries of the site, that were then to be stitched into the 3D Model.

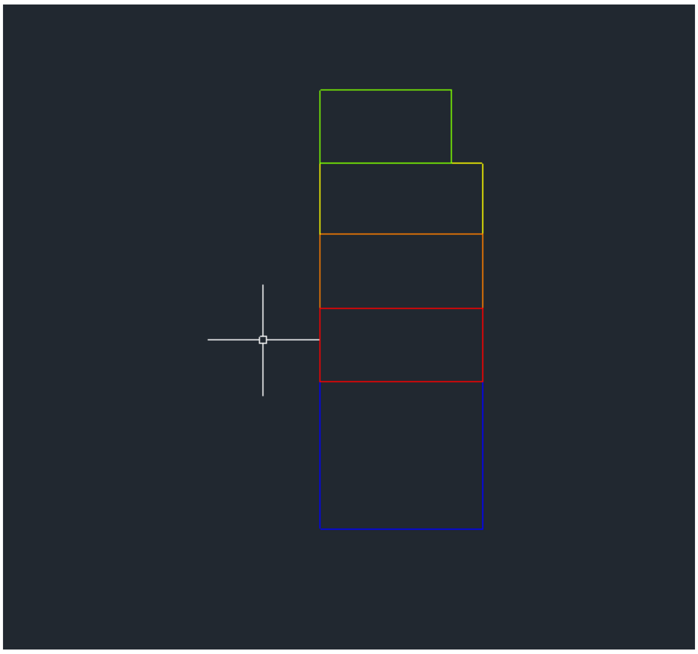
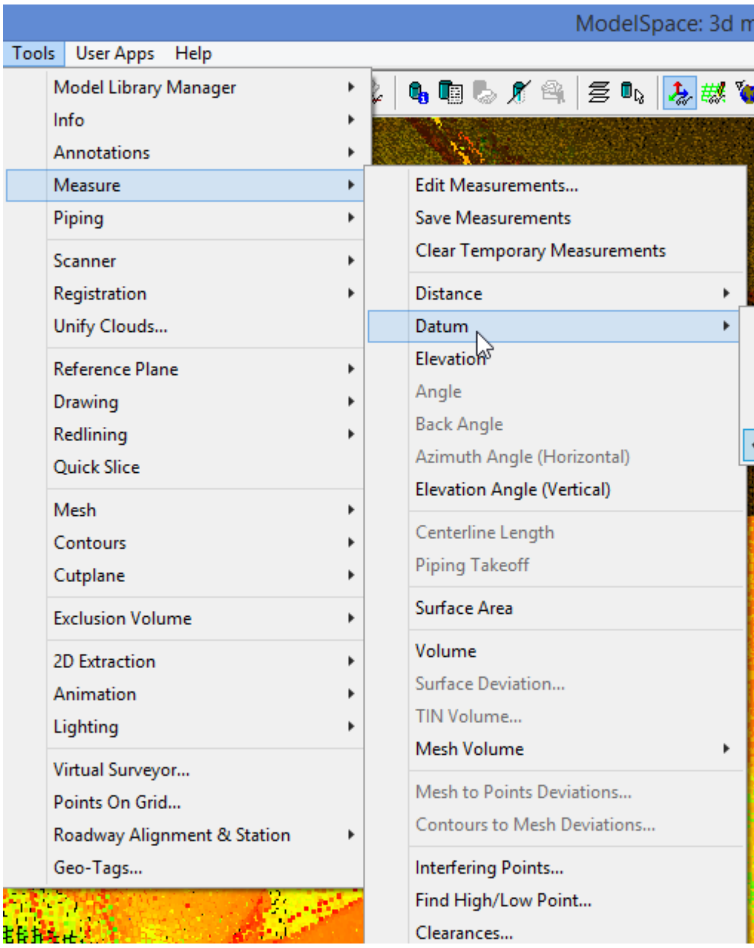


Figure 4.33 Parcels being recreated in AutoCAD

Once the parcels were recreated in blocks within *AutoCAD*, each of the parcels needed to be converted into 3D in order to represent the 3D cadastre, which the parcels are in reality. This was done through using the extrude function, where each of the parcels is extruded along its Z-axis by a specified height. The specified height was determined through using the measure function within *Leica Cyclone* to measure the separation between the ceiling and the floor of the site and can b done through using the measure command with the tool menu of *Leica Cyclone*, and then selecting the datum option. The mean height from the floor to the ceiling was determined to be 2.7 metres and as such each of the parcels were extruded by this value. This can be seen in the following images of 4.34 and 4.35.



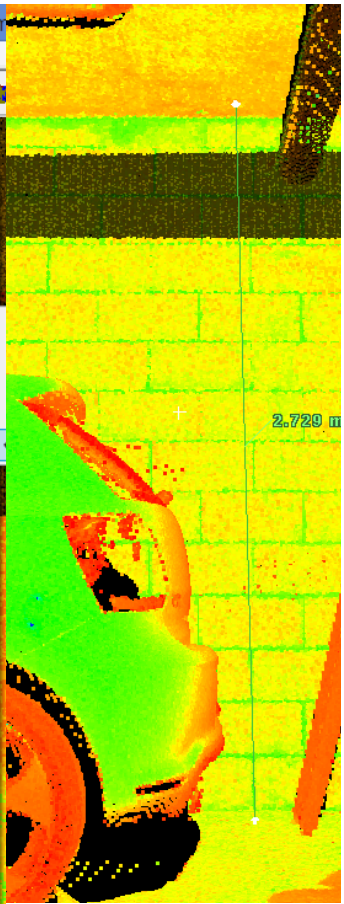


Figure 4.35 Datum Height

Figure 4.34 Process of Measuring a Datum Height

Once the parcels were extruded, the appearance of each of the parcels could then be manipulated. The default display of the extruded parcels is that of a wireframe however this can simply be changed within the view menu that can be found within the main ribbon of *AutoCAD*. The visual styles of the parcels were changed to *solid shaded* resulting in the extruded parcels being displayed as 3D solids rather than wireframes.

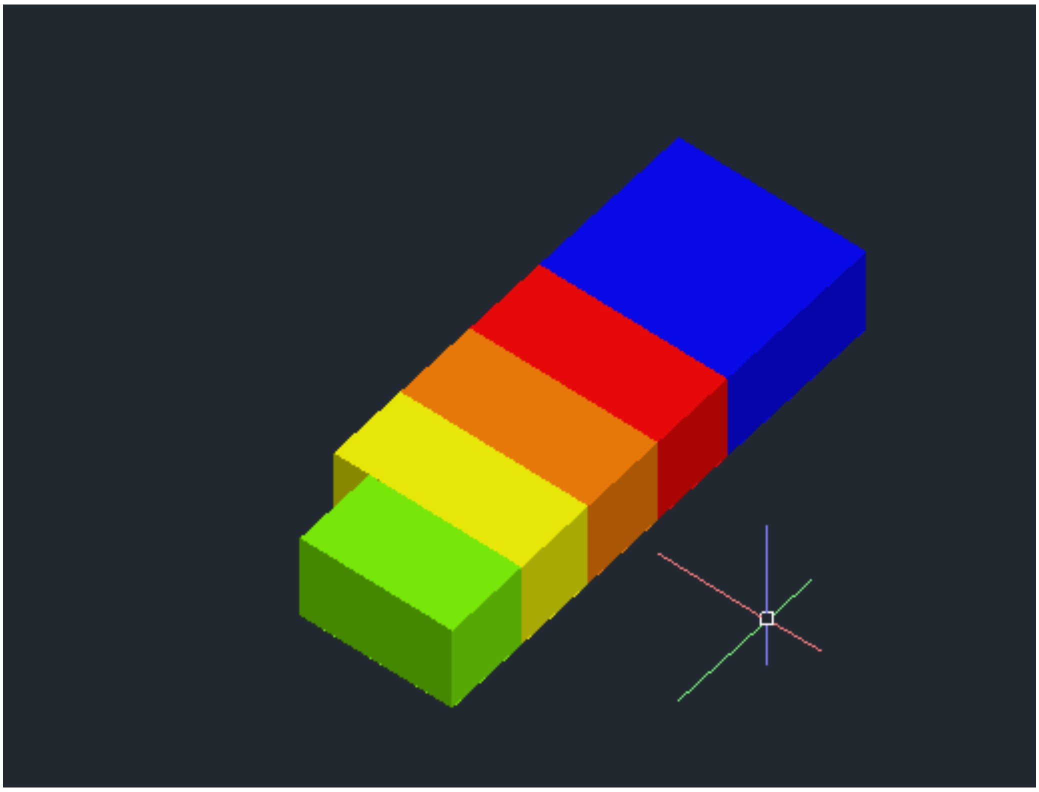


Figure 4.36 Extruded parcels of the site viewed as shaded solids

It was also edited in the next step the transparency of the parcels to further aid in the visualisation of other parts of the model as well as the parcels. The walls, roof and other features of the site were set at a transparency of 50 in a scale of 0 being completely opaque and 90 being invisible, whilst the parcels were set at a transparency value of 70.

Then at this point, each of the parcels were segregated into individual layers reflective of their actual parcel names which in the final visualisation of the 3D cadastre would be further added through being able to view each of the parcels by their unique identifiers as appears on the registered strata plan for the site, SP90738.

Once preceding steps were complete, the incorporation of them into the 3D model of the site could be commenced. Firstly the roof layer was turned off to mark the process easier and then using the 3D align function within *AutoCAD*, the block of extruded parcels had a corner selected and then in the 3D model the corresponding corner was selected. Then the second corner was selected of the parcels and then of the model and the same again for the third corner. Once the third corner was selected the command would execute and the cadastral parcels were aligned into the 3D model.

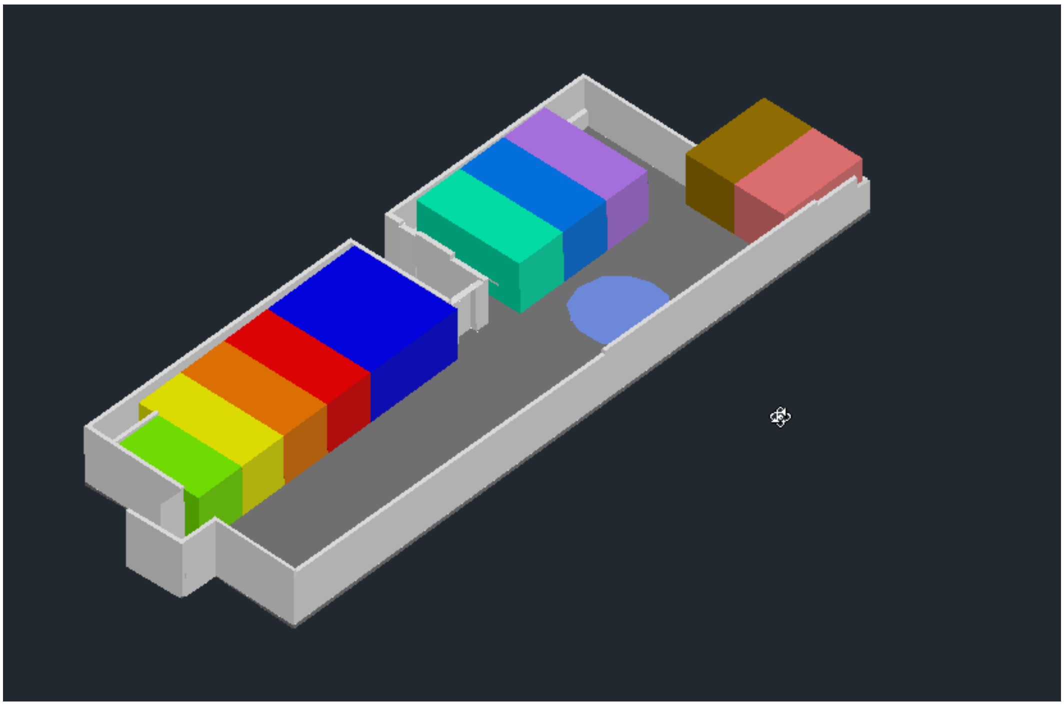


Figure 4.37 Combined Cadastral and 3D Model

This process was one that was time consuming and involved a significant amount of tinkering, as the selection of the wrong points or of a part of the model that was not corresponding with the 3D parcels would cause a misalignment of the two datasets to one and other. Errors could also arise out of this process by having incorrect or incomplete models that would also cause the two datasets to misalign to one and other and not be truly representative of both the cadastral and geometric nature of the site.

To further improve the visualisation of the cadastral model the unique identifiers of the parcels and the semantic information of the parcels was also to be added. The text was created through the very commonly used text command and then was straightforwardly inserted into the model so that its position was coincident with the top part of the parcels and would appear in terms of drawing order in front of the solids of the parcels. It can be seen in the following figure how the text appears above the surfaces of the floor in terms of the dimensions of the parcels and on top of the parcel solids themselves in terms of the parcel identifiers and area.

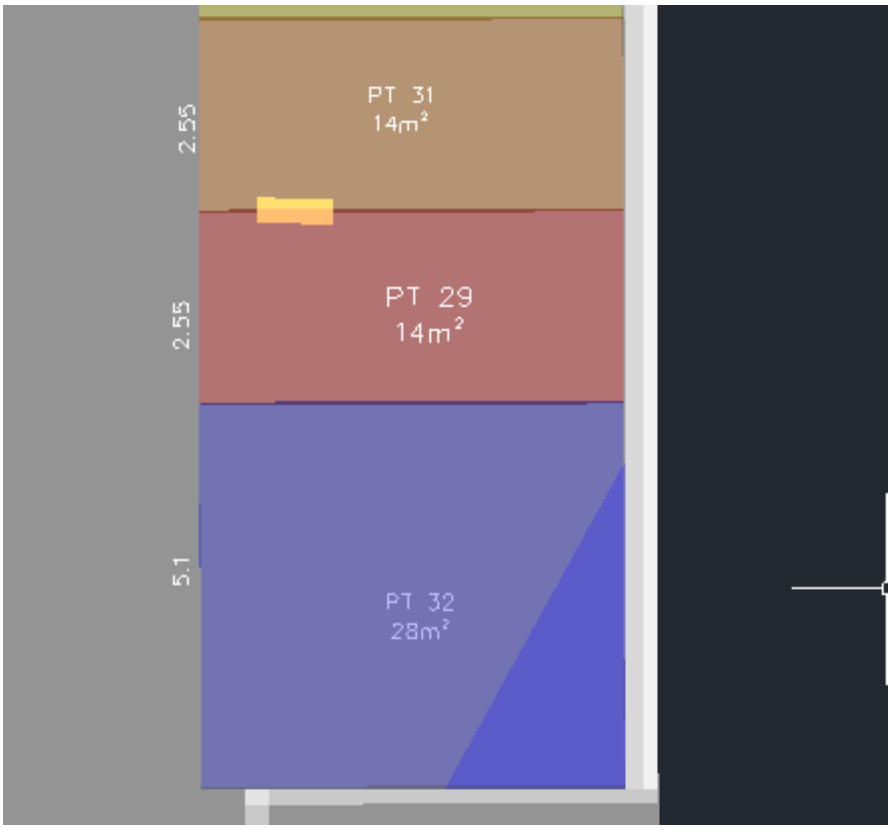


Figure 4.38 Dimensioning Parcels

4.7 Microstation and 3D PDF

Once all the text was inserted into the model it was then in a state where it could then be brought into *Microstation* for the creation of the 3D PDF. This was a very simple process as the combined model could be saved in a .DWG format that is able to be directly imported into *Microstation* through using the import function and selecting the .DWG format without any other processes or file conversions being involved.

