

University of Southern Queensland

Faculty of Health, Engineering and Sciences

**Terrestrial Laser Scanner for 3D Modelling of USQ
Toowoomba Campus**

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Abstract

3D digital model is a virtual representation of the real world and demand for creation of these models is increasing. Various industries recognized the advantages of these types of models. Level of detail can vary for different applications, from low level detail 3D models that can be used in tourism industry, to high level detail 3D models used in construction and engineering. 3D models of built environment provide base for efficient planning of new developments and efficient management of existing buildings and areas. Modelling of 3D models is time consuming task and depends on requirements of the final model as well as on quality of acquired data.

Data for 3D modelling can be acquired by utilizing various surveying technologies or by combination of them. Terrestrial Laser Scanner technology allows collection of high amount of high quality data in relatively short time. It is this capability, of collecting data with great detail, which makes this technology appropriate for data collection as a base for 3D model. If this is combined with traditional survey methods spatial certainty of the model is ensured.

Although the high amount of data is advantage when creating 3D models, it can present challenge in modelling built environment and this research project will research how the acquired data can be modelled into final 3D model.

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Antonio Jelacic

0061075346

A handwritten signature in blue ink, appearing to be 'AJ', written over a horizontal line.

Signature

10/10/2016

Date

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Chapter 1

Introduction

1.1 A Introduction

Advancement in hardware used in collection of spatial data and development of software that is capable to produce complex models of environment allowed us to move from traditional 2D presentation of data to 3D spatial presentations. 3D models as replicas of the real world are essential for urban applications such as: mapping, facilities management, engineering, emergency services, tourism, i.e. (Armenakis & Sohn 2009). The resulting model is a data-rich, object-oriented and parametric digital representation of the building from which data appropriate to various user needs can be extracted and analysed for effective decision-making (Mahjoubi, Moobela, & Laing 2013).

There are number of techniques and technologies used in capturing data for creation on 3D models of built environment. These include traditional surveying techniques: total stations, GPS, photogrammetry and fairly new technology: remote sensing. Collecting data with traditional methods is time consuming task. Terrestrial laser scanner is fairly new technology that allows collection of high amount of data in relatively short period. The scanner can digitize all the 3D information concerned with a real world object such as buildings, trees and terrain down to millimetre detail (Arayici 2007) therefore; very accurate 3D representations of built environment can be produced.

Advanced digital mapping tools and 3D laser scanner enables digital documentation of buildings, enables creation of educational resources within the built environment as well as the reconstruction of the built environment (Arayici 2007). Creation of 3D models of built environment enables virtual visits and walk throughs of building landmarks and complex analysis of their history and condition.

1.2 Motivation

University of Southern Queensland consists of about sixty building plus outdoor facilities like sport centre, parking lots, community areas, etc. Management of all of those assets requires substantial work and documentation. Traditionally, all that documentation is based on two dimensional technical drawings which make it very difficult to manage. Creation of 3D models of built environment based on data collected by terrestrial laser scanner will allow creation BIM (Building Infrastructure Modelling) models. Building Information Modelling (BIM) is a digital representation of physical and functional characteristics of a facility (NIBS 2016). BIM represents geometry of objects in three dimensions, shows spatial relationship between them and describes them with attributes and by using BIM information all information is available electronically what allows efficient management and maintenance of existing buildings and will allow more efficient planning as University will grow.

Furthermore, University of Southern Queensland has been a leader in distance learning for a long time attracting students from across Australia and from overseas. By creating 3D model of University we are creating virtual reality and by combining it with GIS (Geographic Informational System) and IT (Information Technology) capabilities more interactive types of studies can be created. That will enhance learning experience for of campus students by giving them that on campus feeling.

Also, marketing opportunities should not be forgotten. Virtual visits by virtual fly-throughs, interactive maps, and virtual University open days are just some of the possibilities that can be used in promoting the University. Completion of this project can give University that extra advantage in this highly competitive market.

1.3 The Problem and Objectives

Many industries recognized the benefits of virtual models and demand for 3D representation of the built environment is increasing. Although there are non-measurement systems that allow creation of 3D models of the environment they can't provide level of detail and spatial

certainty needed. Aim of this project is to provide information on level of detail that can be collected and how collected data can be modelled into 3D model.

Objectives set for this projects are:

- To determine how the collected data of the built environment can be modelled into 3D model.
- To create photorealistic model of the buildings by combining data from different sources.
- To create 3D model that can be used in web based applications (e.g. Google Earth).

Acquisition of data is mostly automated process while the data processing and creation of the final 3D model is mostly manual and time consuming task, so decision was to limit this project to area of the “Quad” section of the Toowoomba Campus. The area is suitable for this project because it has all the characteristics of built environment: buildings, trees, benches, etc. Also due to high volume of potential noise in measurements (people walking, mixed edges, different reflectivity surfaces) presents good polygon for exploring the ways how to remove those noises without reducing the quality of model.

1.4 Project Outcomes and Benefits

This project is designed to provide information about modelling 3D objects inside the Toowoomba Campus based on data collected by Terrestrial Laser Scanner. It will provide information and experience that can be used for continuation work of creating the 3D model of entire Campus.

The expected outcomes of the project include: creation of highly detailed 3D model of the “Quad” area and surrounding buildings with spatial certainty, 3D model of the “Quad” area and surrounding buildings that is incorporated in Google Earth, Virtual fly-through of the photorealistic 3D model of the “Quad” area.

Results of the project will create base for further expansion of 3D campus project, what would then provide the University authorities the valuable data about condition of the buildings and environment and that data could be used in planning of the facilities or refurbishment of the

existing ones, as well as for promotional purposes by creating the virtual walk-throughs of entire Campus.

1.5 Conclusion

The aim of this project is to utilize laser scanner and its data for creation of 3D model. The projects intends to use the laser scanning technology to capture data of the “Quad” area of USQ Toowoomba Campus from multiple scanning positions, process the raw data and create 3D model out of point cloud.

Literature review in Chapter 2 will provide information about laser scanner technology as well as differences between scanner types and potential errors. Furthermore, information about processing and modelling will be provided. Chapter 3 will provide information about project planning and project execution. Firstly project area will be presented together with the project design. Next equipment needed for completion of the project will be reviewed and field procedures will be established. Finally, data processing techniques will be presented. Procedures for processing and modelling and presents final result of the project will be explained in Chapter 4 and Chapter 5 will highlight outcome of the project and will give the recommendations for future works.

Chapter 2

Literature Review

2.1 Introduction

Before commencing the actual research a literature review was undertaken to acquire information regarding the subject matter. Through the literature review of the previous works information was gathered about: Terrestrial laser scanner technology, data acquisition and modelling of the data, and representation of data

2.2 Laser Scanner Technology

Laser is a device that emits light in a narrow, low-divergence beam with well-defined wavelength and that laser light, due to its coherent properties and constant velocity of travel, is well suited for object measurement (Quintero et al. 2008). Laser scanners have laser transmitter that emits light and receiver that detects its reflection.

Royal Institution of Chartered Surveyors (RICS) defines laser scanners as measuring devices that measure three-dimensional coordinates across an object's surface automatically, in a systematic manner, at high speed and in near-real time using laser range finding. LST ability to capture 3D points in x, y, z accurately, rapidly, completely and in high resolution gives it edge over conventional measuring instruments (Kho, Low & Hao).

Current laser scanner technology can be divided into two categories: static and dynamic (Quintero et al. 2008). Static laser scanner is on fixed position, mounted on the tripod, during the acquisition of data while mobile laser scanner is mounted onto a mobile platform: airplane, car or unmanned aerial vehicle and it is used with positional systems like GPS. Laser scanners capture and record the geometric information of the object's surface by using a closely spaced grid of points, namely the point clouds (Pfeifer & Briese 2007). Position of the

each point is established by measuring travel time of the laser (Hao 2011). There are two measuring methods: Time based measurement and triangulation based measurements.

2.2.1 Time Based Measurements

Time base measurements are based on a time frame between two events. There are two types of time based scanners: Pulse based or Time-of-Flight and Phase based (Quintero et al. 2008).

Pulse based (TOF)

A short (typically 5 to 10 nanoseconds) laser light pulse is transmitted towards the object. The time of flight dt of the transmitted pulse from the scanner to the object surface and back is recorded and since the speed of electromagnetic radiation c is known range D can be calculated (Kukko 2013). Figure 2.1 shows time of flight laser scanner pulse based principle.

$$D = \frac{(dt * c)}{2}$$

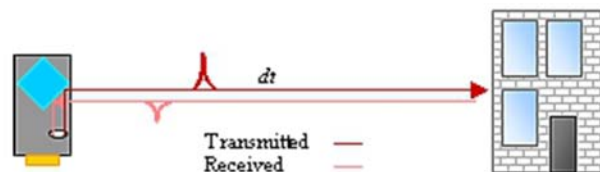


Figure 2.1: Time of Flight laser scanner pulse based (Kukko 2013)

Typically, medium range (2 - several hundred meters with precision in order of 5mm), and long range (up to approximately 2 km with precision in order of centimetres), scanners operate using timed pulse principle. (RCIS n.d.). Figure 2.2 shows an example of pulse based scanner, it is Leica ScanStation 2.



Figure 2.2: Leica ScanStation2 (LeicaGeosystems 2015)

Phase based

The emitted (incoherent) light is modulated in amplitude and fired onto a surface (Quintero et al. 2008). The phase shifts $d\phi, i=1\dots n$ of the modulated carrier and measurement waves between the transmitted and received signal are measured, the ambiguity N of the shortest wavelength is solved from the phase shifts in the modulated carrier waves, and finally the phase shift of the shortest measurement wavelength is converted into a range from the scanner origin to the object. The frequencies of the modulated amplitude waves must be known, since the shortest modulated wavelength λ_0 gives:.

$$r = \left(N + \frac{d\phi}{2\pi} \right) \lambda_0$$

Where r is the range, N - number of full wave cycles of the shortest modulated wave (Kukko 2013). Figure 2.3 show time of flight phase based principle.