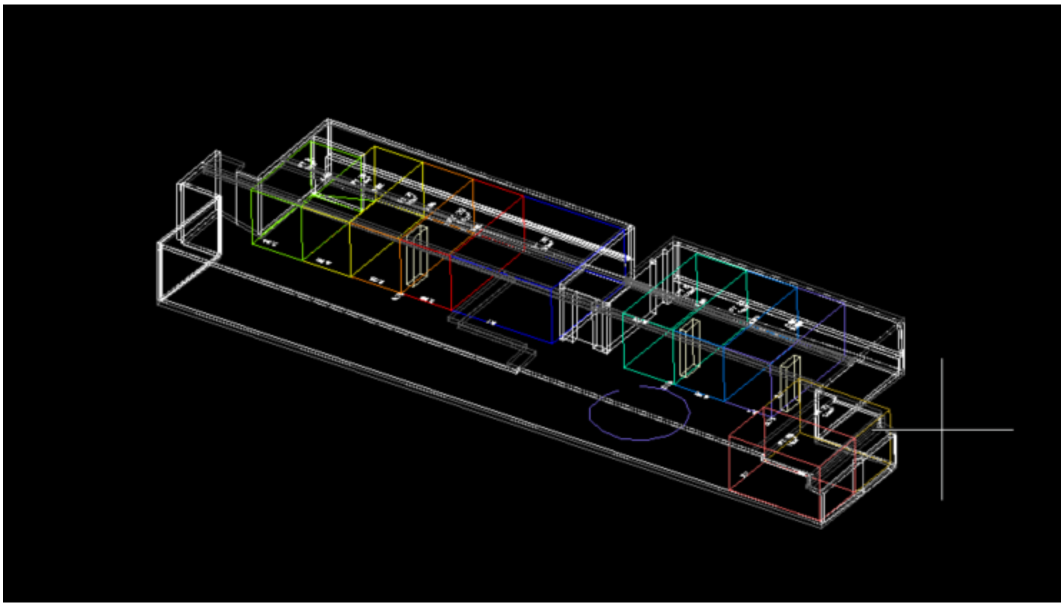


Figure 4.39 Import of Model into Microstation

The reasons of choosing *Microstation* as the software to produce the 3D PDF as it as the inbuilt capabilities of producing 3D printing and 3D PDFs and required no further licensing or costs. This is in comparison to other software such as commercially available plugins to *AutoCAD Civil 3D*, as currently *AutoCAD* does not have a direct capability to be able to print in 3D without using other software. Another reason was that there was that there were a lot of resources available for training and tinkering with the model to get its visualisation correct.

It can be seen from the above figure that the model imports as a wireframe; this can be changed through using the view settings menu and selecting solids to make the objects appear as solids. It is also important to note that the visual characteristics such as colours of the parcels and their transparency values and the layer that were defined in *Civil 3D* are carried over into *Microstation.*

Given the model will be outputted as an interactive 3D PDF another important setting is to have the clip back and front turned off as this allows the whole model to be limited to the set design view when viewing the model in 3D. This helps improve the viewing capabilities of the model when it is being rotated manipulated and prevents the model from being viewed at really small scales that greatly affects the quality of the viewing and manipulation of the model and the functionality of the 3D PDF

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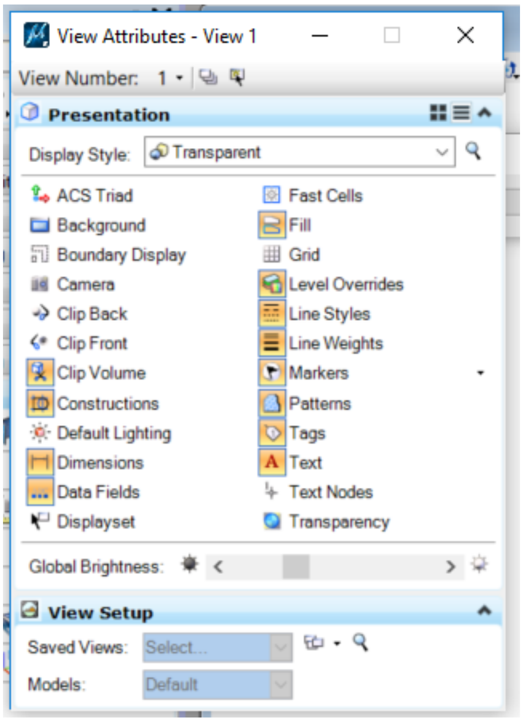

Figure 4.40 View Settings Microstation

Once the view settings have been finalised, the model is then ready to be printed. This process can be initiated through going to the file menu and selecting the print command that launches the print window. In the print window in the drivers' selection field, the Bentley Drivers must be selected and followed by the driver of *pdf.ptlcppfg*. Once these settings are set, the checkbox *Print 3D* should be selected and the desired scale of the model should chosen. This is the scale that the model will have set as the default view in the 3D PDF and its default view is also shown in the print preview screen of this menu.

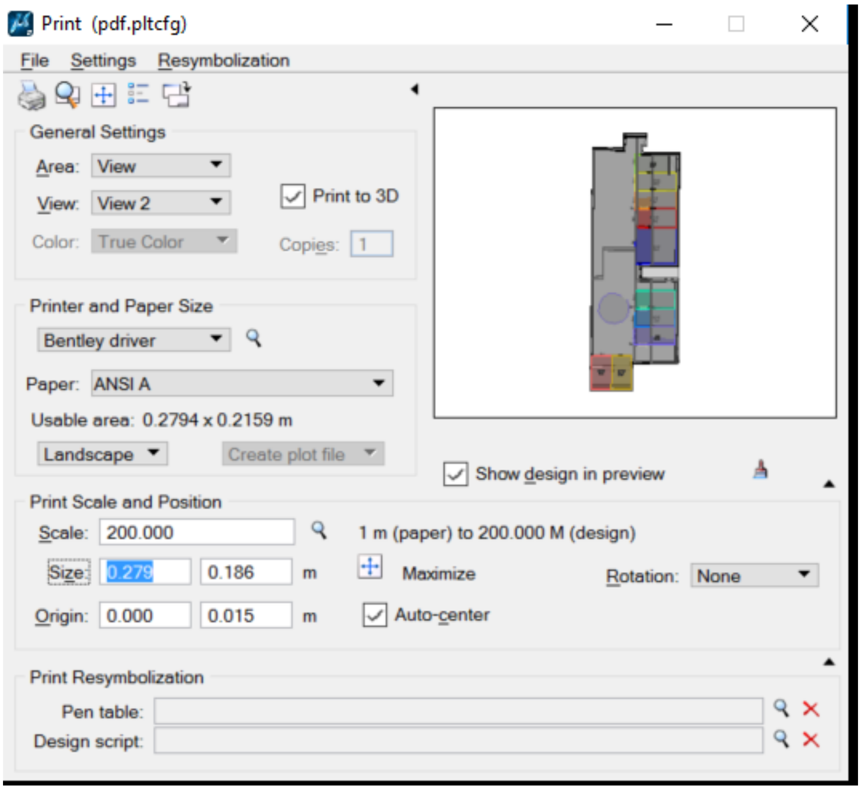

Figure 4.41 Print Settings for 3D PDF

Once these settings are finalised the model is printed and able to be opened up as a 3D PDF in software such as *Adobe Reader* under the saved file name entered upon the selection of the print command in the top left of the print menu. The final model can be seen as a 3D PDF in the following images.

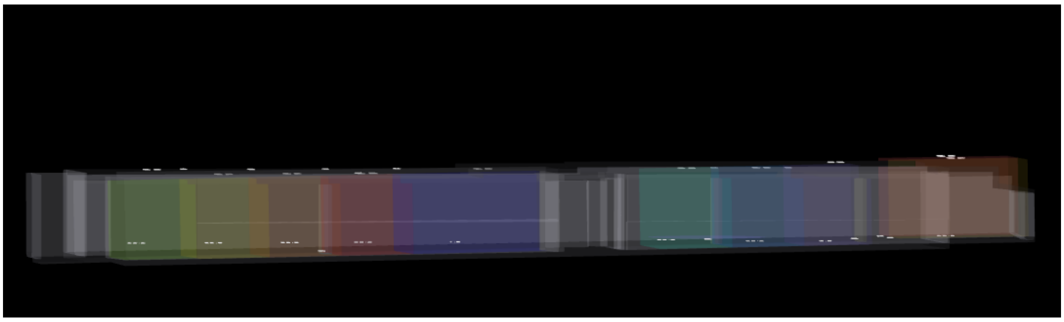

Figure 4.42 Section View of Model in 3D PDF

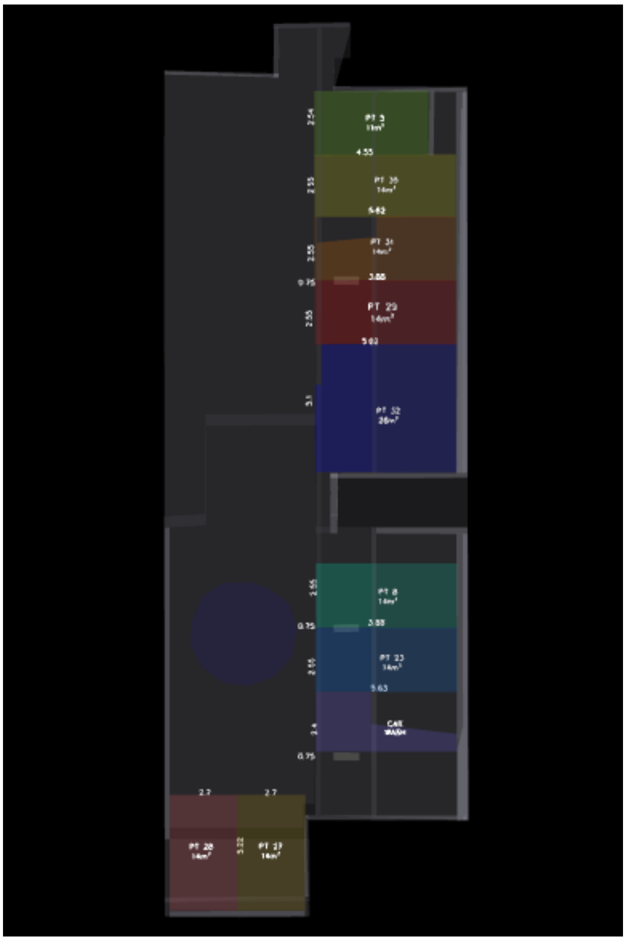

Figure 4.43 Topographic View of Model in 3D PDF

4.8 Conclusion

In this chapter the data processing and 3D modelling methods and techniques were presented. It was first presented how the point clouds were registered and geo-referenced and then how features were extracted from the registered point cloud and modelled in order to procure a 3D model of the chosen site. It was then demonstrated how the cadastral information of the site was then combined into the extract 3D model of the car park. Finally it was explained how the 3D PDF of the model was outputted and the result of the 3D PDF being presented.

Chapter 5: Discussion

5.1 Introduction

In this chapter, the results of the visualisation of the 3D cadastre will be discussed along with the potential applications of such a visualisation. A review concerning the objectives of the project will be offered and the achievements of the project will be benchmarked against these objectives. Finally some recommendations for further research are offered and entailed by some concluding remarks.

5.2 Analysis and Discussion

As discussed in chapter four, the resulting 3D PDF has been generated for the purpose of visualising the 3D cadastre of the subject site of SP90738 located in St. Leonards NSW. When the PDF is opened, one of the first things that strikes the user is the segregation of the parcels and the features of the site into different colours by which aids their distinction from one and other.

The use of visualisation tools such as transparency, extrusion, different colouring schemes and layer control allows for greater control and understanding of both the physical features of the site such as the walls and the roof, as well as the legal features of the site being the 3D land parcels of the site and their associated semantic information.

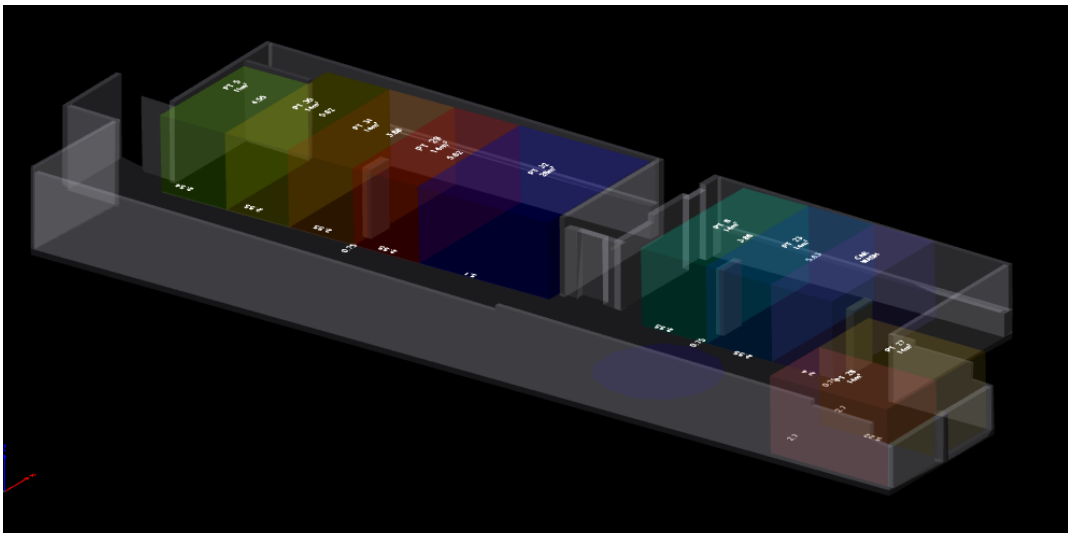

Figure 5.1 3D Cadastre within 3D PDF

Once the user then starts interacting with the 3D PDF, the benefits of the visualisation of a 3D cadastre come to the fore with the ability of the visualised model to be rotated, spun and zoomed in and out of regarding the subject of interest to the user. There is subsequently an infinite number of ways that the 3D cadastre of the site can be viewed through using the 3D PDF in order for the user to improve their comprehension of the 3D cadastre and its geometric and semantic information. There is also the capacity to change the viewing style of the 3D PDF with options shown in figures 5.2 and 5.3.

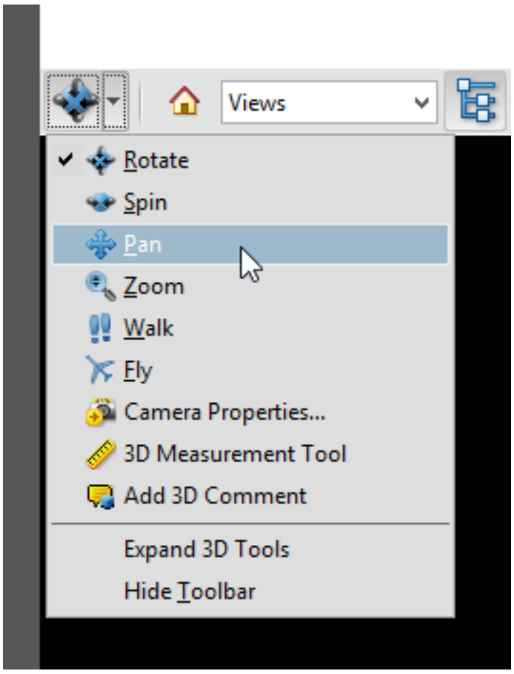

Figure 5.2 Viewing Tools in 3D PDF

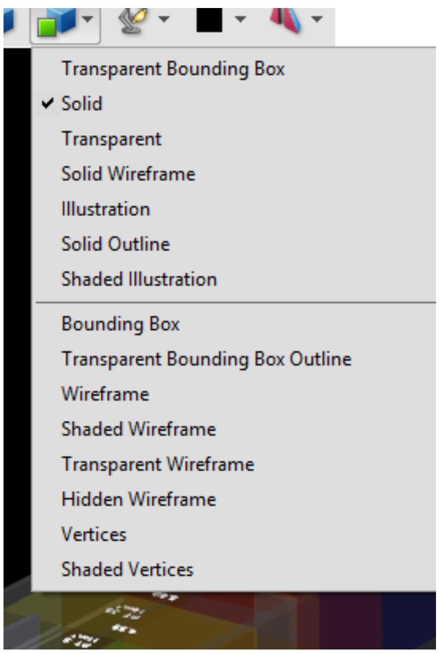

Figure 5.3 Viewing Options in 3D PDF

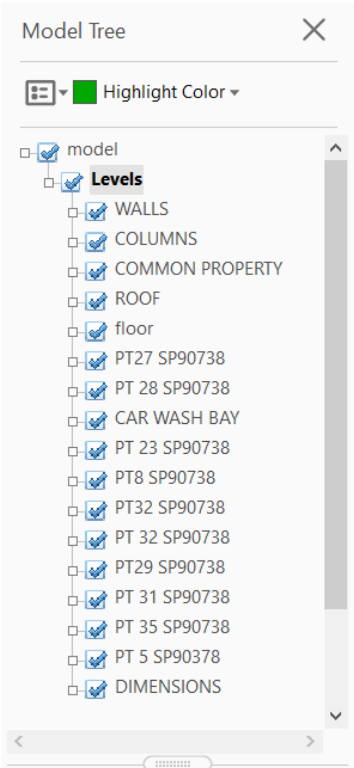

Figure 5.4 Model Tree of 3D PDF

Another benefit of the 3D PDF is the ability to use layer control to turn features on and off using the model tree of the 3D, and as the user desires allows for the customisation of the visualisation as they please. This also applies to the semantic information of the parcels physical features of the site being the walls, columns, floor and roof which can also be turned on and off to improve the visualisation of the 3D cadastre and the users comprehension of the entities within it. Another benefit is that any combination of parcels can be viewed or parcels can be viewed in isolation in order to see its relationship with the surrounding 3D cadastre.

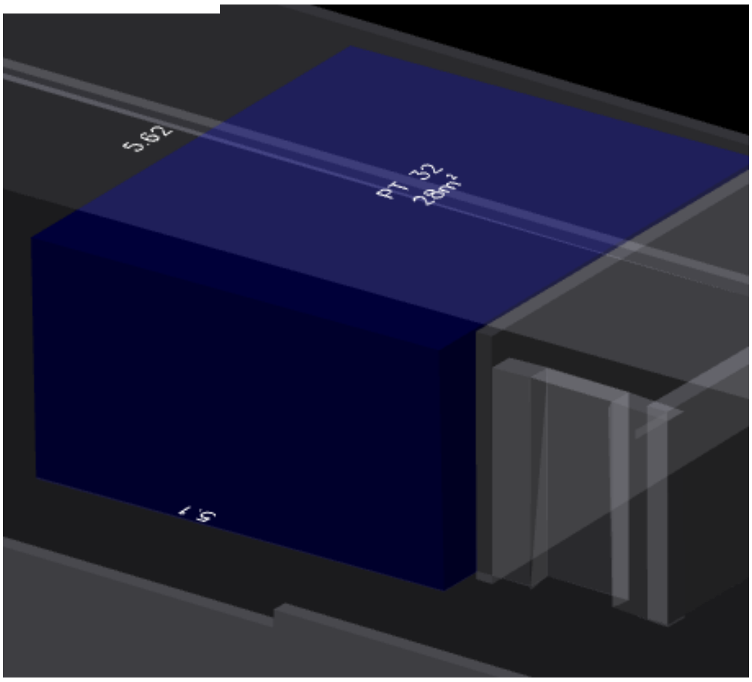

Figure 5.5 Viewing Parcel in Isolation

Reviewing the visualisation principles in 3D cadastres discussed in the paper by Wang et al in 2012, there are extensive visualisation of 3D cadastres benchmarks discussed which the author believes to be essential for understanding and interpreting 3D cadastres. One the principles discussed is the characteristic of visualisation principles with some key questions put forward, namely:

- Selective – does the visualisation allow for the selection of one object from the group of another?
- Associative – Does the visualisation allow for the identification of objects as a part of a group of features?
- Quantitative – Does the visualisation of the object allow for the quantifying of the change in the objects?
- Order – does the visualisation allow the user of a 3D cadastre to understand a difference in the class of the objects?

Considering these points against the visualisation of a 3D cadastre that has been produced using a 3D PDF of the site, the following judgements are passed:

- Selective – it is quite obvious that through the use of varying colours and the layer control of the different parcels that it allows for the distinction and selection of one parcel from another. The interactivity of the 3D PDF clearly enhances this point.
- Associative – again the use of colouring and layer control clearly allows the user to grasp what features are what within the model, for example all the walls are controlled within one layer and one colour, whilst all the land parcels, despite being different colours, it is quite obvious that they are apart of the legal entities of the site.
- Quantitative – the quantification of the objects within the 3D cadastre is difference to other objects is perhaps limited, as this can only be done through the measurement of the parcels using the measure tool within the 3D PDF. It is limited however in this respect as for instance, the parcels can't be measured perpendicularly from the western wall of the site in terms of an offset distance.
- Order – This could be related to the classification of objects into layers, whereby it could be that all the parcels, despite their segregation into

layers consistent with their unique identifier, belong to a greater hierarchy being the legal entities of the site, whilst the roofs, walls, columns and floors of the site could fall into the category of physical features of the site.

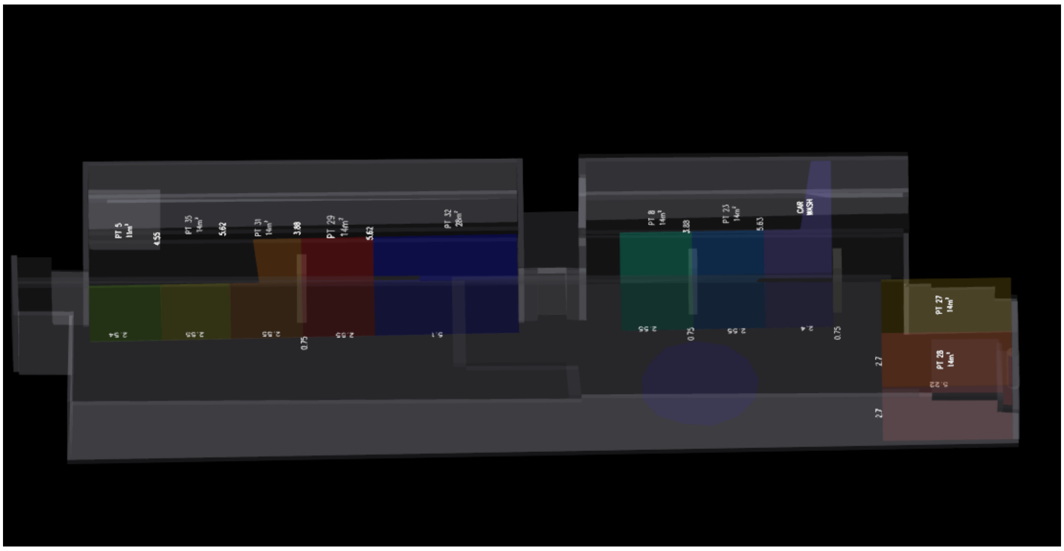

Figure 5.6 Parcels shown with physical features of site

Another suite of points put forward by Wang et al. concerns the specific requirements for the visualisation of 3D cadastres concerning the seven visualisation principles concerning objects, which were discussed in the literature review of Chapter 3. These essential parameters are listed below as defined by the authors, and then applied to the context of the visualisation of a 3D Cadastre using a 3D PDF:

- Representation of bounded and partially bounded 3D legal units – This is clearly done within the model of the 3D PDF, with the parcels created and extruded within the extracted model of the site through the processes described in chapter four. Within the 3D PDF, the parcels can be clearly seen in terms of their horizontal and vertical extent, with the vertical extents in particular being bound by the roof and floor of the model.
- Represent relation between 3D legal objects and 2D property units – within the model this point is not overly represented, as all objects within

the site are in effect 3D by nature, as they were created by a strata plan. However it is no way inconceivable that this could be done quite easily through using a TLS and the processes used within this project.

- Representation of 3D legal objects with corresponding physical objects – This is done within the 3D PDF as the relationship between the physical and legal objects of the site can be clearly seen. For instance, it can be clearly seen that the limits of the 3D parcels on the eastern side of the model align with the face of the capping beam wall, whilst another example is the fact that the upper limit of all the parcels is coincident with the roof.
- Represent spatial relationship between 3D legal objects – This is done through the use of the dimensions which have been incorporated within the cadastral model, whilst also the capacity to measure within the 3D PDF also caters to this notion.
- Label with official dimensions – this is done through the use of the dimensions layer within the 3D PDF, whereby the parcel of interests semantic information can be clearly seen within the procured model.

Overall in terms of the parameters laid out by Wang et al, it is obvious that the 3D PDF procured through the use of the TLS and the processes described in chapter four clearly satisfy most of the parameters put forward by the authors.

Another point of comparison for the visualisation of the 3D Cadastre using a 3D PDF is against that of the actual strata plan of the site. Comparing the 3D PDF against the strata plan for the site, the key differences between the two sets of survey information are that the full extents of the lots in terms of their vertical boundaries are easily seen within the 3D PDF whereas within the strata plan they are described by stratum statements accompanying the topographical layout of the site.

It is an obvious assessment the 3D PDF allows the user to actually see the vertical limits of the lots whilst the stratum statements requires the user to interpret the statement, apply it and conceptualise the vertical limits. It can be

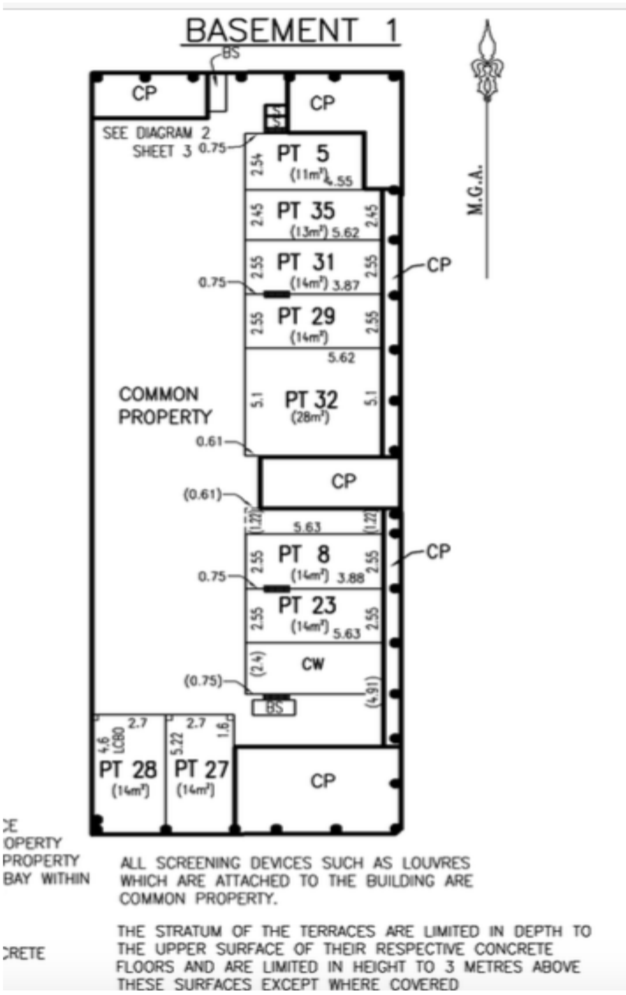

Figure 5.7 Strata Plan of the site

appreciated that in the circumstances whereby there is a range of complex 3D property aspects such as easements and stratum lots on top of one and other that these could be easily misinterpreted and applied incorrectly, resulting in mistakes being made concerning the correct location of 3D property.

Another key difference between the two sets of information include is the strata plan being able to show areas of detail, whereas the 3D PDF relies on the user being able to zoom in on the 3D PDF to an area of interest. The use of extra detail on strata plans helps convey

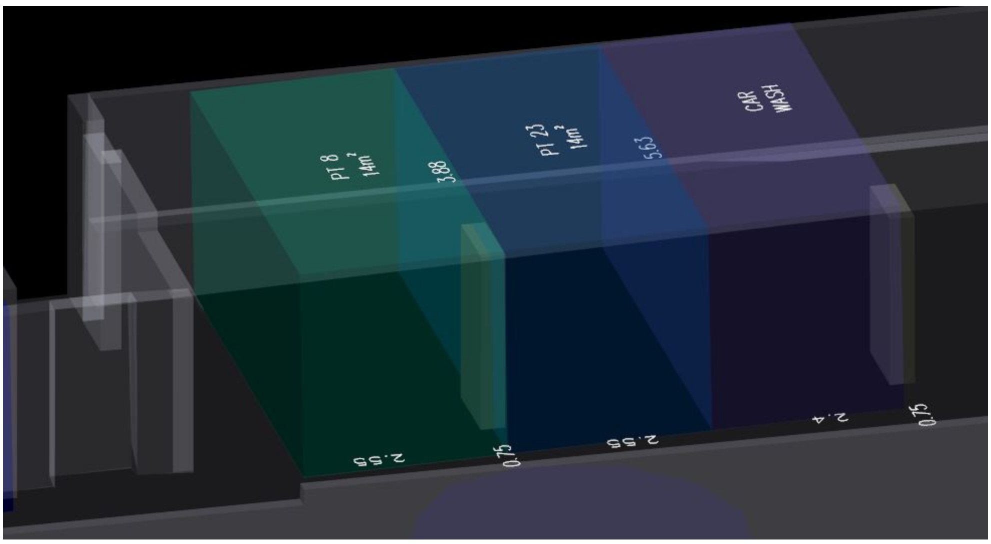

Figure 5.8 Boundaries of site shown in 3D

the finer details of where the boundaries lie and their relation to the features of the site or for features that are too small to be seen at the conventional scale of the strata plan such as the storage spaces and to which lots they belong to.

The 3D PDF is lacking in this respect as due to the storage spaces on the site being wire mesh cages, they were not picked up very well within the scanning of the site and as such were not included apart of the model, this may be indicative that other features like this which are common in these types of developments may not always be able to be visualised using a terrestrial laser scanner.

Another feature that the 3D PDF lacks is all the administrative items that are attached to a strata plan including the unit entitlements, date of registration, surveyors name, the surveyor generals seal, subdivision certificate number and certifiers certificate number. These administrative features are an essential component of strata plans in NSW and 3D cadastres, and some of these could be incorporated in a query and analysis function, however the feasibility of this function within a 3D PDF is outside the scope of this project.

A concluding point concerning the use of a 3D PDF to visualise the 3D cadastre of the site is that it allows for any user to be able to use the procured model and there is no requirement for specialist software or training for it to be utilised, as such it can be used by a whole range of stakeholders be they landholders, surveyors architects, government officials or whoever.

5.3 Accuracy and Applications

An important consideration with any surveying application is the accuracy of the produced model and the end product, which is generally a consequence of the methodologies and processes used and produced during the procurement of the model and the end results, and often the accuracy of such survey products determines the extend of their application.

With the creation of an extracted 3D Model of the selected site and the combination of that model with the one of the cadastral parcels and the subsequent synthesisation of the two models together, there are some considerations to accuracy. The first consideration concerning accuracy is that by using the TLS, the accuracy of the procured point cloud is dependent on both the registration process and the subsequent statistics that are generated by this process.

As illustrated previously within chapter four, the registration statistics for this project were very good with a mean registration error of 4mm for the entire project, which as stated, gave confidence in moving forward into the modelling phase. By extension, this registration process was dependent on the control survey, which was checked against the known MGA and AHD values for the permanent marks when they were connected to by the conventional survey traverse.

Another consideration with regards to accuracy is the merging of the cadastral model into the extracted 3D model of the site. Given the process used to incorporated the cadastral model into the extracted model was to use common tie points, this itself is an imperfect way of merging the two models together as there is an inherent risk of error through not selecting the exact tie point between the two models.

Another factor affecting this is the fact that the dimensions on the strata plan are rounded and may not necessary is accurate to the millimetre level. This is indicative in the combined model, as there exists several small gaps within it, an example being between the lift wall and the southern boundary of PT 32 of approximately 15mm, whereas the two are meant to be homogenous as per SP90732.

However, given this point, the procured model is in effect governed by SP90732 and by the fact that strata boundaries are generally parallel and perpendicular to the structures of the site, as such there are no survey marks to be able to tie into to and, with certainty, ascertain the site boundaries. In more complex examples and where survey marks delineating boundaries are present, these could be incorporated into the control survey, as such relating them to the scanning targets, and the cadastral boundaries of such a project could be reinstated and extruded as demonstrated by this project to create a combined model showing a 3D Cadastre. This process would remove the error associated with selecting tie points and manually merging the two models together, and as such would give more confidence when incorporating the boundaries into the site that they are indeed correct and accurate.

Reflecting on the above points, the applications of the project could include, obviously for visualisation purposes as previous stated numerous times throughout this project to improve the comprehension and understanding of an array of end users, stakeholders and professionals about the extent and nature of 3D property boundaries and subsequent rights, restrictions and responsibilities. This could be undertaken in a range of developments and properties, be they residential apartment buildings, mixed use dwellings, commercial buildings and in situations where transport corridors and public spaces may exist above and below these types of property.