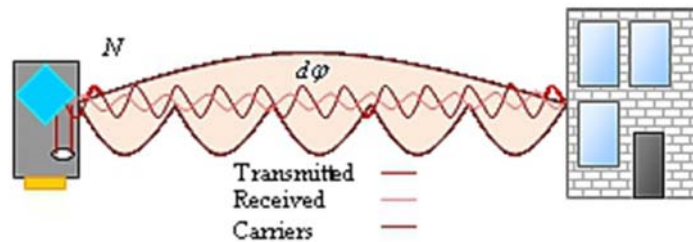


Figure 2.3: Time of Flight scanner phase based principle (Kukko 2013)

The laser light can be modulated by using:

- Sinusoidal modulation
- Amplitude based (AM) or frequency based (FM) modulation
- Pseudo-noise or polarization modulation

Short range scanners (50-100 m) uses the phase based principle with precision of several millimetres (RCIS n.d.). Figure 2.4 shows an example of phase based scanner, it is Faro Focus 3D, which is going to be used in this project.



Figure 2.4: Faro Focus 3D (Faro Technologies 2011)

2.2.2 Triangulation Based Measurements

Mathematical base of triangulation based measurements is triangle (Figure 2.5).

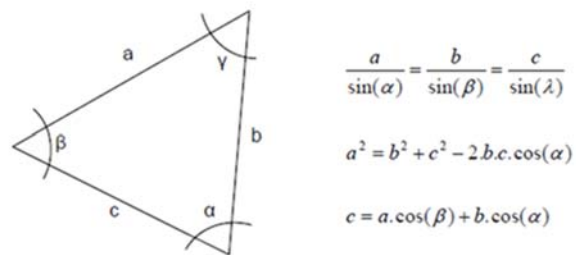


Figure 2.5: Triangulation principle (Quintero et al. 2008)

Triangulation laser scanner uses the same principle. Scanner emits the light onto the object and uses the camera to look for the location of the laser's projection on the object. The laser emitter and the camera are setup under a constant angle, creating a triangle between them and the laser projection on the object (Quintero et al. 2008).

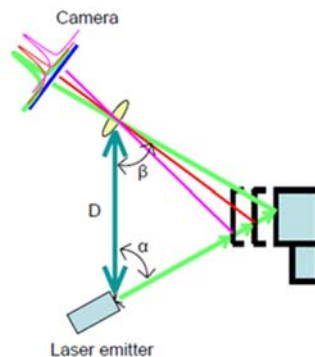


Figure 2.6: Triangulation Laser Scanning Principle (Quintero et al. 2008)

From Figure 2.6 we can see that by knowing the distance (D) between camera and the laser, angle (α) of laser emitter and the angle (β) of the camera the distance to the object can be calculated.

Close range scanners, typically up to few meters with sub-millimetre precision are usual triangulation based scanners used to model small objects or artefacts in a laboratory (RCIS n.d.).

2.3 Accuracy

Before using any type of surveying equipment understanding about their limitation and possible errors than can occur is needed. Although each scanner manufacturer publish their own specifications and accuracies to illustrate the capabilities of their product that specifications giver are not directly comparable (Boehler & Marbs 2005). In their investigation of laser scanner accuracy Boehler and Marbs (2005) stated: “Every point cloud produced by a laser scanner contains a considerable number of points that show gross errors. If the point cloud is delivered as a result of surveying, a quality guarantee, as possible for other surveying instruments, methods, and results, cannot be given.” Sources of error are divided into four categories: instrumental, object related, environmental and methodological (Quintero et al. 2008).

2.3.1 Instrumental Errors

Instrumental errors are dependent on the scanner design and can be random or systematic. Random errors mainly affect the range measurement precision and the angular location of pulsed time-of-flight rangefinders. Systematic errors may be generated by the non-linearity of the time measurement unit or by temperature drift in the time measurement electronics causing range drift among other errors (Quintero et al. 2008).

Laser beam divergence

As laser beam travels the laser beam is widening, the greater the distance travelled greater the divergence. Beam divergence influence the cloud resolution and has influence on positional uncertainty of the observed point. Practically, this beam divergence has an effect on the angular location of the point measured. The apparent location of the observation is along the centreline of the emitted beam (Quintero et al. 2008). According to Lichti and Gordon 2004, the beam uncertainty is approximately equal to one-quarter of the laser beam diameter.

Edge problems

Result of beam divergence is edge problem. When a laser beam hits the edge of an object, the beam is split into two. One part of the beam reflects on the first part of the jump edge, while the other part travels further to hit another surface (Figure 2.7). The result of this is that the information from one laser pulse that is sent back to the receiver comes from two different locations in space and result is incorrect position of the point (Quintero et al. 2008).

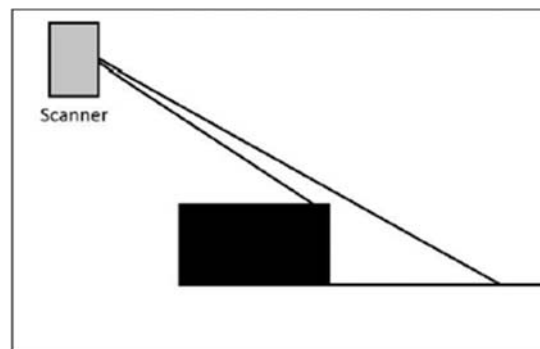


Figure 2.7: Edge detection (Light 2014)

The range error in these points can vary in magnitude from a fraction of a millimetre to several decimetres (Boehler & Marbs 2005).

Range uncertainty

Beraldin et al (2005), reviewed the laser scanners with particular attention to the fundamental measurement limits. They summarized the range uncertainties for two main classes of laser scanners: time based and triangulation based scanners.

For triangulation based scanners the range uncertainty can be expressed:

$$\delta_z \approx \frac{Z^2}{f * D} \delta_p$$

Where (f) is effective position of the laser spot (effective focal length), (D) is the triangulation baseline, (δ_p) is the uncertainty in laser position that depends on the type of laser spot sensor, peak detector algorithm, signal-to-noise ratio and the image laser spot shape, and (Z) is the distance to the surface.

For the time of flight scanner with pulsed laser, range uncertainty for single pulse is approximately given by:

$$\delta_z \approx \frac{cT_t}{2\sqrt{SNR}}$$

Where (T_t) is the pulse rise time, and (SNR) is the signal to noise ratio.

For time of flight scanners with continuous wave the range uncertainty is approximately given by:

$$\delta_z \approx \frac{\lambda_m}{4\pi\sqrt{SNR}}$$

Where (λ_m) is wavelength of the amplitude modulation (or c/fm)

Difference in range uncertainty between different types of laser scanners is shown in Figure 2.8.

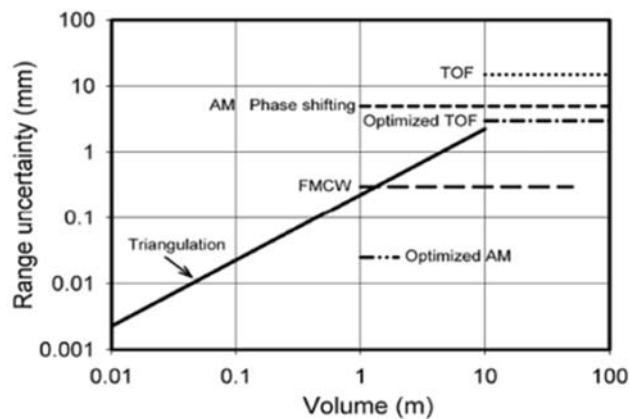


Figure 2.8: Difference in range uncertainty between different types of laser scanners (Blais 2006)

Ranging scanners for distances up to 100 m show about the same range accuracy for any range. In contrast to the ranging scanners, the accuracy of ranges acquired with triangulation scanners diminishes with the square of the distance between scanner and object (Boehler and Marbs, 2005).

Angular uncertainty

Most laser scanners make use of rotating mirrors to guide the laser signal in a certain direction. A small angle difference can cause a considerable coordinate error when the distance from the scanner increases. Errors can be detected by measuring short horizontal and vertical distances between objects (e.g. spheres) which are located at the same distance from the scanner and comparing those to measurements derived from more accurate surveying methods (Boehler & Marbs 2005).

Axes errors in a terrestrial laser scanner

In the development of laser scanner calibration procedures, a geometrical model of the scanner is needed. Therefore, we define the following axes:

Vertical axis: This is the vertical axis that allows the rangefinder to move the laser beam horizontally. Depending on the type of scanner, panoramic or camera-scanner, this is the rotation axis of the scanning head or the axis orthogonal to the axes of the two mutually orthogonal oscillating mirrors;

Collimation axis: This is the axis that passes through the centre of the scanning mirror and the centre of the laser spot on the object surface;

Horizontal axis: This is the rotation axis of the scanning mirror;

Due to manufacturing tolerances, these axes are not perfectly aligned, leading to a collimation error as well as a horizontal axis error (Quintero et al. 2008).

2.3.2 Object Related Errors

Laser scanner emits laser beam and measures the reflection of the beam. Reflection beam is under influence of physical laws of reflection and the optical properties of the materials. Laser beam is affected by the absorption of the signal travelling through the air, the reflection of the material being measured and the angle of incidence between the laser beam and the surface being measured. Surfaces with high reflectance (i.e. bright surfaces) give more reliable and precise range measurements than the very dark (black) surfaces that absorb most of the visible spectrum. However, if the object reflectivity is too high (metal surface, retro reflective tape ...), the laser beam is fully deflected in the mirroring direction and will hit another surface or spread into the open (Quintero et al. 2008). Observing surfaces with different reflectivity result in systematic errors in range. For some materials these errors may reach amounts several times larger than the standard deviation of a single range measurement. (Boehler & Marbs 2005).

As Clark & Robson (2004) showed, colour properties of the materials cause systematic range discrepancies. Ingesand, Ryf & Shulz (2003) showed that laser beam can penetrate to certain types of material (i.e. wood) and refracts inside of the material. These effects lead to additional constant to a distance measurement, which has to be taken into considered with the computation.

2.3.3 Environmental Conditions

Temperature

Any scanner will only function properly when used in a certain temperature range. Even within this range, deviations may be observed, however, especially in the distance measurement. Important thing to be noted is that the temperature inside the scanner may be far above the temperature of the surrounding atmosphere (Boehler & Marbs 2005). Besides the temperature of the equipment, important is the temperature of the scanned surface because the background radiation of the hot surfaces reduces the signal to noise ratio and thus the precision of the range measurements (Quintero et al. 2008).

Atmosphere

Atmospheric conditions, variation in temperature, pressure or humidity can affect propagation speed of laser light. For short distances effect may not seriously affect the result but for long distance measurements or high precision scans corrections for atmospheric conditions need to be applied (Quintero et al. 2008).

Interfering radiation

Laser scanners operate in a very limited frequency band, the precision of the range measurement may be influenced by external radiation, for instance from strong external illumination sources. Filters can be applied in the receiving unit allowing only this frequency to reach the receiver resp. the camera. (Boehler & Marbs 2005).

2.3.4 Methodological Errors

Methodological errors occur due to the chosen survey method or the user experience which is not too familiar with this technology (Quintero et al. 2008). For example choosing the scanner that is inadequate for given work, low range scanner is used for collecting data over longer distances. Another error can occur when chosen survey method is not in line with scanners capabilities, setting resolution to high or too low, expanding the range between scanning positions beyond scanners range.

2.4 Application of Laser Scanning

Laser scanners are fairly new technology that is still evolving. Its potential to acquire large amount of highly accurate data in relatively short period allows creation of complex and highly detailed 3D models. Furthermore, it is non-contact measurement technique, what minimizes potential risks for the operator. Many industries recognized these benefits and have embraced that technology for their applications (see Figure 2.9).

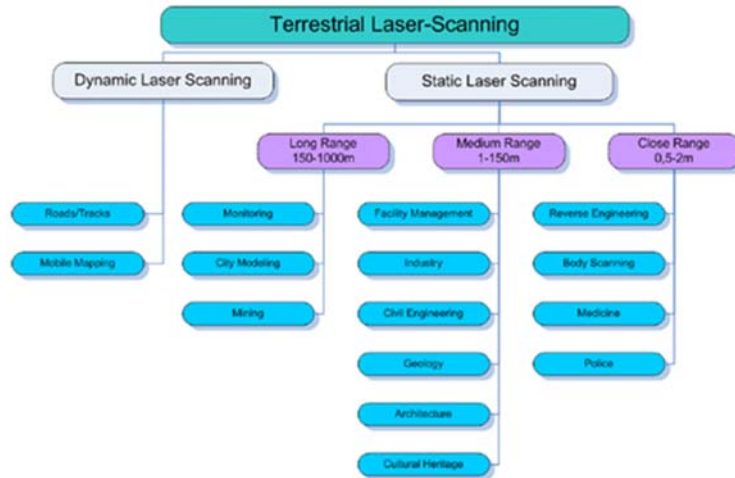


Figure 2.9: Laser Scanner applications (Quintero et al. 2008)

2.5 Registration

Usually during the object scanning with laser scanner multiple scans from multiple scanning positions are needed to obtain data over the entire surface (Figure 2.10).

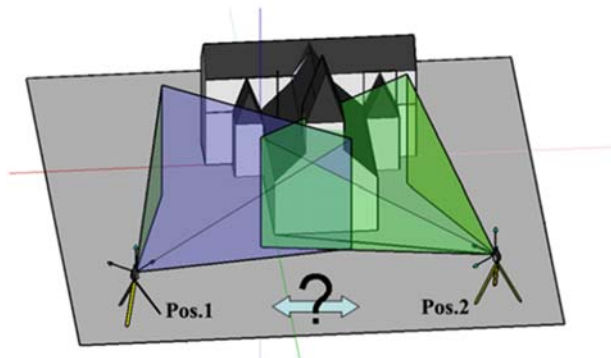


Figure 2.10: Two scan positions (Quintero et al. 2008)

The registration is used to determine the transformation of data from two different views so that data can be integrated under the same coordinate system. Integration is the process of creating a single surface representation from the sample points of two or more range images (Bi & Wang 2010). According to (Quintero et al. 2008) there are two registration techniques: Direct and indirect (Figure 2.11).

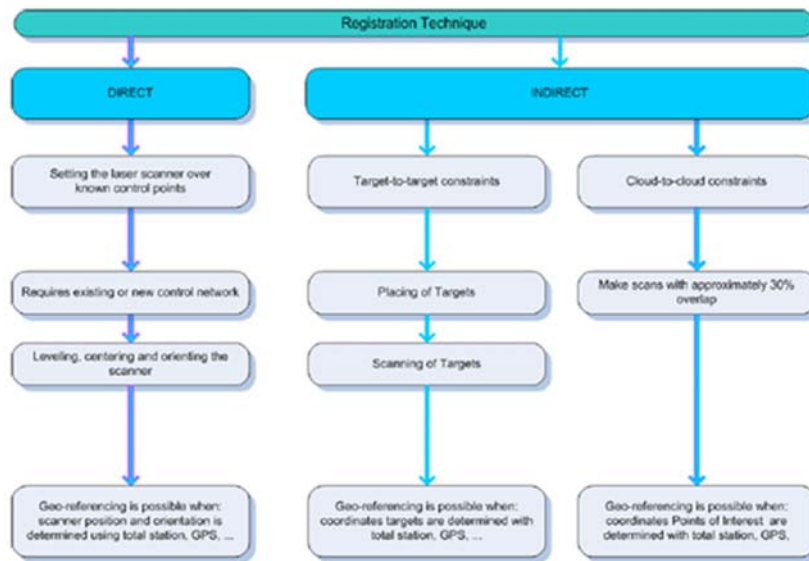


Figure 2.11: Registration techniques (Quintero et al. 2008)

2.5.1 Direct Registration

With using direct registration position and orientation of the scanner is directly computed. Scanner is positioned over known point it is levelled and orientated. This technique reduces the number of targets to be placed and there is no need for overlapping scans, thus it is faster than using the indirect registration (Quintero et al. 2008).

2.5.2 Indirect Registration

When using the indirect registration at least three targets are required, to minimize the errors it is better to use more, are used to align datasets.

Target to target registration

The targets to be used are the one made by scanner manufactures or printed paper target can be used. If the area are not easily accessible natural targets can be used, i.e. edges of the windows or cornices (Quintero et al. 2008).

Cloud to cloud registration

Besl and Mckay (1992) introduced this process and Chen and Medioni (1992) demonstrated the registration of partially overlapping data (Altuntas & Yildiz 2008). This registration technique is called Iterative Closed Point processing. This type of registration can be used if two point clouds have enough overlap (30-40%). Process requires to pick at least corresponding points. Since these 3 points will never be exactly the same points ICP algorithm iteratively checks the distances between all the points of the point clouds and estimates the transformation to align both sets thus resulting in minimal error.

Surface to surface registration

The method is developed by Gruen and Akca 2005, method aligns datasets by matching one or more 3D search surfaces with a 3D template surface, minimizing the sum of squares of the Euclidean distances between the surfaces (Altuntas & Yildiz 2008). This type of registration can be useful in situations where scans contain substantial quantities of noise. In this case, scan is separated and processes and transferred to surfaces and the registration is used to align the datasets (Quintero et al. 2008).

2.6 Data Processing

When the raw data is registered it needs to be processed into a final deliverable form. That is time consuming and mostly manual process. As we can see from Figure 2.12 degree of automation decreases as we progress from acquisition to registration and onto modelling phase.

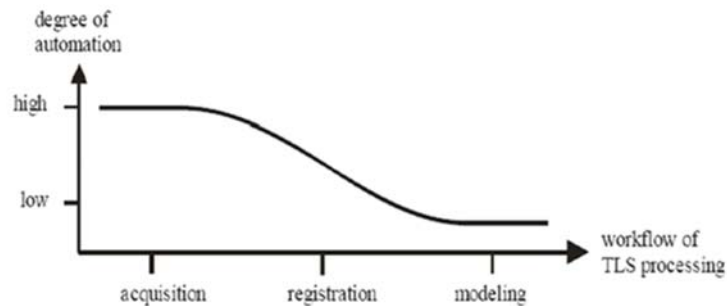


Figure 2.12: Automation in the Terrestrial Laser Scanner workflow (Blais 2006)

Process of creating some useful information out of raw data can be divided into 4 basic steps.

2.6.1 Pre-processing and Registration

Data is filtered to remove any invalid data or to reduce point number. Data can be invalid for many reasons: bad reflection, atmospheric effects, edge errors, reflectivity of the surface elements, etc. Most of the available software tool have automatic filtering functions and are mainly based on two principles. First principle removes points by identifying points that don't have points in the immediate surroundings and second principle moves the points slightly to achieve an optimal smoothness of the surface (Quintero et al. 2008). Also data can be filtered to reduce point number in a dense area (Bi & Wang 2010) to reduce computation time.

In registration process multiple scans are integrated in one common coordinate system as described in chapter 2.5.