Another application for visualisation of a 3D cadastre using a TLS and a 3D PDF could be for marketing purposes in the cases whereby existing buildings such as warehouses or other types of buildings are being converted into residential apartments for urban renewal. The existing building could be scanned and then the proposed residential lots could be converted into a 3D model to enable potential purchasers the chance to conceptualise the lots on offer in relation to the building. This again would allow for potential purchasers to fully grasp what they are buying and as such will be more informed when making the buying decision.

Overall there are several applications for this type of project. However it is obvious that a 3D PDF certainly has its limitations. Considering this, it is a valid assumption that a 3D PDF visualising a 3D Cadastre can not be used in isolation and that 2D plans will need to be used to supplement the 3D PDF, particularly in concern to the administrative and finer details of strata plans.

5.4. Conclusion

This chapter articulated a discussion of the results of the project, which was the visualisation of a 3D Cadastre using a 3D PDF. Elements of the literature review were revisited and discussed, along with comparison with the strata plan of the site. The accuracy and applications of the project were then discussed.

6.0 Conclusion

6.1 Introduction

In this chapter, the objectives of the project are revisited along with some suggestions for further research. Some final remarks about the project are then stated.

6.2 Review of Objectives

As stated in chapter 1, the aims of this project were to investigate the feasibility of using a TLS to visualise a 3D cadastre and then evaluate the best way to convey this visualisation to an array of users through conducting a literature review in Chapter 2. This has been achieved through first using the TLS to scan the chosen site and then using the registered point cloud to produce a 3D model that were articulated within the confines of Chapters 3 and Chapter 4 respectively.

Chapter 4 also then articulated how the visualisation of the 3D cadastre was achieved through the use of a 3D PDF, of which some elements of the results were discussed in Chapter 5. Considering these points, the project has been successful in achieving its objectives and has thoroughly detailed the process by which a 3D cadastre can be visualised using a TLS.

6.3 Suggestions for further research

Suggestions for further research could include:

- Integration of the combined model into a Building Information Model through the use of software such as AutoCAD Revit, whereby the cadastral model could be one of may aspects to the BIM model that is used for a whole range of building and facility management functions.
- Development of a query and analysis function for the combined model, whereby users can query and search for land titles, parcels, dimensions of lots and other features of interest, whilst still maintaining the interactivity of the model.

- Integration of the 3D PDF of the model into a database whereby a user seeking information about a land parcel could retrieve it contained within. The administrative aspects of the 3D cadastre could also be featured into this database.
- Use of more complex 3D cadastre whereby there exist other features such as roads, easements and other property types and the subsequent visualisation of that 3D cadastre using 3D PDF or other means such as Google Earth.

6.4 Conclusion

This project demonstrated how a 3D Cadastre could be visualised using a 3D PDF through using a TLS. The aim of the project was for users and stakeholders of a wide range of backgrounds to be able to visualise the rights, restrictions and responsibilities that are attached to 3D property as outlined in chapter one. The project demonstrated the processes by which the visualisation of the 3D cadastre using a TLS and then subsequently by a 3D PDF were performed from the initial scan of the site, 3D modelling and creation of a 3D PDF of the 3D Cadastre.

The content within this project is highly relevant moving into the future as urban environments continue to increase in density, creating more and more complex 3D property units and rights as and 3D Modelling and interactive models become an increasingly important tool in delivering highly informative spatial information products.

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8.0 Appendices

Appendix A

Project Specification For ENG4111/4112 Research Project

Title: Visualization of 3D Cadastres using Terrestrial Laser Scanning

Major: Surveying

Supervisors: Dr. Zhenyu Zhang

Enrolment: EXT S1, 2016 ENG4112 – EXT S2, 2016

Project Aim: To investigate the means of visualizing 3D cadastral information such as a strata/stratum plan with a Terrestrial Laser Scanner.

Program: Issue A, 16th March 2016

1. Research the background information concerning 3D Cadastres, their significance and processes for visualizing such information. Determine the requirements for the visualization and what information should be displayed.

2. Obtain the necessary equipment and determine a site for the research project. Obtain the necessary survey plan information

3. Conduct a field survey of the subject site and collect the necessary field data

4. Process, reduce and analyse the collected information.

5. Develop a visual 3D model of the 3D cadastre surveyed/scanned and incorporate the necessary cadastral information (lot, area, boundaries etc.)

6. Evaluate results of the 3D model and its effectiveness in visualizing 3D cadastral information,

   If time and resources permit:

7. Develop other visualization means of a 3D cadastre model

8. Comparison between models

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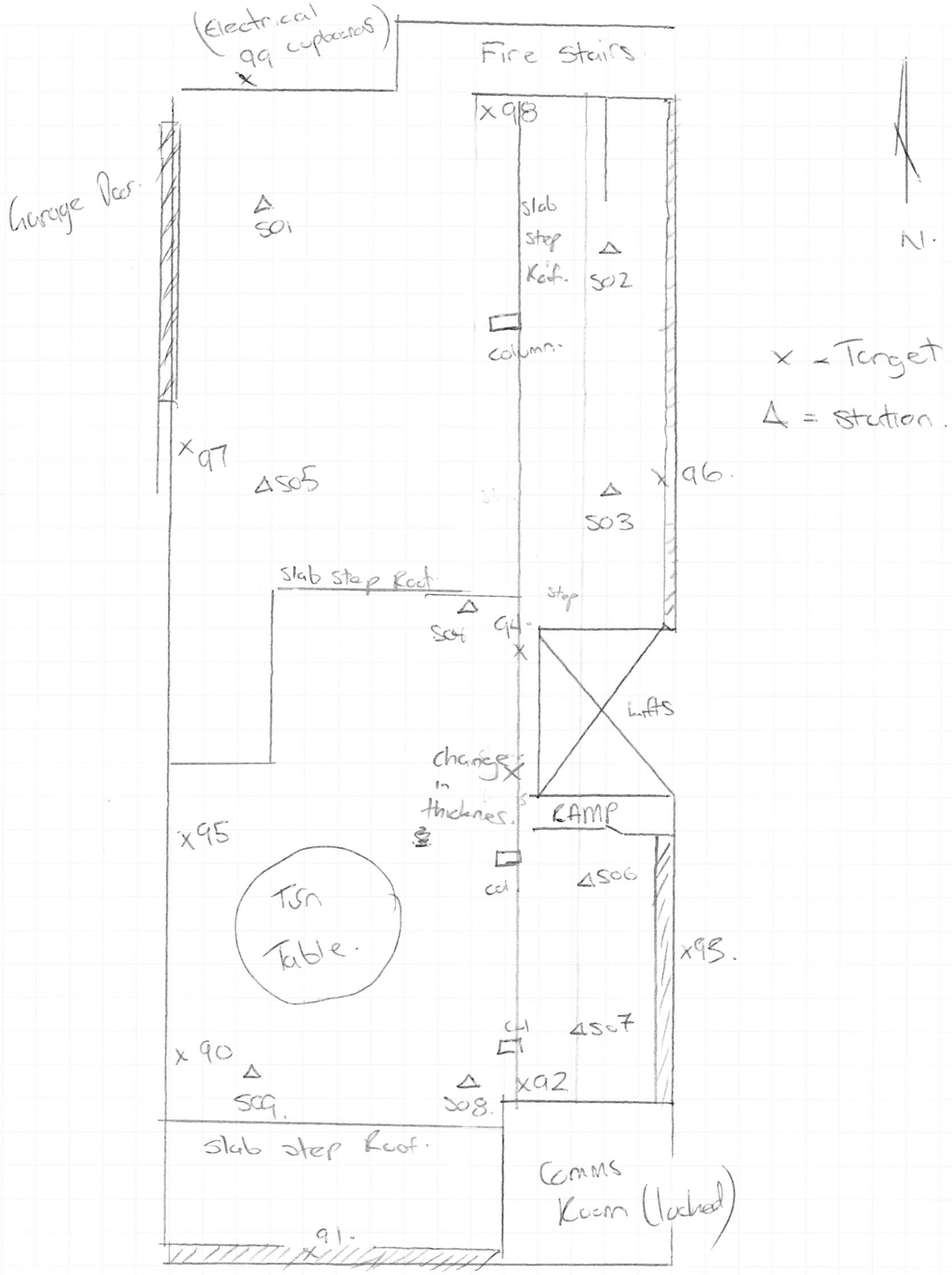
W: www.lawrencegroup.com.au

Project

Project: USQ Thesis Scanning
Our Ref:
Date: 12/3/16.

Details

Details: Field Notes of Basement Scan.



Misc.

Survey Team: NG. Instrument: Calibrated: Signature:

Leica ScanStation C10

The All-in-One Laser Scanner for Any Application

See also ScanStation C10 brochure!

New platform represents the most capabilities and best value packed into a single instrument

Leica ScanStation C10: new standard for pulsed scanners
The industry's most popular class of laser scanner – ScanStation – is now in a compact, all-in-one ScanStation C10 platform: scanner, battery, controller, data storage, and video camera. In addition, ScanStation C10 also features major advances in productivity, versatility, and ease-of-use for as-built and topographic High-Definition Surveying™ (HDS™).

All-in-one scanner capabilities for higher value
ScanStation C10 gives users the advantage of high-accuracy, long range scanning plus the advantage of fast, full-dome interior scanning – all in one instrument. The key is the new Smart X-Mirror™ design that automatically spins or oscillates the mirror for optimum productivity. Smart X-Mirror also automatically aligns the embedded, high-resolution video camera with the laser for fast targeting and fast, accurate texture mapping of scans.

Full field-of-view + traverse + high accuracy + excellent range = Versatility
ScanStation C10 includes the hallmark versatility features that have made the ScanStation class so popular. These capabilities let users take advantage of scanning for more applications and more sites, while minimizing field labor.

Easy to learn
ScanStation C10 includes surveyor-friendly, total station-like onboard graphic control, including the ability to view target scans in 3D. Users can also take advantage of laptop control for more comprehensive scan viewing.

- when it has to be **right**

Leica Geosystems

Leica ScanStation C10
Product Specifications

General	
Instrument type	Compact, pulsed, dual-axis compensated, very high speed laser scanner, with survey-grade accuracy, range, and field-of-view; integrated camera and laser plummet
User interface	Onboard control, notebook, tablet PC or remote controller
Data storage	Integrated solid-state drive (SSD), external PC or external USB device
Camera	Auto-adjusting, integrated high-resolution digital camera with zoom video

System Performance	
Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad / 60 µrad (12″ / 12″)
Modeled surface precision/noise**	2 mm
Target acquisition***	2 mm std. deviation
Dual-axis compensator	Selectable on/off, resolution 1″, dynamic range +/- 5′, accuracy 1.5″

Laser Scanning System	
Type	Pulsed; proprietary microchip
Color	Green, wavelength = 532 nm visible
Laser Class	3R (IEC 60825-1)
Range	300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
Scan rate	Up to 50,000 points/sec, maximum instantaneous rate
Scan resolution	
Spot size	From 0 – 50 m: 4.5 mm (FWHH-based); 7 mm (Gaussian-based)
Point spacing	Fully selectable horizontal and vertical; < 1 mm minimum spacing, through full range; single point dwell capacity
Field-of-View	
Horizontal	360° (maximum)
Vertical	270° (maximum)
Aiming/Sighting	Parallax-free, integrated zoom video
Scanning Optics	Vertically rotating mirror on horizontally rotating base; Smart X-Mirror™ automatically spins or oscillates for minimum scan time
Data storage capacity	80 GB onboard solid-state drive (SSD) or external USB device
Communications	Dynamic Internet Protocol (IP) Address, Ethernet or wireless LAN (WLAN) with external adapter
Integrated color digital camera with zoom video	Single 17° x 17° image: 1920 x 1920 pixels (4 megapixels) Full 360° x 270° dome: 260 images; streaming video with zoom; auto-adjusts to ambient lighting
Onboard display	Touchscreen control with stylus, full color graphic display, QVGA (320 x 240 pixels)
Level indicator	External bubble, electronic bubble in onboard control and Cyclone software
Data transfer	Ethernet, WLAN or USB 2.0 device
Laser plummet	Laser class: 2 (IEC 60825-1) Centering accuracy: 1.5 mm @ 1.5 m Laser dot diameter: 2.5 mm @ 1.5 m Selectable ON/OFF

Electrical	
Power supply	15 V DC, 90 – 260 V AC
Power Consumption	< 50 W avg.
Battery Type	Internal: Li-Ion; External: Li-Ion
Power Ports	Internal: 2, External: 1 (simultaneous use, hot swappable)
Duration	Internal: >3.5 h (2 batteries), External: >6 h (room temp)

Environmental	
Operating temp.	0° C to 40° C / 32° F to 104° F
Storage temp.	-25° C to +65° C / -13° F to 149° F
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Dust/humidity	IP54 (IEC 60529)

Physical	
Scanner	
Dimensions (D x W x H)	238 mm x 358 mm x 395 mm / 9.4″ x 14.1″ x 15.6″
Weight	13 kg / 28.7 lbs, nominal (w/o batteries)
Battery (internal)	
Dimensions (D x W x H)	40 mm x 72 mm x 77 mm / 1.6″ x 2.8″ x 3.0″
Weight	0.4 kg / 0.9 lbs
Battery (external)	
Dimensions (D x W x H)	95 mm x 248 mm x 60 mm / 3.7″ x 9.8″ x 2.4″
Weight	1.9 kg / 4.2 lbs
AC Power Supply	
Dimensions (D x W x H)	85 mm x 170 mm x 41 mm / 3.4″ x 6.7″ x 1.6″
Weight	0.9 kg / 1.9 lbs

Standard Accessories Included

Scanner transport case
Tribrach (Leica Professional Series)
4x Internal batteries
Battery charger/AC power cable, Car adapter, Daisy chain cable
Data cable
Height meter and distance holder for height meter
Cleaning kit
Cyclone™ SCAN software
1year CCP Basic support agreement

Additional Accessories

HDS scan targets and target accessories
Service agreement for Leica ScanStation C10
Extended warranty for Leica ScanStation C10
External battery with charging station, AC power supply and power cable
Professional charger for internal batteries
AC power supply for scanner
Tripod, tripod star, rolling base, external wireless LAN adapter (third-party)

Notebook PC for scanning with Cyclone software ∆	
Component	**required (minimum)**
Processor	1.7 GHz Pentium M or higher
RAM	1 GB (2 GB for Windows Vista)
Network card	Ethernet
Display	SVGA or OpenGL accelerated graphics card (with latest drivers)
Operating system	Windows XP Professional (SP2 or higher) (32 or 64) Windows Vista (32 or 64), Windows 7 (32 or 64)

Control Options

Full color touch screen for onboard scan control
Leica Cyclone SCAN software for laptop PC (see Leica Cyclone SCAN data sheet for full list of features)
Remote controller (Leica CS10/15 or any other remote desktop capable device)

Ordering Information

Contact Leica Geosystems or authorized representatives

All specifications are subject to change without notice.
All ± accuracy specifications are one sigma unless otherwise noted.
* At 1 m – 50 m range, one sigma
** Subject to modeling methodology for modeled surface
*** Algorithmic fit to planar HDS targets
∆ Minimum requirements for modeling operations are different. Refer to Cyclone data sheet specifications

Scanner: Laser class 3R in accordance with IEC 60825-1 resp. EN 60825-1
Laser plummet: Laser class 2 in accordance with IEC 60825-1 resp. EN 60825-1