2.6.2 3D Modelling

Although the point cloud after registration process gives us ability to view scanned object it is not in the suitable format for integration in GIS and 3D environment (Koussa & Koehl 2009). To be able to represent 3D object in those environments modelling process needs to be applied. According to Rottensteiner (2002) there are two modelling concepts: geometric and topological modelling and semantic modelling.

The geometric and topological model describes the spatial objects from both shape and position perspective by means of the absolute geo-referenced 3D coordinates: each spatial object is abstracted as a set of vertexes in 3D space first, the geometry of a vertex is just its position in space as given by its coordinates; topological relationship is applied to structure lower level primitives by defining each other's neighbourhoods (Hao 2011). Based on the topological relationship between the geometric primitives in different dimensions, four types of 3D object representations methods are defined (Rottensteiner 2002). Table 2.1 represents characteristics of each method.

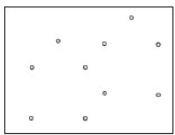
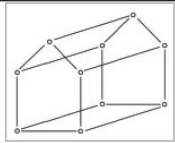
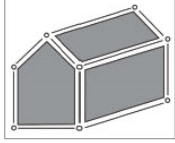
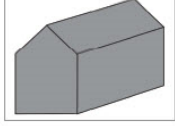
	3D object representation	Characteristics
Unconstructed set of points		<ul style="list-style-type: none"> • Defining an object by using a set of unordered vertices. • No topologic relationship between the points • 3D shape impression is only formed visually by the observers • Structure, size, volume cannot be recovered
Wireframe model		<ul style="list-style-type: none"> • Defining an object by vertices and edges. • For 3D representation, the wireframe is ambiguous
Surface model		<ul style="list-style-type: none"> • Defining an object by vertices, edges and faces; • Representing a spatial object in 2.5 D
Volumetric model		<ul style="list-style-type: none"> • Defining an object by vertices, edges, faces and volumes • Concerning with the representation of 3D solid primitives, especially for the building objects.

Table 2.1: 3D object representation methods (Rottensteiner 2002)

In semantic model, 3D object consist of spatial description including geometry and topology and a thematic description including the information or characterize that the object represented in the geographic space. This approach is mainly applied in the object based programming language and object oriented DBMS aspects (Molenaar & Oosterom 2009).

2.6.3 Post processing

Editing work after the creation of the model covers: hole filling, smoothing, edge correction, etc. (Remondino 2003) Also, if available, photographic information can be applied to model. Two different algorithms exist to project photographs onto the 3D model, texture mapping and texture draping. Texture mapping projects only visible part of the image on the model and texture draping pulls the image over the model (like wrapping the canvas over the object) (Quintero et al. 2008).

2.6.4 Visualization and Animation

The visualization of a 3D model is often the only product of interest for the external world and remains the only possible contact with the model. Therefore a realistic and accurate visualization is often required (Remondino 2003). There are three modes in which models can be visualized. Wireframe mode – it consists points, lines and curves, doesn't contain texture or shading information. Shaded mode – two most well know shading algorithms are flat shading and smooth shading. Texture mode – it is used for photorealistic visualization (Figure 2.13).



Figure 2.13: A closed view of a 3D model of the Bamiyan Buddha represented in wireframe, flat shade and texture mode (Gruen, Remondino & Zhang 2002)

An animation of a 3D model can be defined as a sequence of ‘snapped’ frames, obtained from a visualization package and joined together. We can animate either the camera or the 3D model (all model or its single parts independently) or both. The model is viewed from different viewpoints and each view contributes to the sequence (Remondino 2003).

2.7 Equipment

2.7.1 Faro Focus 3D Scanner

The Faro Focus is phase based high-speed three dimensional, middle range laser scanner with indoor/outdoor range up to 130 metres. It emits a laser beam from a rotating mirror out towards the area being scanned. The laser beam is being distributed at a vertical range of 305° and horizontal range of 360°. The emitted laser beam is then reflected back to the scanner by

objects in its path. By determining the difference between the phases of emitted and received signal distance to the object is determined as well as their vertical and horizontal angles. The result is an assembly of millions of 3D measurement points, called point cloud. Scanning functions are controlled by operating touch screen. Two main parameters that control the amount and quality of collected data are resolution and quality.

Resolution controls number of collected points. The resolution is expressed as distance between collected points on distance of 10 m. For example, highest resolution 1/1 means that point spacing between collected points on 10 m range will be 1.534 mm, and on lowest resolution 1/32 point spacing on 10 m range will be 49.087 mm.

Quality parameter controls the rotation speed around horizontal axis of the scanner. Faro Focus laser scanner takes multiple shots on particular point and then calculates the average to get the final position of that point and by controlling the rotation speed we control the number of shots that scanner makes towards particular point. Quality ranges from lowest 1x, meaning scanner takes one shot towards point, to highest 4x where scanner takes four shots towards point and calculates the average.

Resolution and quality settings control number and quality of collected points as well as time needed for individual scan. Time of individual scan can vary from 2 minutes to 2 hours depending on the settings.

Another available option is Scan with colour. When that option is turned on scanner will at the end of each scan use the inbuilt camera to take photos of the site and later in the process those photos could be used to apply colours to the scans. That feature adds another 3-4 minutes per scan.

General specifications of the Faro Focus 3D scanner are shown below in Table 2.2:.

General Specification	
Range	0.6 m – 130m indoor or outdoor
Measurement speed (pts/sec)	122000/244000/488000/976000
Color Unit	Up to 70-megapixel color
Field of view (vertical/horizontal)	300°/360°

Laser	
Laser Class	Laser Class 1
Wavelength	1550nm
Data Handling and Control	
Data Storage	SD, SDHC, SDXC
Scanner Control	Touch-screen display
Multi Sensor	
Dual axis compensator	Accuracy: 0.0015°, Range:±5°
Height sensor	Via an electric barometer
Compass	The electronic compass gives the scan geographic orientation

Table 2.2: General specification Faro Focus 3D (Faro Technologies 2011)

2.7.2 Faro Scene 3D

Faro Scene 3D is point-cloud software is specifically designed for the FARO Focus3D. Scene 3D processes and manages scanned data by using automatic object recognition as well as scan registration and positioning. Scene 3D can also generate high-quality colorized scans and provides tools for automated target-less scan positioning.

Processing starts by importing the scans into the software. It is followed by scan pre-processing where various filters and options can be applied (Figure 2.14). Filters available in Faro Scene are: dark scan points distance based, and stray. The dark scan points remove all points under certain reflectance value. Dark surfaces absorb light and so reflectance value is low and measurement is inaccurate. Distance based filter removes points outside the certain distance range. As measurements tends to get less accurate with increasing distance from the scanner and if the area of the scan is covered with multiple scans it makes sense to keep just the points picked up by closest scan position. Stray filter removes outliers or faulty points. Filter is based on grid size, distance threshold and allocation threshold. Grid size defines the

size of the area used for calculation, distance threshold specifies how far the scan point can deviate from mean value and allocation threshold defines the minimum percentage of the scan point that needs to be inside grid area and within distance threshold. If the percentage is less than minimum point will be deleted.

Furthermore, if photos were taken during the scanning process, Scene can colourize the scans giving it more realistic feel.

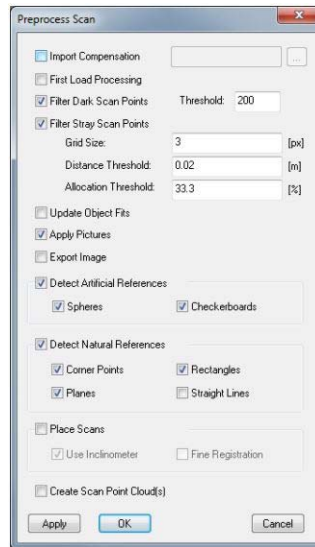


Figure 2.14: Faro Scene 3D pre-process scan option list

Scene 3D offers two registration modes: automatic or manual registration. In automatic mode software first use planar view to roughly orientate individual scans in same plane and then uses cloud to cloud option to put the scans in same coordinate system. Manual registration is based on manual target recognition in corresponding scans. Operator is marking the common targets (point, plane or sphere) in two scans after what software connects the scans. Software also has capability to export registered scans in numerous formats for further processing and modelling.

2.7.3 Artificial Targets - Spheres

Targets are used to register or combine multiple individual scans that are each on their own coordinate system onto a single aligned coordinate system. Targets can be natural (planes,

corners, walls, etc.) or artificial (checkboard or sphere). For this project Faro Standard Reference Sphere will be used (Figure 2.15).



Figure 2.15: Laser scanner reference spheres (LaserScanning Europe 2014)

Reference sphere is a hollow made of plastic with excellent reflective properties. Spherical shape allows the biggest possible scanning efficiency from various directions. Because of its spherical shape target doesn't have to be rotated between the scan what lowers the risk of errors. Diameter of the sphere is 145 millimetres and has magnetic base that can be easily fixed on magnetic surface (Faro Technologies 2011).

2.7.4 Miscellaneous equipment

In order to complete the field survey miscellaneous equipment will be required:

- Minimum two tripods, one for laser scanner and other for sphere positioning.
- Star pickets, wooden stakes, magnetic base for positioning the spheres at different elevations.
- Offset tape for measuring laser scanner and target heights
- Laptop and external hard drive for data backup

After the scanning procedure is done data will be transferred via memory card to computer where data will be processed and final product will be created.

2.8 TLS data and 3D modelling

Result of laser scanning process is point cloud that contains millions of points. That data is excellent starting point for creation of the 3D model of built environment but often it is difficult to manage due to: the size of the file, lack of interoperability between the survey tools and the modelling software and due to complicated phase of elaboration of the data (Tommasi, Achille & Fassi 2016).