776241en – III.12 – galledia

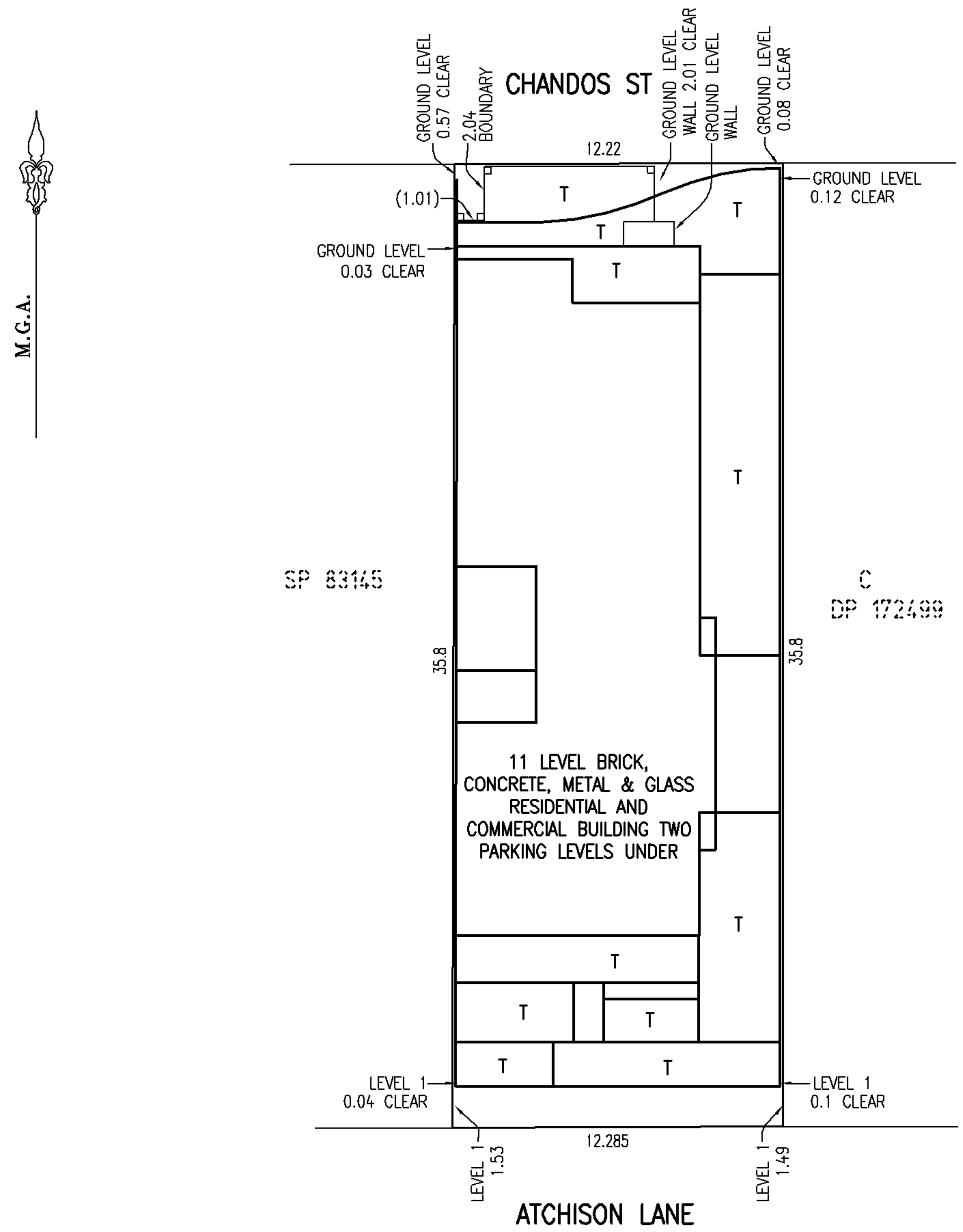
Leica Geosystems AG
Heerbrugg, Switzerland

www.leica-geosystems.com/hds

- when it has to be **right**

Leica Geosystems

LOCATION PLAN

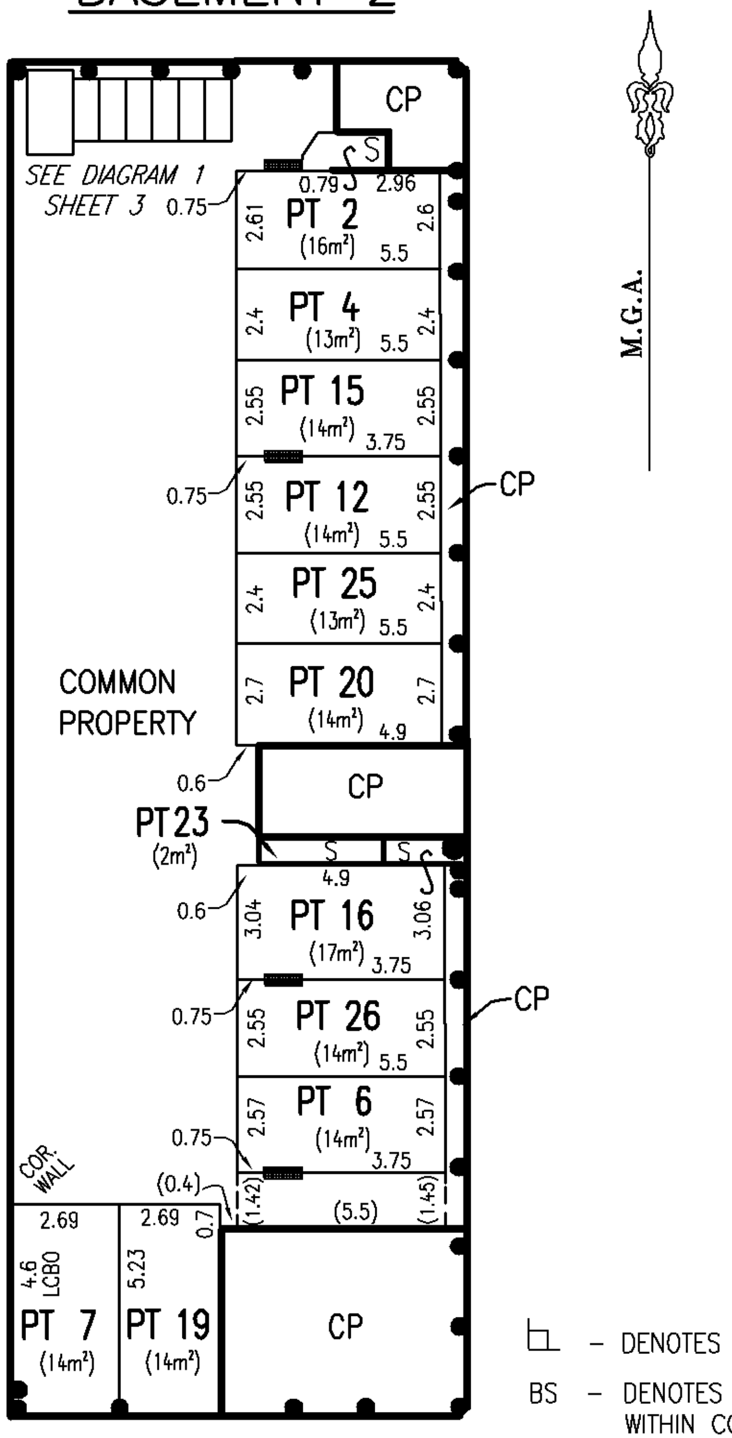


T – DENOTES TERRACE

⊾ – DENOTES 90°

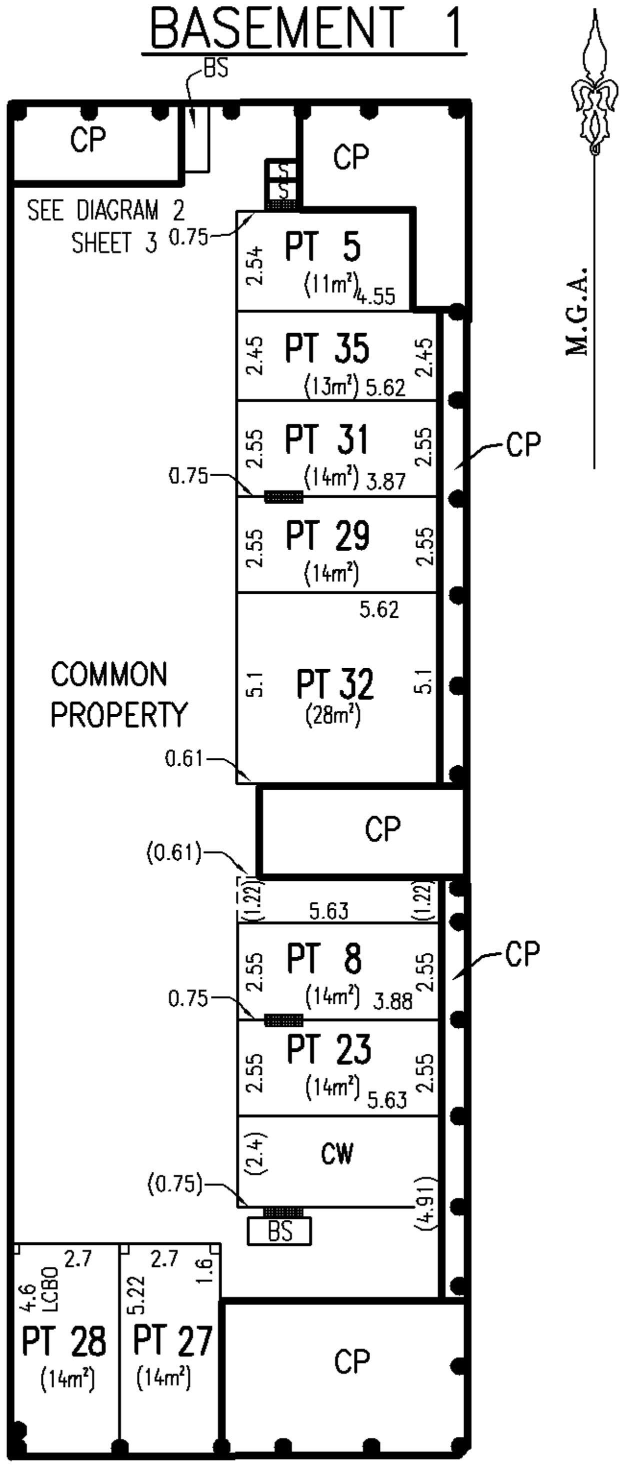
Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1: 200	REGISTERED 23-12-2014	SP90738

BASEMENT 2



SEE SHEET 3 FOR COLUMN DETAILS

BASEMENT 1

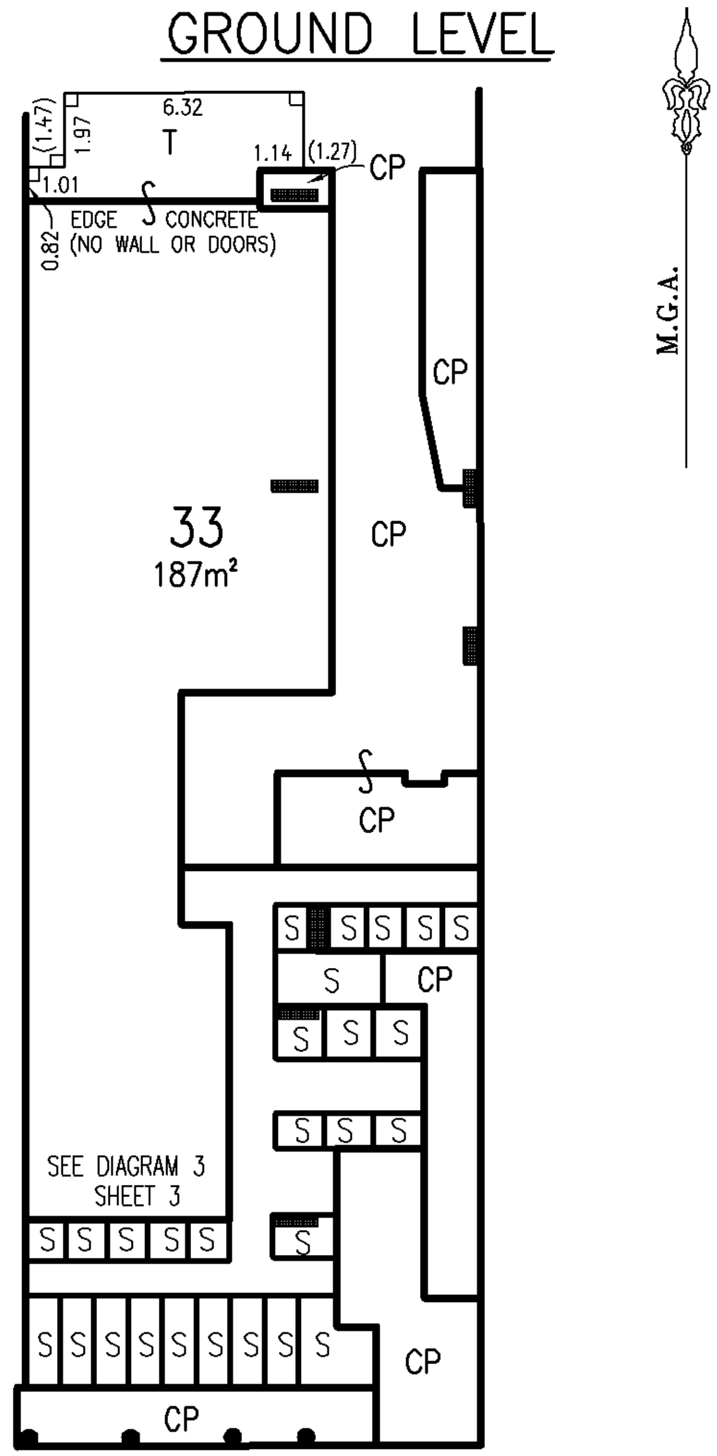


⊾ – DENOTES 90°
BS – DENOTES BIKE SPACE WITHIN COMMON PROPERTY
CP – DENOTES COMMON PROPERTY
CW – DENOTES CARWASH BAY WITHIN COMMON PROPERTY
S – DENOTES STORAGE
T – DENOTES TERRACE
LCBO – DENOTES LINE CONCRETE BEAM OVER

ALL SCREENING DEVICES SUCH AS LOUVRES WHICH ARE ATTACHED TO THE BUILDING ARE COMMON PROPERTY.

THE STRATUM OF THE TERRACES ARE LIMITED IN DEPTH TO THE UPPER SURFACE OF THEIR RESPECTIVE CONCRETE FLOORS AND ARE LIMITED IN HEIGHT TO 3 METRES ABOVE THESE SURFACES EXCEPT WHERE COVERED

GROUND LEVEL



THE STRATUM OF LOT 33 IS LIMITED TO THE INTERNAL FACES OF THE ENCLOSING CONCRETE, MASONRY AND STEEL FRAMED CONCRETE WALLS, THE INTERNAL FACE OF THE GLASS SHOP FRONT, THE UPPER SURFACE OF THE CONCRETE FLOOR AND THE UNDERSIDE OF THE CONCRETE CEILING STRUCTURE. ALL FINISHES AND INTERNAL FITOUT PLACED WITHIN THE LOT FORM PART OF THE LOT AND NOT COMMON PROPERTY. ALL STRUCTURAL CUBIC SPACE INCLUSIVE OF SERVICE LINES LOCATED WITHIN THE EXTENT OF THE LOT REMAIN AS COMMON PROPERTY. ANY MEMBRANE COVERING CONCRETE FLOORS IS COMMON PROPERTY.

AREAS SHOWN ON THE FLOOR PLAN HAVE BEEN CALCULATED FOR THE PURPOSE OF THE STRATA SCHEMES (FREEHOLD DEVELOPMENT) ACT 1973 ONLY. THEY MAY DIFFER FROM FLOOR AREAS FOR OTHER PURPOSES.

THOSE PARTS OF SERVICE LINES WHICH SERVICE ONE LOT ONLY AND ARE LOCATED OUTSIDE OF THAT LOT ARE COMMON PROPERTY.

FOR CLARITY NOT ALL COMMON PROPERTY STRUCTURES ARE SHOWN.

Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1: 200	REGISTERED 23-12-2014	SP90738

BASEMENT 2

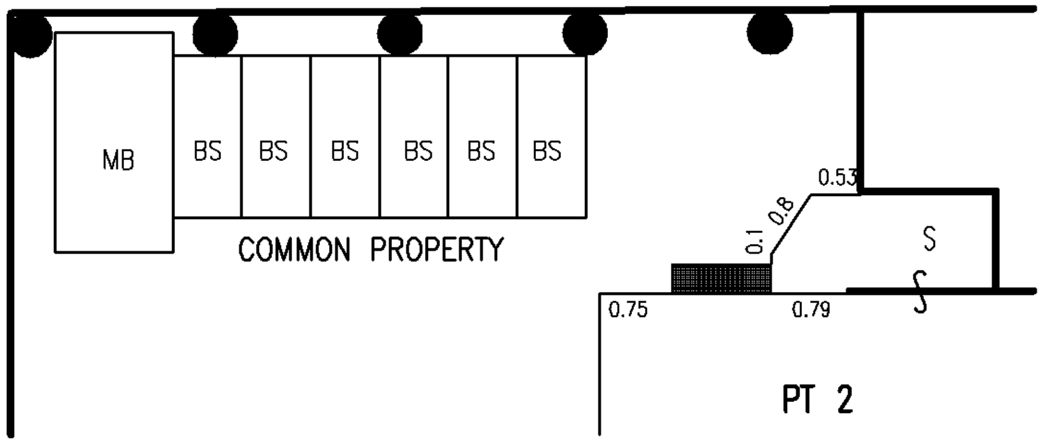


DIAGRAM 1
SCALE 1:75

BASEMENT 1

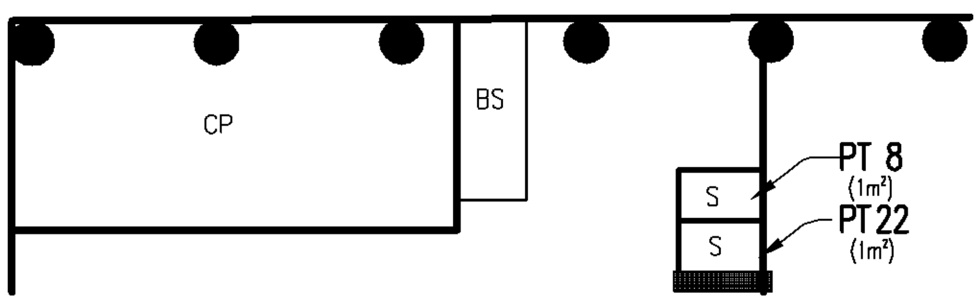
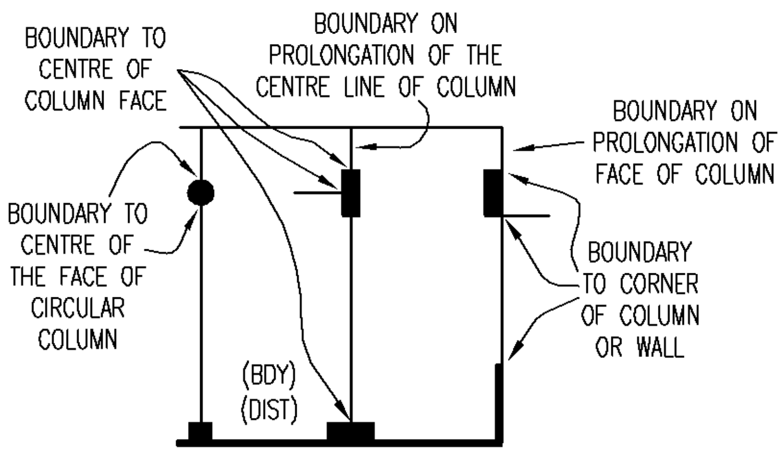


DIAGRAM 2
SCALE 1:75

TYPICAL KEY – UNLESS OTHERWISE NOTED



MB – DENOTES MOTORBIKE SPACE WITHIN COMMON PROPERTY
BS – DENOTES BIKE SPACE WITHIN COMMON PROPERTY
CP – DENOTES COMMON PROPERTY
S – DENOTES STORAGE

GROUND LEVEL

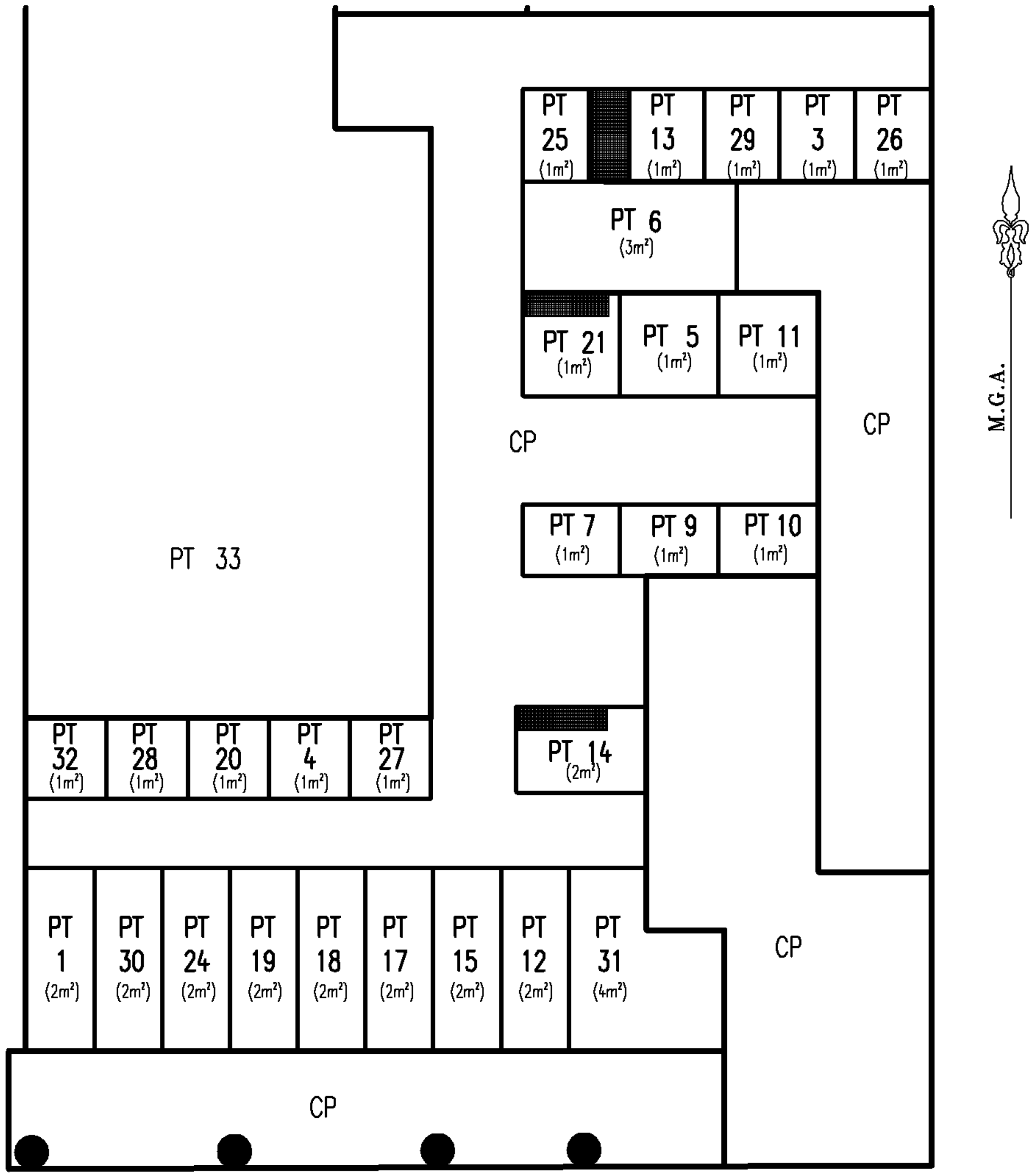


DIAGRAM 3
SCALE 1:75

AREAS SHOWN ON THE FLOOR PLAN HAVE BEEN CALCULATED FOR THE PURPOSE OF THE STRATA SCHEMES (FREEHOLD DEVELOPMENT) ACT 1973 ONLY. THEY MAY DIFFER FROM FLOOR AREAS FOR OTHER PURPOSES.

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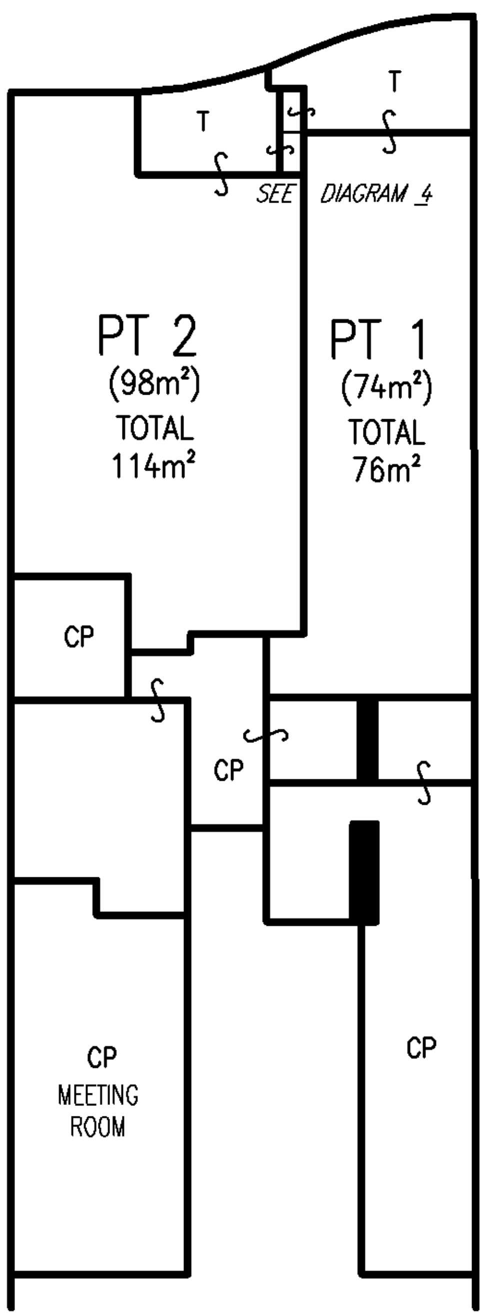
Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1:AS SHOWN	REGISTERED 23-12-2014	SP90738	

LEVEL 1



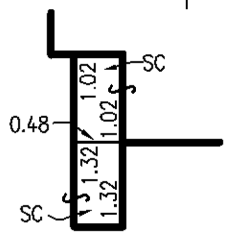
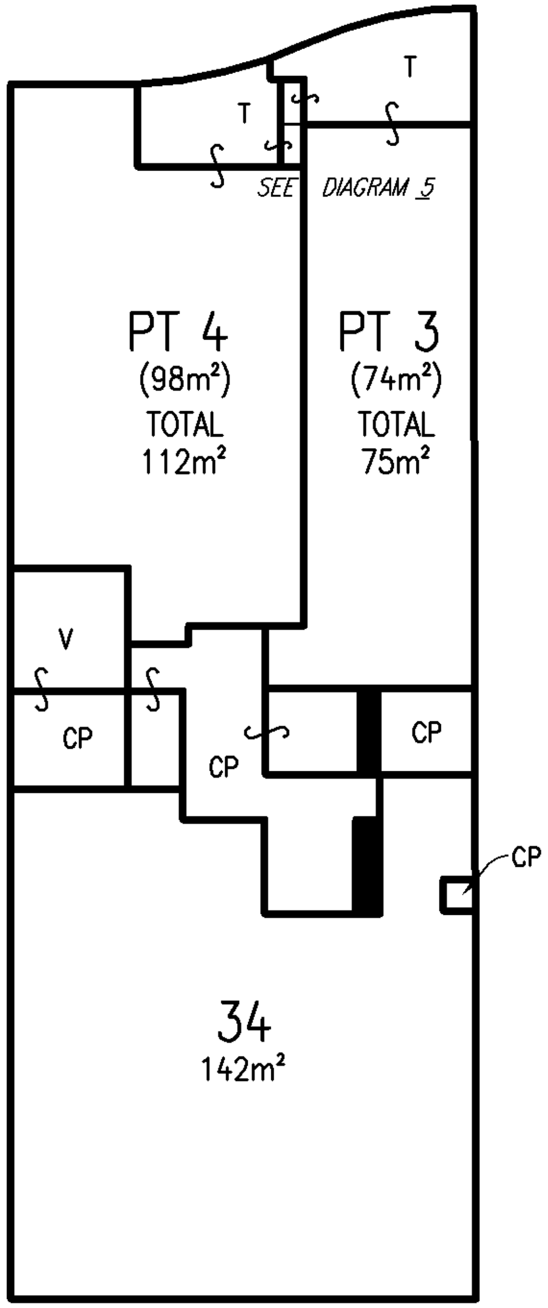


DIAGRAM 4
NOT TO SCALE
(COVERED SERVICE CUPBOARDS)

LEVEL 2



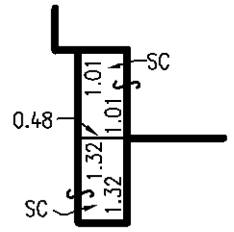
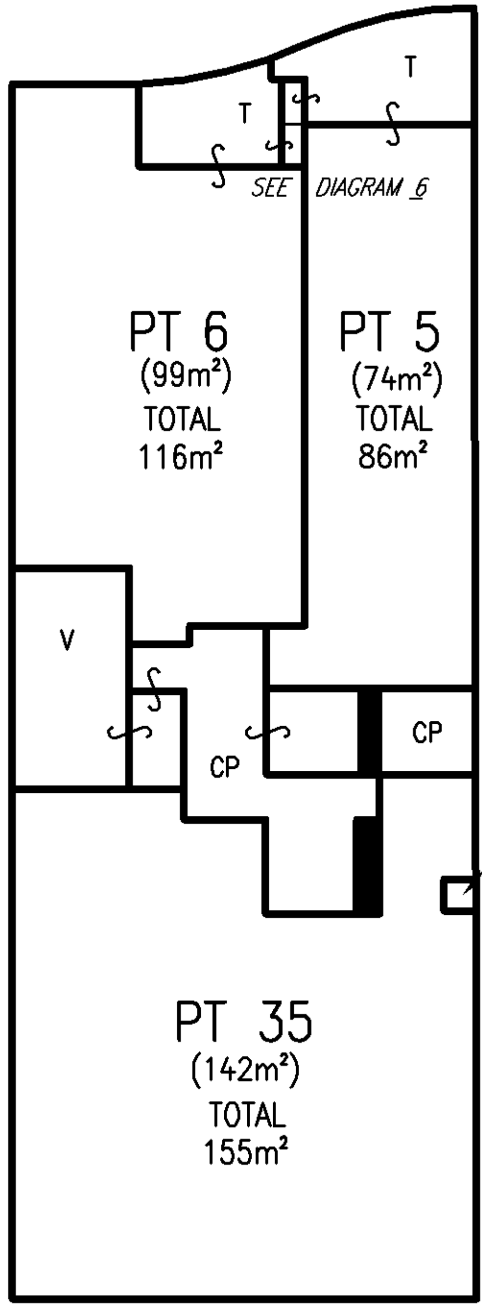


DIAGRAM 5
NOT TO SCALE
(COVERED SERVICE CUPBOARDS)

LEVEL 3



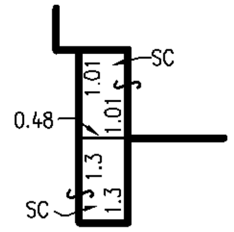


DIAGRAM 6
NOT TO SCALE
(COVERED SERVICE CUPBOARDS)

ALL SCREENING DEVICES SUCH AS LOUVRES WHICH ARE ATTACHED TO THE BUILDING ARE COMMON PROPERTY.

CP – DENOTES COMMON PROPERTY
T – DENOTES COVERED TERRACE WITH TILED FLOOR
V – DENOTES VOID
SC – DENOTES COVERED SERVICE CUPBOARD

THE STRATUM OF LOTS 34 & 35 IS LIMITED TO THE INTERNAL FACES OF THE ENCLOSING CONCRETE, MASONRY AND STEEL FRAMED CONCRETE WALLS, THE INTERNAL FACE OF THE GLASS SHOP FRONT, THE UPPER SURFACE OF THE CONCRETE FLOOR AND THE UNDERSIDE OF THE CONCRETE CEILING STRUCTURE. ALL FINISHES AND INTERNAL FITOUT PLACED WITHIN THE LOT FORM PART OF THE LOT AND NOT COMMON PROPERTY. ALL STRUCTURAL CUBIC SPACE INCLUSIVE OF SERVICE LINES LOCATED WITHIN THE EXTENT OF THE LOT REMAIN AS COMMON PROPERTY. ANY MEMBRANE COVERING CONCRETE FLOORS IS COMMON PROPERTY.