There are few categories of software available to work with point clouds that enable their visualization, management and reconstruction. First category is software such as Autodesk Recap, Bentley Pointools, Geomagic, etc., that allows using point clouds for viewing, exploring, editing as well as measuring purposes. Next, there is CAD software such as Autodesk Autocad or Bentley Microstation that allows importing of the point clouds where 2D profiles can be extracted and 3D models created by applying traditional working methods. Third category is modelling software such as Rhino and 3Ds Studio Max where is possible to directly generate the surface from the point cloud and then extract profiles and sections. And finally there is Building Infrastructure Model (BIM) software such as Autodesk Revit and Graphisoft Archicad that uses the construction elements (walls, floors, roofs, etc.) to create 3D models (Tommasi, Achille & Fassi 2016).

There are two main working methods for building 3D model: the direct modelling and parametric modelling. In direct modelling point cloud is used as a base to vectorize the profiles required for 3D model (Figure 2.15). Profiles are used to create the sections and sections are used to create the surface of the object. The parametric modelling allows creation of 3D models through pre-established models editable in any step of the process by the insertion of parameters. Two categories of parametric modelling are: parametric-generative and parametric-object oriented. Parametric-generative modelling is based on mathematical approach and on use of algorithms for extraction of curves and surfaces of the object. Rhino 3D is the software that uses that approach for 3D printing, reverse engineering and in product and graphic design. Parametric-object oriented modelling is based on the use of constructive elements to build the 3D model. Autodesk Revit utilizes that method for creation of BIM models.

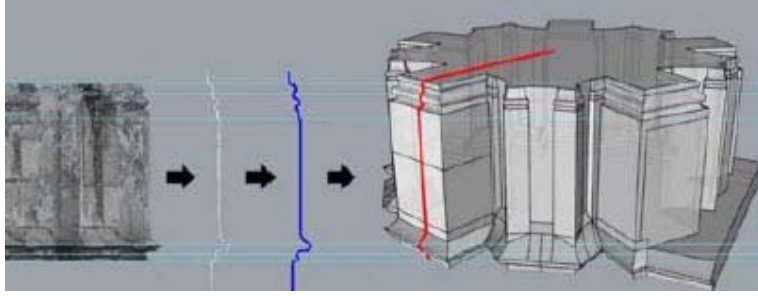


Figure 2.16: Vectorized profile

2.9 Conclusion

This chapter reviewed information about laser scanner technology. Categories of laser scanners were presented as well as different working principles. Accuracy was discussed by explaining the sources of potential errors and influence they have on collected data. Stages in data processing were described as well specifications of the equipment and software used for completion of this project. Finally, types of software for working with point clouds and working methods for creation of 3D models were mentioned.

Chapter 3

Methodology

3.1 Introduction

Chapter 1 set the goals and objectives of this project, and Chapter 2 described the technology that will be used. The purpose of this chapter is to provide understanding of the processes that will be undertaken to fulfil the project aim. To ensure that project goals will be met appropriate methodology needs to be established. Methodology will include study area assessment, data acquisition and data management processes, as well as data archiving.

3.2 Study Area Assessment

Locality

The theme of this project is usage of laser scanner data for creation of 3D model of built environment inside the USQ Toowoomba Campus. USQ Toowoomba Campus is situated in in south west part of Toowoomba in Darling Heights suburb, some 100 km west of Brisbane (Figure 3.1).

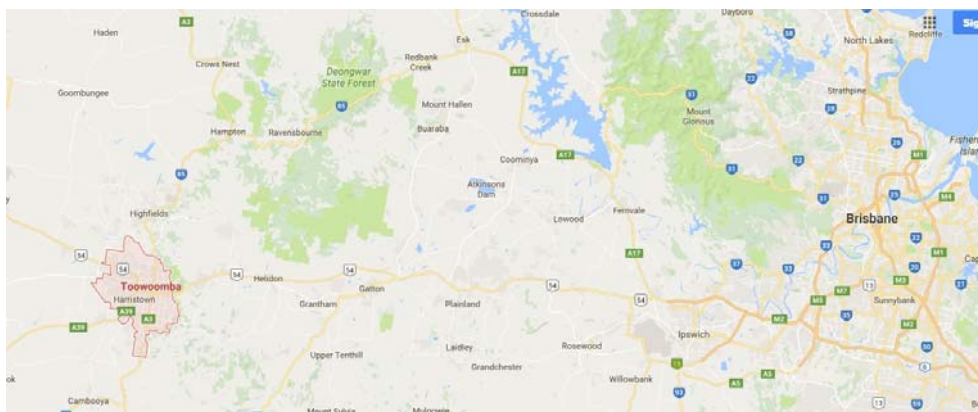


Figure 3.1: Locality map (Google Earth 2016)

Site Scale

Site scale is important while planning the survey because it will determine the equipment used and time needed for completion. Equipment selection was based on availability so the site scale together with equipment limitations will determine the time needed for completion of the project.

For subject site the “Quad” area was chosen. Size of the area, based on satellite images, is approximately 10 thousand square meters (Figure 3.2).



Figure 3.2: Highlighted Subject Area (Google Earth 2016)

Site Conditions

Existing site conditions are also very important when planning the survey. Laser scanner measures and collects the data of the object that it can see, so if there are some obstacles between scanner and the object measurements are not possible. Example is administration building (Figure 3.3) that has walls covered in vegetation what means that exact measurements of that wall are not possible.



Figure 3.3: Parts of wall covered in vegetation

Also, big trees located in the middle of the ‘Quad’ area will block the laser scanner view so extra scanning positions are needed to cover all the area (Figure 3.4)



Figure 3.4: Part of the scanned area

Another aspect of the site condition assessment is safety. Potential safety risks need to be assessed and appropriate measures applied to ensure safety for operator and equipment. For this subject are no site related safety risks were identified.

Site Accessibility

Beside the personal safety of the operator, public safety needs to be taken into an account while planning the survey. Subject site is accessible to public so the operator needs to ensure that public is not exposed to adverse effects of the laser or scanning process itself. That will be achieved using the appropriate signage and barricades to establish the no-go zone around the laser scanner.

Site accessibility also refers to ability to move freely across the site and that all areas of the site are accessible for equipment and accurate data acquisition. Because the fact that subject site is an open area and that project specifications include scanning of the exterior only, there are no accessibility issues.

Site Context

Site is situated in urban area and variables like traffic and people passing by needs to be taken into account while planning and conducting the survey. High amount of traffic presents the potential risk to the quality of the data so the survey needs to be planned for the period where there is least frequency of traffic or scanning positions need to be planned so the adverse effects of the traffic are eliminated.

3.3 Equipment

After the project goals and aims are set, site assessed and analysed technical assessment can be done. Technical assessment includes choosing the type of scanner for the project as well as other equipment needed for data acquisition phase. Based on project specifications and type of scanner used timeframe and cost of the data collection can be determined. Furthermore, appropriate software for initial data processing needs to be chosen as well as software for data clean-up and modelling and format for deliverables and data archiving determined.

Selection of the equipment was based upon its availability. All equipment used is owned by University of Southern Queensland and it is available at Toowoomba Campus. Faro Focus 3D scanner will be used for data collection and its specification is in line with demand of this project. Faro Focus is a middle range, phase based scanner with accuracy of ± 2 mm and allows high speed data collection. Its small dimensions (24x24x10 cm) and weight of just 5.2 kg means that can easily be moved around the site and its user friendly interface makes it easy to use. Also, Faro Focus is equipped with low power laser, Class 3R according to International Electrotechnical Commission (IEC), what means that if handled carefully does not presents risk to eyes or skin for operator or public.

Furthermore, Faro artificial targets – spheres will be used for registration purposes. Although mathematically three corresponding targets in two scans are needed to combine scans together, for this project five corresponding targets will be used what will result with 10 visible targets in each scan. Five spheres will be moved after each scan in traverse like procedure (foresight in one scan will became backsight in following one). More targets used decrease the number of potential errors in registration process. Those targets will be positioned in each scan according to the manufacturer's instructions in order to enable maximum efficiency.

Detail description and specifications of the equipment used is given in Chapter 2.7.

3.4 Project Design

Before commencing laser scanning, investigation of the subject area was conducted to determine number of scans needed to fulfil project objectives as well as position of individual scans. The scan positions needs to ensure that blind spots are minimized and to ensure that point coverage is at maximum. Another element that needs to be taken into the consideration when planning the positions of the scans is equipment limitation. Faro Focus 3D laser scanner will be used and spheres will be used as artificial targets. Limiting factor of the Faro Focus 3D is the range at what scanner can identify spheres and that range is around 15 metres. Consequence is that scan positions could only be 30 metres apart. Taking all this into account 15 scanning positions were roughly determined. Furthermore, artificial targets, spheres, must be carefully positioned with good geometry and with different elevations around scanner to ensure good usability later on in registration process. Figure 3.5 shows fifteen positions from which the scans will be conducted.

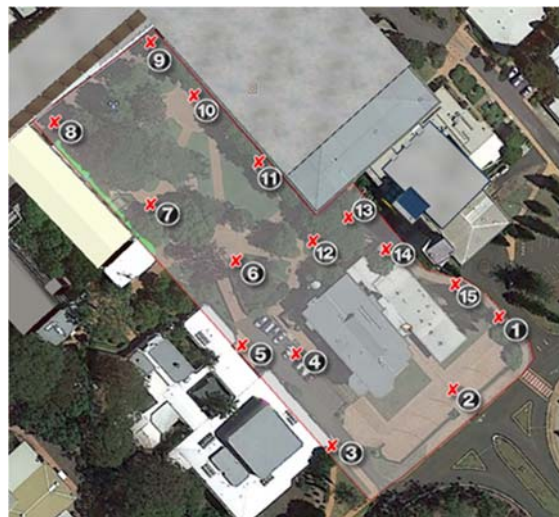


Figure 3.5: Project scan positions (Google Earth 2016)

Taking into account all stated above workflow for field survey is designed:

1. Arrive at the Toowoomba Campus and borrow all needed equipment from instrument laboratory and ensure that all equipment is in working order.
2. At arrival at subject site pre-risk assessment needs to be completed ensuring that participants are aware of potential risks and safety procedures and that health and safety requirements have been met.