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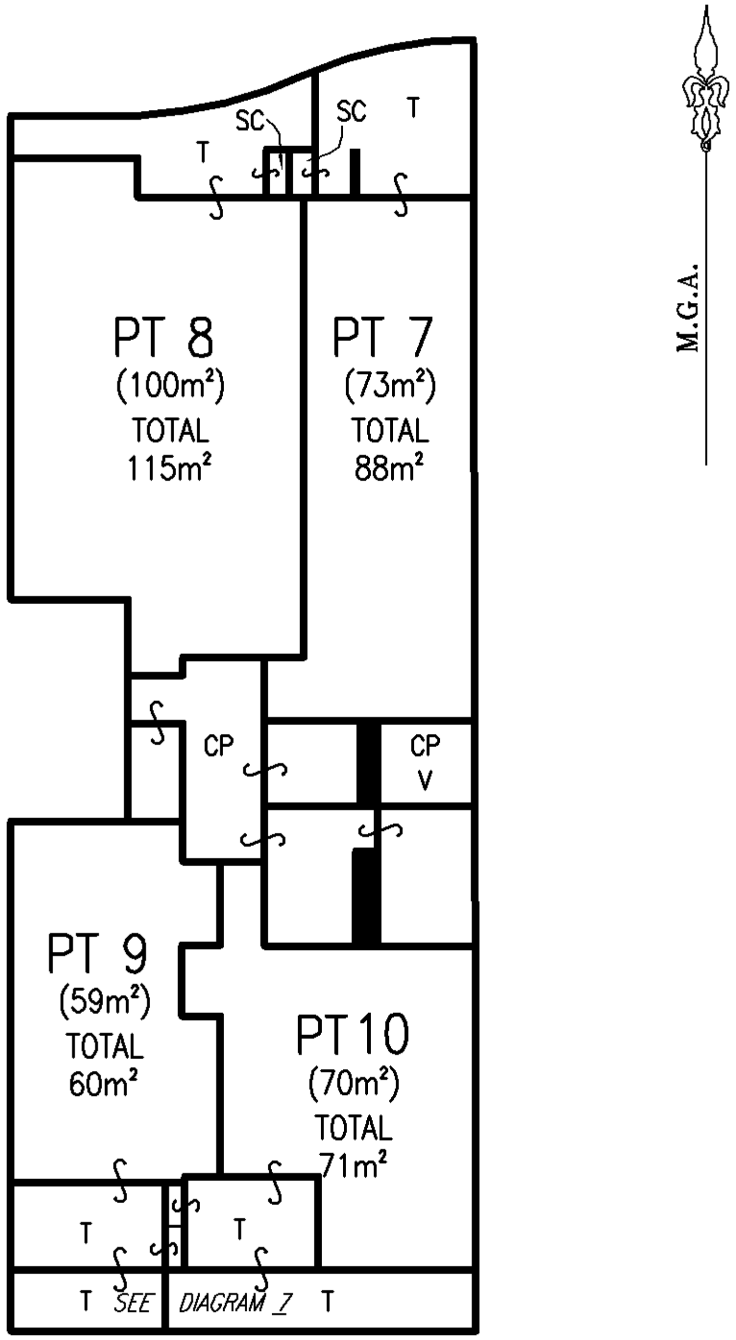
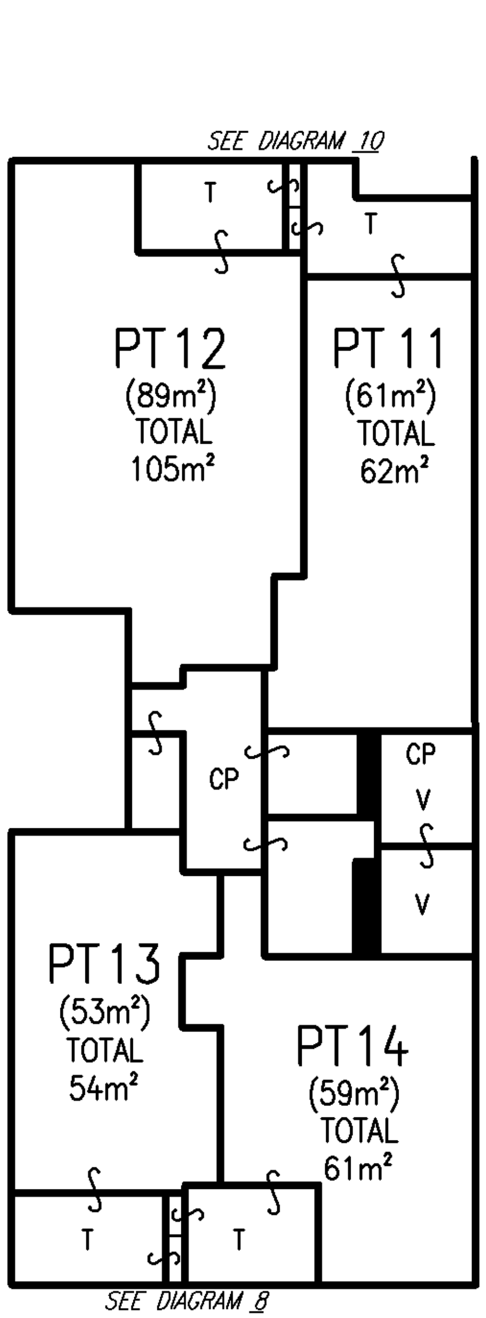
Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1: 200	REGISTERED 23-12-2014	SP90738

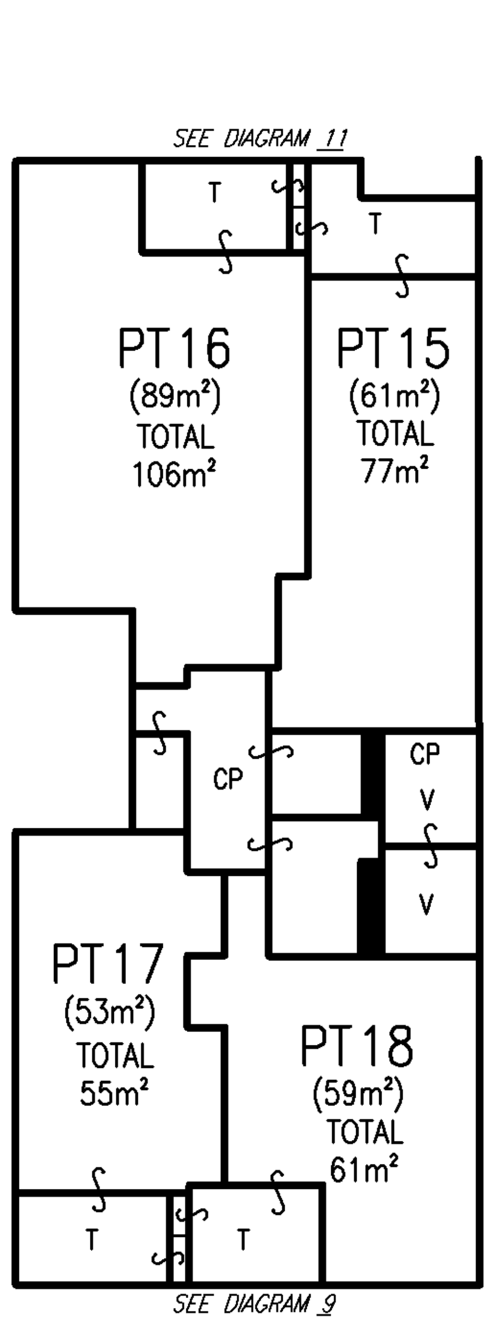
LEVEL 4



LEVEL 5



LEVEL 6



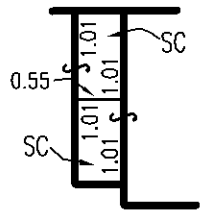


DIAGRAM 10
NOT TO SCALE
(COVERED SERVICE CUPBOARDS)

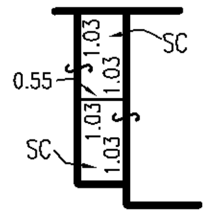


DIAGRAM 11
NOT TO SCALE
(COVERED SERVICE CUPBOARDS)

CP – DENOTES COMMON PROPERTY
T – DENOTES TERRACE
V – DENOTES VOID
SC – DENOTES COVERED SERVICE CUPBOARD

ALL SCREENING DEVICES SUCH AS LOUVRES WHICH ARE ATTACHED TO THE BUILDING ARE COMMON PROPERTY.

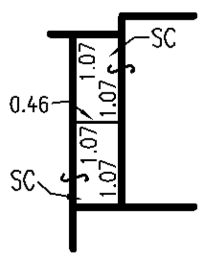


DIAGRAM 7
NOT TO SCALE

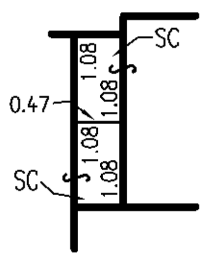


DIAGRAM 8
NOT TO SCALE

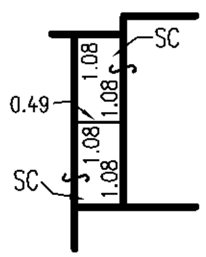


DIAGRAM 9
NOT TO SCALE

THE STRATUM OF THE TERRACES ARE LIMITED IN DEPTH TO THE UPPER SURFACE OF THEIR RESPECTIVE CONCRETE FLOORS AND ARE LIMITED IN HEIGHT TO 3 METRES ABOVE THESE SURFACES EXCEPT WHERE COVERED

AREAS SHOWN ON THE FLOOR PLAN HAVE BEEN CALCULATED FOR THE PURPOSE OF THE STRATA SCHEMES (FREEHOLD DEVELOPMENT) ACT 1973 ONLY. THEY MAY DIFFER FROM FLOOR AREAS FOR OTHER PURPOSES.

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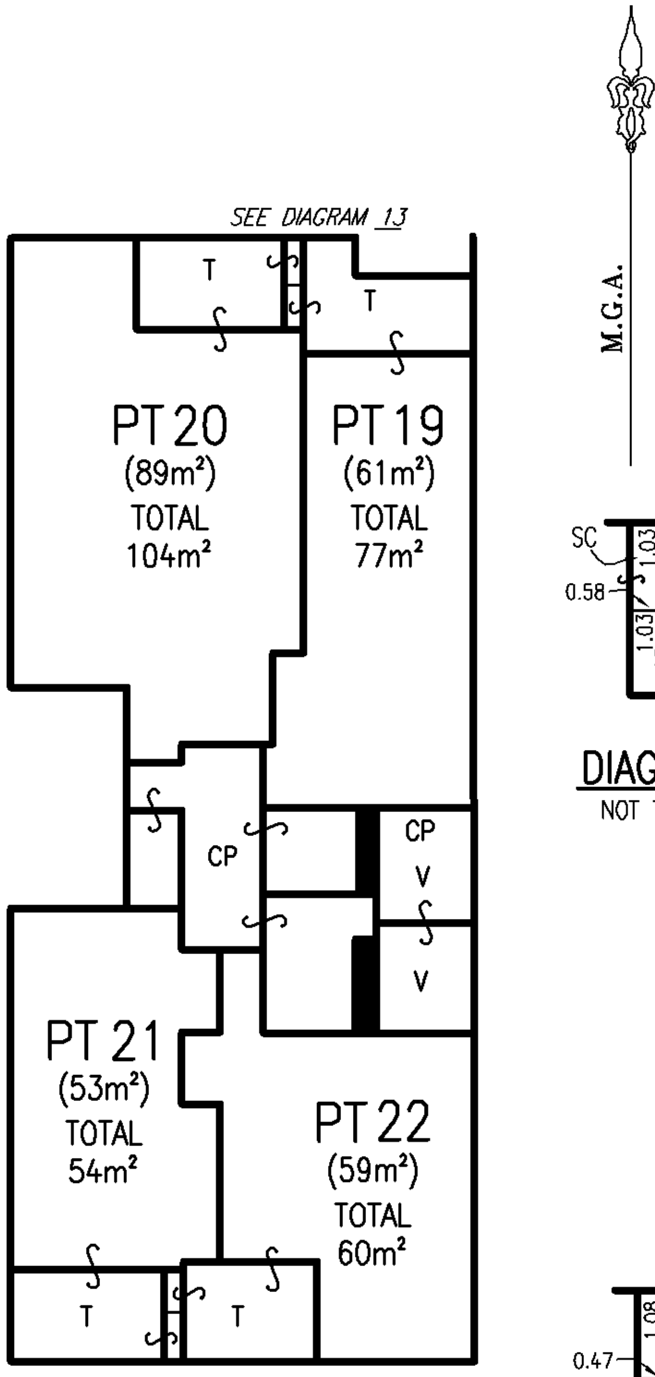
Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1: 200	REGISTERED 23-12-2014	SP90738

LEVEL 7



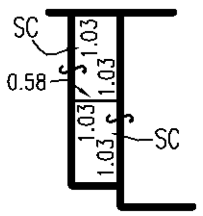


DIAGRAM 13
NOT TO SCALE

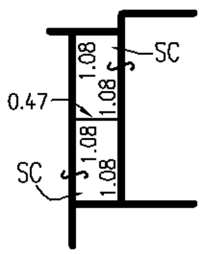
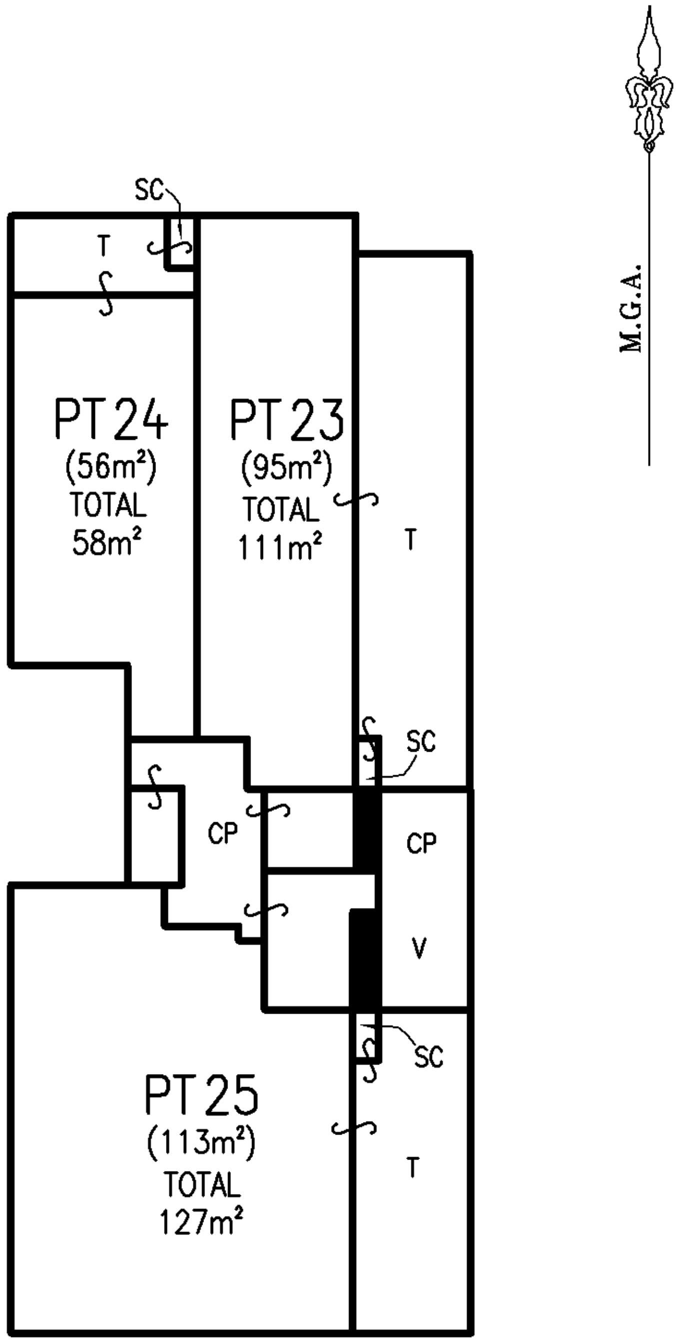
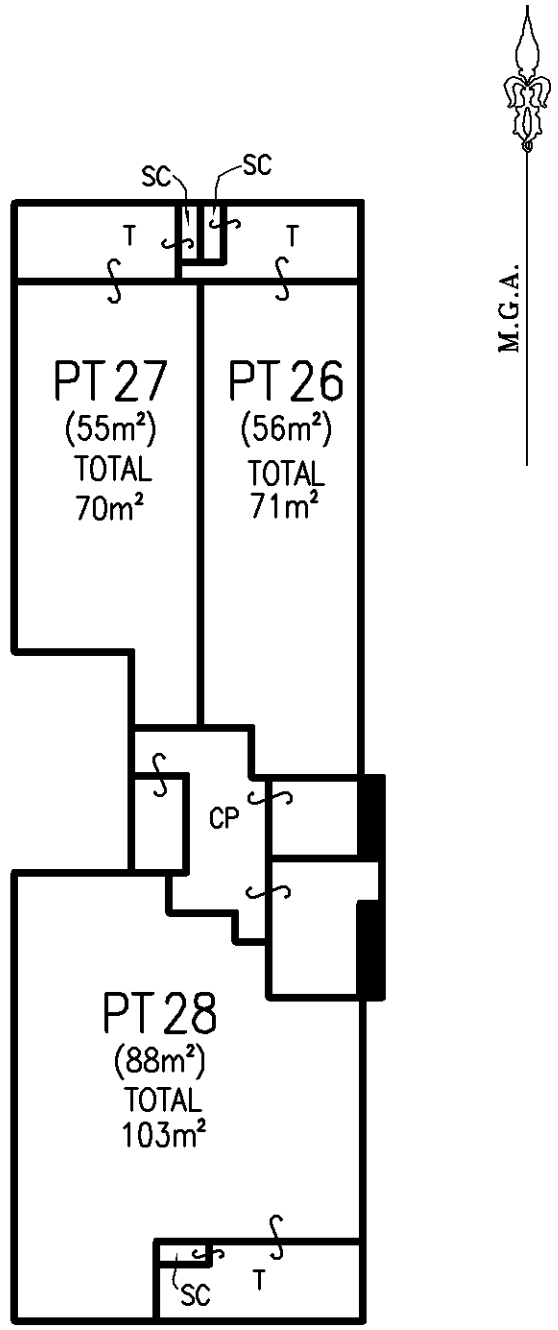


DIAGRAM 12
NOT TO SCALE

LEVEL 8



LEVEL 9



CP – DENOTES COMMON PROPERTY
T – DENOTES TERRACE
V – DENOTES VOID
SC – DENOTES COVERED SERVICE CUPBOARD

THE STRATUM OF THE TERRACES ARE LIMITED IN DEPTH TO THE UPPER SURFACE OF THEIR RESPECTIVE CONCRETE FLOORS AND ARE LIMITED IN HEIGHT TO 3 METRES ABOVE THESE SURFACES EXCEPT WHERE COVERED

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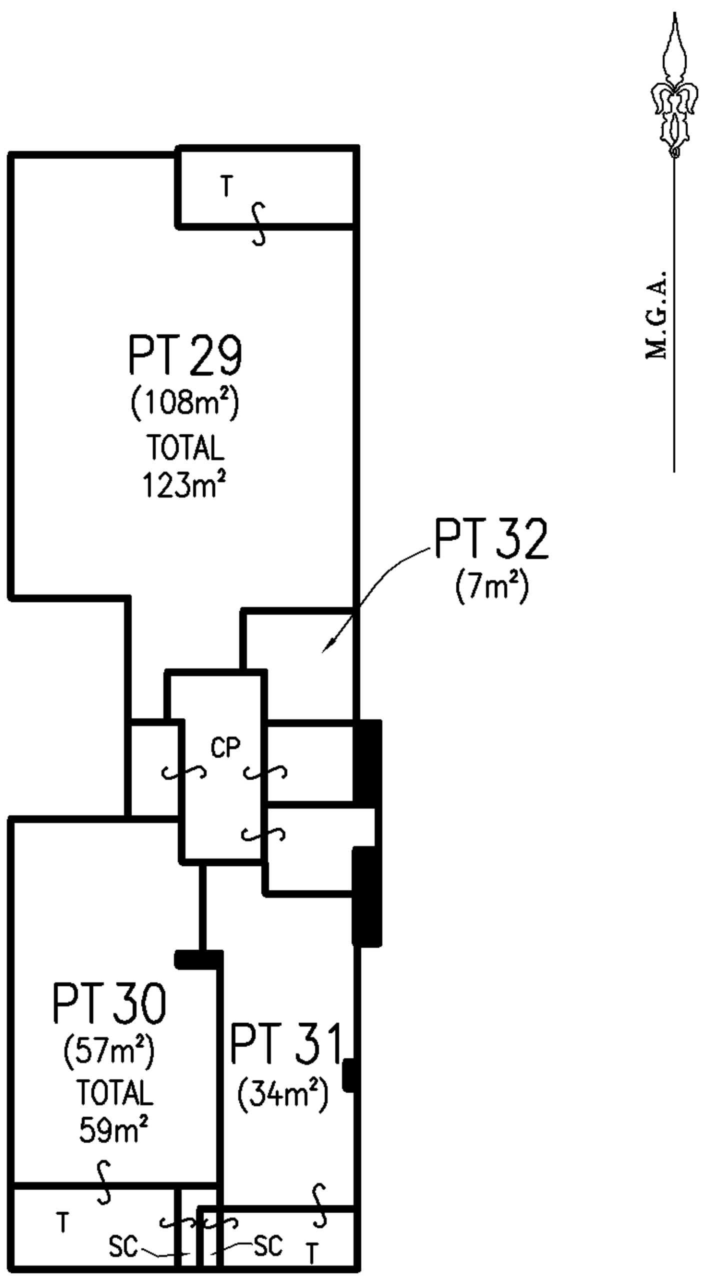
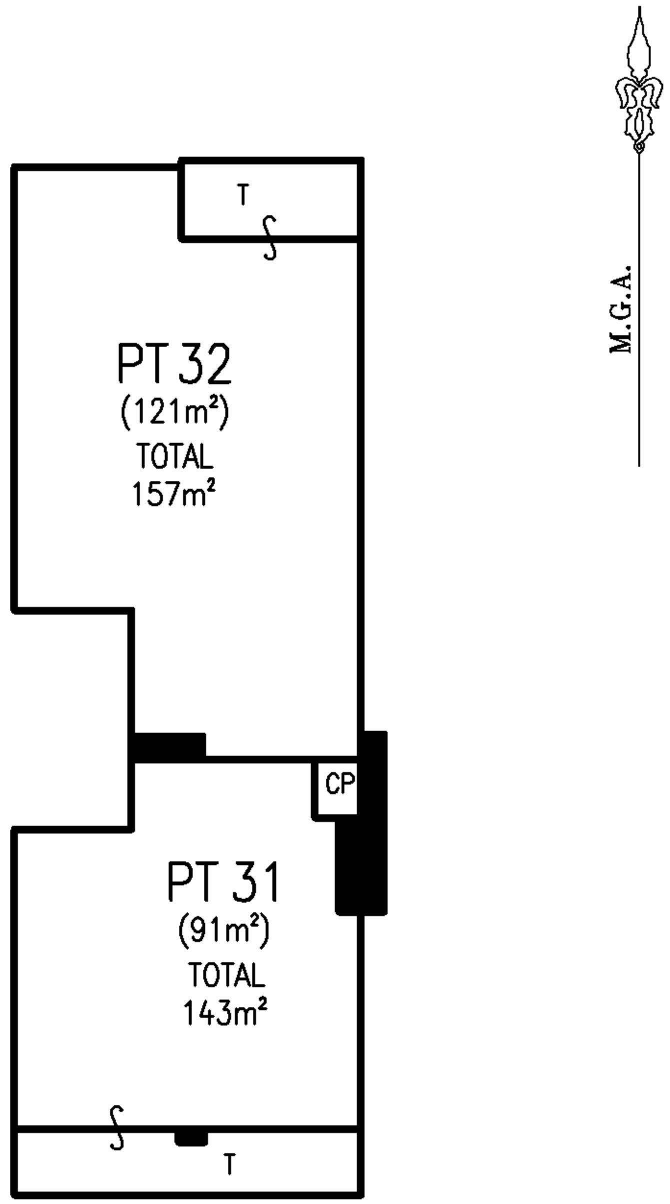
LEVEL 10



LEVEL 11



AREAS LOCATED BELOW INTERNAL STAIRS FORM PART OF THEIR RESPECTIVE LOT ARE NOT COMMON PROPERTY.

THE STRATUM OF THE TERRACES ARE LIMITED IN DEPTH TO THE UPPER SURFACE OF THEIR RESPECTIVE CONCRETE FLOORS AND ARE LIMITED IN HEIGHT TO 2.8 METRES ABOVE THESE SURFACES EXCEPT WHERE COVERED

ALL SCREENING DEVICES SUCH AS LOUVRES AND SHUTTERS WHICH ARE ATTACHED TO THE BUILDING ARE COMMON PROPERTY.

CP – DENOTES COMMON PROPERTY
T – DENOTES TERRACE
SC – DENOTES COVERED SERVICE CUPBOARD

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Surveyor: ANTHONY KELLNER Surveyor's Ref: 120511 SP Subdivision No: 183/2014 Lengths are in metres. Reduction Ratio 1: 200	REGISTERED 23-12-2014	SP90738

STRATA PLAN FORM 3 (PART 1) (2012) WARNING: Creasing or folding will lead to rejection

STRATA PLAN ADMINISTRATION SHEET

Office Use Only

Registered: 23-12-2014

Purpose: STRATA PLAN

Office Use Only

SP90738

Office Use Only

PLAN OF SUBDIVISION OF LOT 1 IN DP 1203142

LGA: NORTH SYDNEY

Locality: ST LEONARDS

Parish: WILLOUGHBY

County: CUMBERLAND

Strata Certificate (Approved Form 5)

(1) ~~*The Council of~~ ....

*The Accredited Certifier ANTHONY ALLEN

Accreditation No. BPB0004

has made the required inspections and is satisfied that the requirements of;

*(a) Section 37 or 37A *Strata Schemes (Freehold Development) Act 1973* and clause 30 *Strata Schemes (Freehold Development) Regulation 2012* ,

*(b) ~~Section 66 or 66A *Strata Schemes (Leasehold Development) Act 1986*~~ and ~~clause 31 of the *Strata Schemes(Leasehold Development) Regulation 2012*~~ ,

have been complied with and approves of the proposed strata plan illustrated in the plan with this certificate.

*(2) The Accredited Certifier is satisfied that the plan is consistent with a relevant development consent in force, and that all conditions of the development consent that by its terms are required to be complied with before a strata certificate may be issued, have been complied with.

*(3) The ~~strata plan is part of a development scheme. The council or accredited certifier~~ is satisfied that the plan is consistent with any applicable conditions of the relevant development consent and that the plan gives effect to the stage of the strata development contract to which it relates.

*(4) The building encroaches on a public place and;

*(a) The Council does not object to the encroachment of the building beyond the alignment of

....

*(b) The Accredited Certifier is satisfied that the building complies with the relevant development consent which is in force and allows the encroachment.

*(5) This approval is given on the condition that lot(s) ^.......... are created as utility lots in accordance with section 39 of the *Strata Schemes (Freehold Development) Act 1973* or section 68 of the *Strata Schemes (Leasehold Development) Act 1986.*

Date: 1/12/14

Subdivision number: 183/2014

Relevant Development Consent number: CDC 2014/43

Issued by: ANTHONY ALLEN (BPB0004)

Signature: ....

~~Authorised Person /General Manager~~/Accredited Certifier

* Strike through if inapplicable.

^ Insert lot numbers of proposed utility lots.

Name of, and address for service of notices on, the Owners Corporation. (Address required on original strata plan only)

The Owners - Strata Plan No 90738

No. 51-53 CHANDOS STREET
ST LEONARDS 2065

The adopted by-laws for the scheme are:

~~* ^ .... Model By-laws.~~

~~* together with, Keeping of animals: Option *A/*B/*C~~

* By-laws in 48 sheets filed with plan.

* Strike through if inapplicable

^ Insert the type to be adopted (Schedules 2 - 7 Strata Schemes Management Regulation 2010)

Surveyor's Certificate (Approved Form 3)

I, ANTHONY KELLNER

of Linker Surveying Pty Ltd Suite 301 Level 3 55 Holt St Surry Hills NSW 2010

a surveyor registered under the Surveying and Spatial Information Act 2002, hereby certify that:

(1) Each applicable requirement of

*Schedule 1A of the Strata Schemes (Freehold Development) Act 1973 has been met

~~*Schedule 1A of the Strata Schemes (Leasehold Development) Act 1986 has been met;~~

(2) ~~(a) The building encroaches on a public place;~~

~~*(b) The building encroaches on land (other than a public place), and an appropriate easement has been created by ^.......... to permit the encroachment to remain.~~

*(3) The survey information recorded in the accompanying location plan is accurate.

Signature: ....

Date: 19 NOV 2014

* Strike through if inapplicable.

^ Insert the deposited plan number or dealing number of the instrument that created the easement

Use STRATA PLAN FORM 3A for certificates, signatures and seals

SURVEYORS REFERENCE: 120511 SP

STRATA PLAN FORM 3 (PART 1) (2012) WARNING: Creasing or folding will lead to rejection

STRATA PLAN ADMINISTRATION SHEET

Office Use Only

Registered 23-12-2014

Office Use Only

SP90738

PLAN OF SUBDIVISION OF LOT 1
IN DP 1203142

This sheet is for the provision of the following information as required:

- A Schedule of Unit Entitlements.
- Statements of intention to create and release affecting interests in accordance with section 88B *Conveyancing Act 1919.*
- Signatures and seals - see 195D *Conveyancing Act 1919.*
- Any information which cannot fit in the appropriate panel of sheet 1 of the administration sheets.

Subdivision Certificate number: 183/2014
Date of endorsement: 1/12/14

SCHEDULE OF UNIT ENTITLEMENT

LOT NO	UE	LOT NO	UE	LOT NO	UE	LOT NO	UE
1	217	11	239	21	217	31	447
2	308	12	353	22	232	32	514
3	221	13	217	23	279	33	334
4	317	14	224	24	224	34	252
5	226	15	244	25	358	35	252
6	355	16	362	26	248		
7	250	17	212	27	237		
8	344	18	228	28	340		
9	215	19	241	29	446		
10	219	20	362	30	266		
				AGGREGATE		10000	

PURSUANT TO SEC. 88B OF THE CONVEYANCING ACT 1919 AND SECTION 7(3) OF THE STRATA SCHEMES (FREEHOLD DEVELOPMENT) ACT 1973 IT IS INTENDED TO CREATE:

1. POSITIVE COVENANT
2. RESTRICTION ON USE OF LAND (WHOLE OF LOT)

SURVEYORS REFERENCE: 120511 SP

STRATA PLAN FORM 3 (PART 1) (2012) WARNING: Creasing or folding will lead to rejection

STRATA PLAN ADMINISTRATION SHEET

Sheet 3 of 3 sheet(s)

Office Use Only

Registered 23-12-2014

Office Use Only

SP90738

PLAN OF SUBDIVISION OF LOT 1
IN DP 1203142

This sheet is for the provision of the following information as required:

- A Schedule of Unit Entitlements.
- Statements of intention to create and release affecting interests in accordance with section 88B *Conveyancing Act 1919*.
- Signatures and seals - see 195D *Conveyancing Act 1919*.
- Any information which cannot fit in the appropriate panel of sheet 1 of the administration sheets.

Subdivision Certificate number: 183/2014
Date of endorsement: 1/12/14

SIGNED, SEALED AND DELIVERED ON BEHALF OF
BEST MAGIC VENTURES PTY LIMITED
ACN154 801 260 BY:

SOLE SECRETARY/DIRECTOR

Tony Chao Huang
PRINT NAME

DIRECTOR

PRINT NAME

EXECUTION BY MORTGAGEE

Certified correct for the purposes of the Real Property Act 1900 by the person(s) named below who signed this instrument pursuant to the power of attorney specified

Signature of attorney:

Attorney's name: Stephen Zhang

Attorney's position: Relationship Executive

Signing on behalf of: COMMONWEALTH BANK OF AUSTRALIA ABN 48 123 123 124

Power of attorney -Book: 4548
-No: 494

SURVEYORS REFERENCE: 120511 SP