3. Perform the filed survey using the laser scanner as described in section 3.4.
4. Return the borrowed equipment and sign off for the day.

Although this process can be done by one person it is planned that two people will be involved in filed survey, surveyor and assistant. The role of an assistant is to help surveyor with transporting the equipment and positioning the spheres as survey progress through the site. Furthermore, Dr Xiaoye Liu, will be involved in filed survey as a supervisor and will oversee the scanning process.

Expected timeframe for completion of the field survey is two days with approximately one hour per setup needed, 40 minutes duration of the scan and 20 minutes for moving scanner and spheres from station to station.

3.5 Field Survey and Data Processing

This section of the chapter describes the survey method and data processing required to create the point cloud of the subject area.

3.5.1 Field Survey Process

Before the actual survey with laser scanner can starts number of requirements must be considered. That includes: the purpose of the survey, aimed measurement quality, point density, amount of overlapping data. Based on these requirements parameters on the scanner will be set, number and placement of scanning positions determined as well as type and number of targets used.

As the aim of the project is to create 3D model of built environment high quality data is required. To achieve that scanner parameters were set to $\frac{1}{4}$ resolution, meaning that one point will be collected each 3.068 millimetres on 10 metre range and quality 4x, meaning that scanner will take mean of four measurements on a single point to determine the point location. That will result in 174.8 million points collected in each scan with time needed for completion of each scan around 40 minutes.

The health and safety requirements must be addressed before starting any work, potential risks identified assessed and mitigation measures proposed and applied. Furthermore, to ensure the safety of all the people in vicinity where the survey is conducted and to ensure safety of the equipment clear signage should be used clearly stating that laser scanning is in process and barricades should be used to establish no-go zone around the scanner itself.

Once all this was set work can start with workflow process described below:

Set up the scanner on position

- After visually checking surrounding fine tune the scanner position to ensure maximum point coverage.
- Position the tripod over the chosen position; ensure that tripod legs are firmly on the ground, in case of slippery surface use sandbags or something similar to lock the legs in position.
- Position the scanner on tripod, tight all the screws and level the laser scanner to a rough horizontal position.

Set up the artificial targets

- Position the spheres in the front of laser scanner in direction of next scanning position. Use the tripods, stakes, star pickets, magnetic bases to position the spheres on different elevation maintaining the good geometry around scanner.
- Ensure that spheres are visible from scanner and that are no obstacles between scanner and spheres.

Perform survey with laser scanner

- Ensure that all parameters are correctly inserted using the scanners software.
- Perform final visual check that scanner and the targets are on right positions.
- Start the scanning process and remove away from the scanner to ensure that you don't cause shadows in the scanning data.
- After the scanner finishes scanning check that data is valid and stored at SD card.
- If any problems occur during scan or found later redo the scan.

Move to the next scanning position

- Repeat the steps from Step 1.

- Set up next five targets in direction of next scan position. Targets from Step 2 will become backside targets and newly setup targets will be foresight targets.
- Repeat the steps from Step 3.

Proceed with scanning with rest of subject area

- Follow steps outlined above until the subject site is completely surveyed.

Download the data

- After scanning process is over download the data from SD card on external hard drive, making the multiple copies to prevent unintentional data lost.

3.5.2 Data Processing

Before it can be used for 3D modelling raw data from the scanner needs to be processed using the appropriate software. Processing of the data includes pre-processing of the data where various filters are used to filter the data and prepares it for registration process. Registration process connects all the separate scans into one coordinate system. It is followed by post processing of the data where excess data and bad data can be removed, number of visible points decreased data exported in various formats for use in number of software. Although there are different software's available for processing the data, i.e. Cyclone, Autodesk Recap, for this project Faro Scene 3D will be used.

Faro Scene 3D is a laser scanner software specifically designed for the FARO Focus 3D. Faro Scene processes and manages scanned data by using automatic object recognition as well as scan registration and positioning. Scene 3D can also generate high-quality colorized scans and provides the tools for automated target-less scan positioning. After processing data needs to be exported and modelled in one of the available modelling software (Faro Technologies 2011).

Data management

Quality and resolution of the scans dictates the size of the data set, bigger the quality and resolution means larger point number which results in larger data sets. Bigger the data sets

bigger the computing requirements. For that reason desktop computer is preferred with multiple core processors, at least 16 GB of RAM memory and dedicated graphics card. Furthermore, thing to keep in mind is that after the processing and registration data set multiplies in size so adequate memory storage needs to be available. Also, advice is to keep multiple copies of the raw data to prevent data loss if something unpredictable happens.

Pre - processing

The first procedure after the data is transferred to office computer is to process all the scans. As it was stated above, scans will be processed in the FARO Scene 3D, software provided by FARO. Process starts with creation of the project in the Faro Scene, continues with importing and saving the scans and it is finished by filtering the data and point cloud creation.

Also, Faro Focus 3D has in built camera that takes panoramic photos of the scanned area and those pictures will be used to colour the point clouds which improves visual representation of the point cloud. When the process is done point cloud is created and user can now visualize and navigate through each scan.

Scanning will be done over two days, so data will be arranged in two clusters to make registration process less complicated.

Registration process

At this point each point cloud is sitting in its own coordinate system, so for this project, there are 15 separate coordinate systems that needs to be combined into one system. Inside Faro Scene 3D software there are two available options to register the point clouds: automatic and manual registration.

If automatic registration is chosen software will first from the planar view, from above, put the point clouds in the same orientation by searching for corresponding surfaces and then will use cloud to cloud option and align all the point clouds by searching the common vertical planes and points. This option will work fine if there are distinctive features that software can identify within the point clouds, i.e. edge of the buildings. On the other hand it will not perform as good in situation where there is lots of noise, i.e. people or moving cars, trees, etc.

For this reason it is better option to use artificial targets (spheres, checkerboards). Then they can be used in manual registration, where within each point cloud targets are modelled and software will recognize corresponding targets and will use them to align the point clouds. Other benefit of using the targets is that targets can be used as control, both horizontally and vertically, if they are surveyed with total station.

For this project, scanning of the subject area will be conducted over two days which means that both of the options stated above will be used. In each day spheres will be used in the scanning process and also registration will be based on targets. However, considering the fact that there will be no corresponding targets between day one and day two cloud to cloud registration method will be used to combine point cloud from two days into one cluster.

It is worth mentioning that at the end of registration process data amount enlarged substantially, from initial 8 GB of raw data, to almost 40 GB of registered data.

Post - processing

As mentioned in Chapter 2, every point cloud created based data collected by laser scanner contains substantial number of gross errors. Those errors are result of instrument imperfections, material properties of the object being scanned, environmental conditions and operator's level of experience. Point cloud needs to be cleaned from any bad measurement and redundant points to allow better visualization and modelling.

For that purpose point cloud, created during the registration process, will be exported using the .e57 file format and will be imported into Recap 360, software created by Autodesk specifically for point cloud data management. Also, Recap 360 will be used for conversion of point clouds to .rcp file format that is used by Autodesk Revit, software that will be used for modelling.

Autodesk Revit is software used by architects, engineers, designers, etc. for object modelling. It allows creation of 3D models of buildings, structures and components through 'Revit model elements'. Model elements represent the three dimensional geometry of the model and are divided into two categories: hosts and components. Hosts elements are: walls, floors, roofs, and ceilings while components are: stairs, windows, doors, furniture, etc. Also, each of these elements is organized according to hierarchy of Categories, Families, Types and Instances. Example of element hierarchy is shown in Figure 3.6.

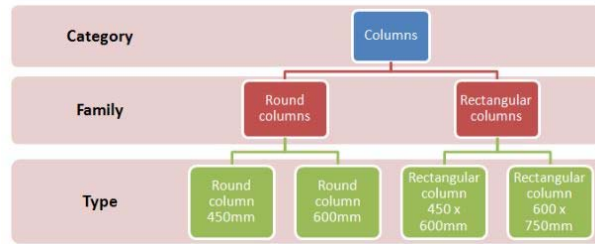


Figure 3.6: Revit element hierarchy (Autodesk 2016a)

Category is a group of elements used to create the model. Families are classes of elements in a category. A family groups elements with a common set of parameters (properties), identical use, and similar graphical representation. Families are organized in the Revit library and there are three kinds of families: System families – predefines set of properties and the graphical representation; Loadable families – properties and graphical representation are determined separately from the project and can be loaded into project and In-place families – properties and graphical representation are built within the project. Each family can have several types. A type can be specific size or a style (Autodesk 2016b). Number of families in Revit’s library is limited so users can build their own families or download them from online resources like RevitCity. Also, Revit has rendering engine that allows creation of realistic image of modelled object. This is accomplished by applying specific material to certain component, by applying colour, intensity, brightness, transparency and range of other options.

Although there are various programs for point cloud management and 3D modelling, Autodesk products will be used for completion of this project. Programs stated above are available for download through Autodesk online services and can be freely used through student licenses.

3.6 Conclusion

This chapter covered methods and described processes that will be undertaken to fulfil goals and the objectives of this project. Subject area was identified and assessed and general information is given about equipment that will be used. Furthermore, data capture process was described as well as processing of the collected data. Finally, working principles of the Revit modelling software were discussed.

Chapter 4

Results and Discussion

4.1 Introduction

In the previous chapter description was given about preliminary details of the project and survey process was described. Also basic information about processing of raw scan data was provided.

In this chapter more comprehensive description of the data processing and data modelling will be explained.

4.2 Registration

As stated in previous chapter, Faro Scene 3D was used for pre-processing and registration of the raw scans. After the scans were imported one workplace was created and that workplace was divided into two clusters based on two days of scanning. In the latest version Faro Scene 6.0 pre-processing is highly automated process where the points are filtered according to the default setup and colour is applied to scans based on photos that scanner takes at the end of each scan. This process took almost two hours to finish due to size of the individual point clouds.

Due to fact that artificial targets were used in scanning process in both days manual registration by target recognition was used. Connection between the scans is established by identifying common targets in corresponding scans (Figure 4.1). In first day seven out of eight scans had five common targets between scans, only in one scan one of the targets was not visible due to people movement. The second day had no issues with the targets so all five targets were visible between the scans. These high number of targets meant that result of the registration within the days were very good.

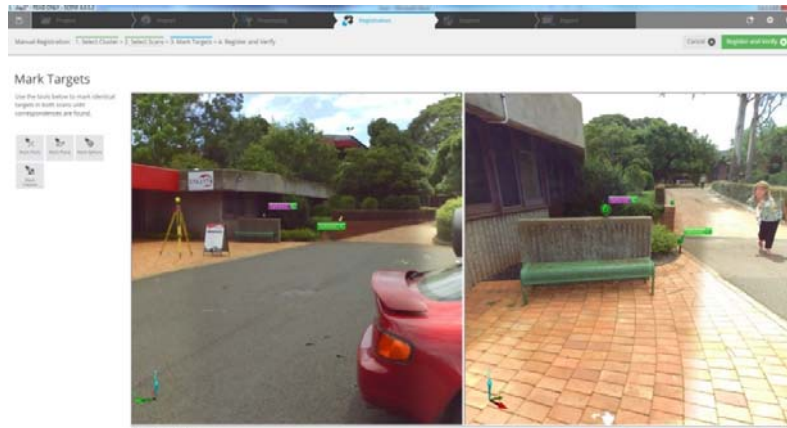


Figure 4.1: Common targets in corresponding scans

Next step was to connect those two clusters into one unified point cloud. Because there were no targets that could be used to connect those two clusters cloud-to-cloud method was utilized. It is automated process where operator doesn't have any influence on the results. Cloud-to-cloud registration took around 15 minutes to finish and together with manual registration process took around two hours. After the process was done one unified point cloud was created that consisted of fifteen separate scans (Figure 4.2).

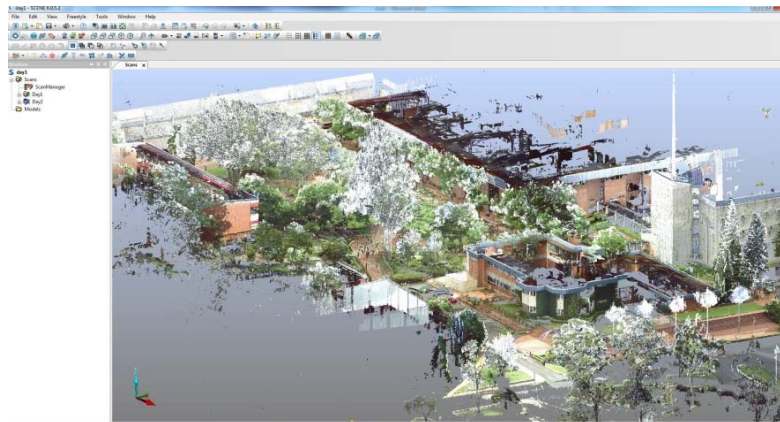


Figure 4.2: Fully registered point cloud

As a test to compare the results of two registration modes, automated registration was performed where Faro Scene automatically detects sphere targets, common surfaces, vertical planes, edges, etc. and aligns the scans accordingly. Although process took only about half an hour to finish results were bad. Software created three separate clusters and it couldn't align them together. Reasons for such bad results were lack of common vertical planes and surfaces, and in high level of noise caused by high amount of trees in area. That was just

another confirmation that when performing scanning, safer and more accurate option is to use artificial targets for registration purposes then to rely solely on automated registration..

4.3 Point cloud processing

After the registration process and prior to modelling, point cloud needs to be processed. For the processing part Autodesk Recap 360 was used. Recap 360 allows import of point clouds in various file formats. Project was exported from Scene in .e57 format which is file format used for storing point clouds, images and metadata produced by 3D imaging systems, such as laser scanners (Imaging System File Format Committee 2010).

Recap 360 workflow is shown in Figure 4.3.

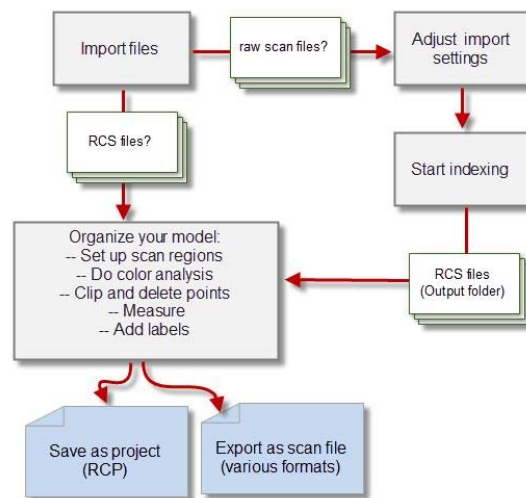


Figure 4.3: Autodesk Recap 360 workflow (Autodesk 2016c)

Initial step is to import the scan data into the software. However, that scan data can't be used until the scans are indexed. Indexing is the process where Recap 360 converts files into the format that can be read by Autodesk programs; Reality Capture Scan format (.rcs). After the scans were indexed clean-up process started. Work limits were set by fencing and all data that fell outside that area was deleted. Next, all noise (bad data) from the point cloud was removed. Majority of the noise was result of the scanner catching reflections through the windows and doors. Smaller amount of noise came from distant scattered points that scanner picked up and those points were deleted as well, because that data due to its nature is

unusable. Recap 360 has inbuilt algorithms for automated point cloud cleaning but that process is not highly accurate and it can happen that software delete the points that shouldn't be deleted, and for that reason all of the work was done manually. It is time consuming task, but doing it manually operator has control over the whole process and more accurate results are achieved.

Fully processed point cloud can be used as a measurement tool, visualization tool or can be brought in CAD environment and used for surface and object reconstruction. Measurements between point scan can be done directly in Faro Scene or Autodesk Recap. Other option is to use services like Real View by Autodesk Recap, or True View by Leica Cyclone or Scene WebShare by Faro. All three of them are online services that are using photos taken by Faro scanner to create panoramic range images. Those images are both visually compelling as well as measurable, and are excellent communication tools for conveying real-world conditions of a scanned environment without having a physical presence (Autodesk 2016d). For this project Real View by Autodesk Recap was used to create panoramic range images (Figure 4.4) For each of 15 scanning positions panoramic views are created allowing user to view and navigate through each scan position as well as measure and annotate scans.



Figure 4.4: Autodesk Recap 360 Real View

By applying colour stylization feature within the point cloud can be analysed. Autodesk Recap allows five types of stylization:

- Scan colour where colour is based on original scan colour (Figure 4.5).



Figure 4.5: Point cloud with original scan colour

- Elevation where colour is based on point Z value (Figure 4.6).

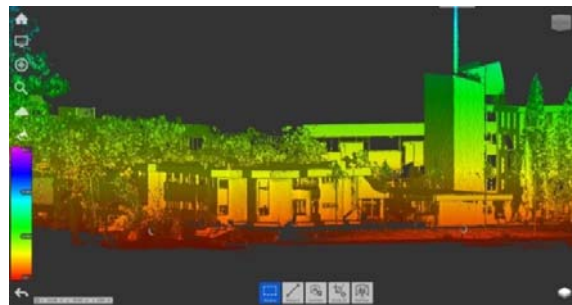


Figure 4.6: Point cloud colour based on elevation

- Intensity where colour is based on intensity value of returning laser pulse wave (Figure 4.7).



Figure 4.7: point cloud colour based on intensity

- Normal – colour is based on normal direction vector of the point (Figure 4.8).

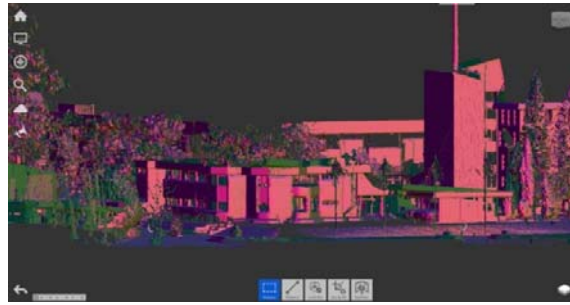


Figure 4.8: Point cloud colour based on normal direction vector

- Scan location – colour is based on scanning position from where point was captured (Figure 4.9).



Figure 4.9: Point cloud colour based on scanning position

In addition to colour stylization there are settings for lighting and shading that can improve visual experience.

Furthermore, point cloud can be used for creation of virtual fly-throughs. These fly-throughs can be used to give better experience and for better understanding of the subject site or can it can be used in promotional purposes. Virtual fly-through of the subject site was created using the Video application within Faro Scene. Application uses the scanning positions to define camera trajectories and offers range of settings for customization (Figure 4.10).



Figure 4.10: Fly path created in Faro Scene

Speed of processing was highly affected by the fact that scanning was done at high resolution and at high quality. Even though computer used for data processing was equipped with Intel i7 multi core processor with 16 GB of RAM, because of the amount of data, everything run slowly with constant high CPU and memory usage. To improve usability point cloud was sectioned by creating multiple regions inside the subject area. Regions have the similar role like layers in AutoCad where the layer can be turn on and off based on need. That meant that everything except the region that was processed was turned off, which improved the computing power by lowering memory and CPU usage.

Final step was saving the project as .rcp file. It is a project file that contains multiple .rcs scan files and can be imported into Autodesk Revit software that will be used for 3D modelling.

4.4 3D modelling

For the purpose of 3D modelling Autodesk Revit 2017 was downloaded from Autodesk online services and student license was acquired. First step was to create and save the project and then previously prepared point cloud in .rcp format was imported (Figure 4.11). For this project only the external scanning was conducted, and based on that information element will be modelled.

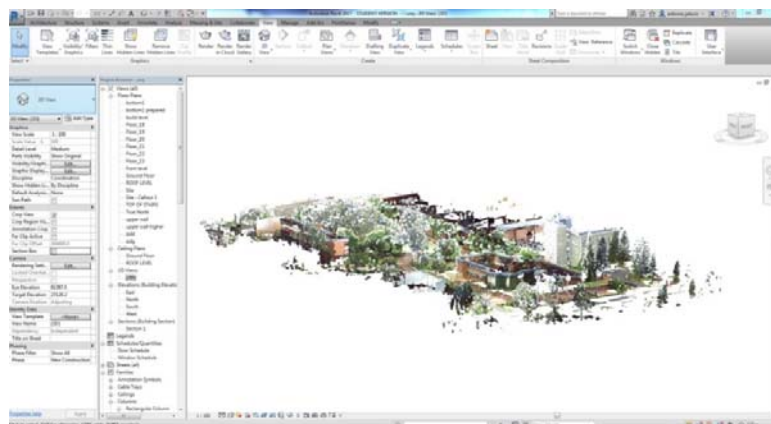


Figure 4.11: Autodesk Revit interface with imported point cloud

Next step was to set the elevation of the building with respect to floor heights. By creating elevations views or floor plans are created and all elements placed while modelling will be set

according to those elevations. Also, section views were created that will be used while modelling (Figure 4.12).

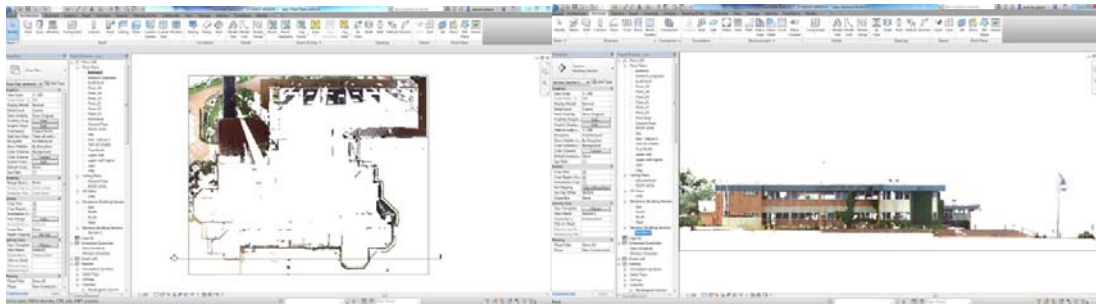


Figure 4.12: Created elevation and section view

For the illustration of the modelling process administration building of the USQ Toowoomba Campus will be used. First model element that was created was wall. Before the actual wall construction family and type of the wall from Revit's library was chosen (Figure 4.13). Selected wall is from basic wall family and type of the wall is brick with 110 mm width. Although selected wall was from system family with predetermined parameters, Revit gives the option of changing parameters to suit individual needs. Also, top and bottom constrain for the wall is set.

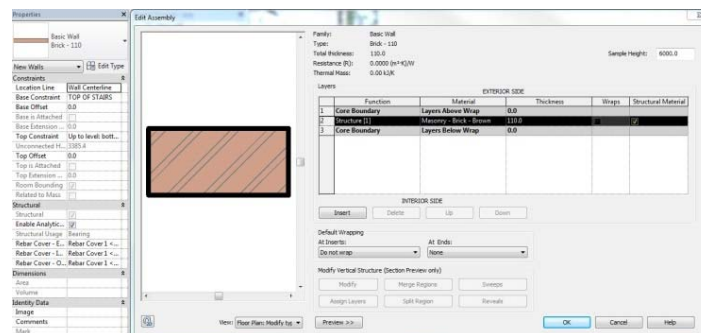


Figure 4.13: Wall properties

For this project there were no 2D plans of the building available so all the modelling was solely based on the point cloud. Before actual drawing of the wall top and base constraints for the wall were set. Constraints are based on elevations set earlier. There are number of available options for drawing a wall: line, pick a line, rectangle, polygon, etc. Draw wall by line option was chosen and wall was created by tracing the floor plan (Figure 4.14).

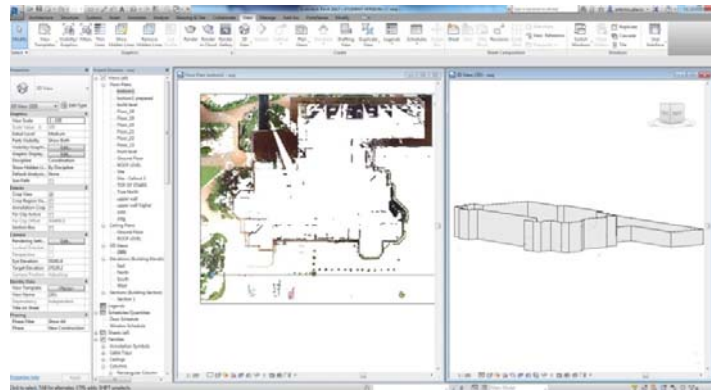


Figure 4.14: Elevation view and constructed walls

Next structural elements created were floor and roof. Similar with walls, there are different types of floors and roofs to choose from Revit family. For floor, generic type of floor was chosen with 150mm thickness. And for roof basic generic flat roof was selected and thickness determined on point cloud. Floor and roof can be drawn using: line, rectangle, arc, etc. or can be drawn by picking the created wall and applying offsets.

Creation of the walls, floors and ceilings was straightforward due to fact that Revit library contained types that were suited for this building. It was not the same situation for creation of the windows and doors because library didn't contain types that would suit. New object types can be created in Revit but that is time consuming task and requires experience operator. Other solution is to use online service like RevitCity that enables sharing and downloading Revit families. By doing the search windows and doors that match were found, downloaded and placed into the model (Figure 4.15).

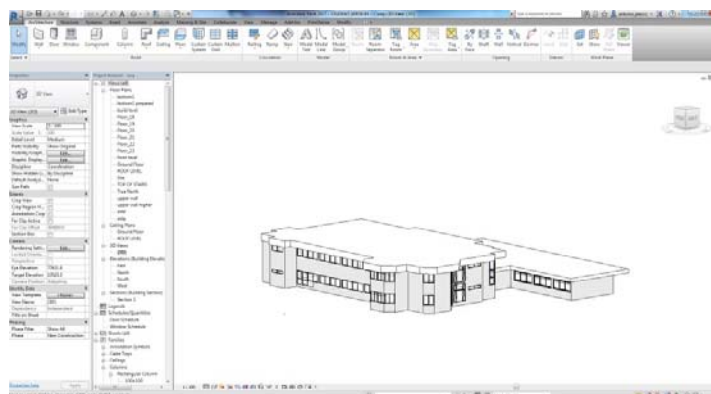


Figure 4.15: Model with created roofs, windows and doors

Revit has ability to create rendering of modelled objects. Rendering is based on material, colour of material as well as other selected options: glossiness, reflectivity, transparency, etc. Rendering can be done inside the Revit or render in cloud. Rendering in cloud is Autodesk online service that allows creation of render images online. Result is the same in both methods (Figure 4.16), but advantage of the render in cloud option is that it takes less time to create render images because it uses server computers to do so while desktop computer will struggle with that task.



Figure 4 16: Rendered model

4.5. Conclusion

This chapter discussed how the raw scanning data was processed to create the unified point cloud by using Faro Scene and Autodesk Recap programs. Finalized point cloud was presented as well as possible applications and outputs. Furthermore, administration building of the USQ Toowoomba Campus was used to present modelling in Autodesk Revit.

Chapter 5

Conclusion

5.1 Introduction

In this chapter conclusion and recommendations will be given based on findings and experience gained during the work on this project.

5.2 Conclusion

The aim of this project was to ascertain how terrestrial laser scanner technology (TLS) can be used for creation of 3D models of built environment, what processes are involved and what the end results are. Through literature review and practical work following conclusions regarding TLS and 3D modelling are made.

TLS technology allows rapid and effective 3D data, but experience and good understanding of the processes involved in data collection is needed for high quality and accuracy to be achieved. Quality and precision of the data can be predictable and easily manageable if technology limitations are addressed during the planning phase. Beside the equipment limitation, downside of the technology is that extensive post processing with complex control points based registration is required to get usable data. Result is unified point cloud consisted of millions of points that represents position of the object in three dimensions as well as object's structure.

Reconstruction of the object surface or 3D modelling is time consuming and highly complex task and quality of the created model depends on quality and resolution of collected data as well as on achieved accuracy and precision. Programs for 3D modelling are powerful and offer range of options for creation of structural elements, but are also complex and, for beginners, working in them can be overwhelming experience and quality of end result will depend on operator skill level. The overall quality of the collected data and operator skills are

especially important where there are no two dimensional drawings and the reconstruction is based solely on point cloud. Finished 3D model is base for creation of complete digital documentation about built environment that can be utilized in various applications.

5.3 Further work and recommendations

Further work to be carried is to use TLS technology to scan whole area of USQ Toowoomba Campus. That would include: exterior and interior scanning of all buildings as well as all outdoor facilities inside the Campus, creation of unique point cloud and 3D modelling of built environment. Because of the fact that USQ Toowoomba Campus is substantial in size mobile laser scanning can be considered as one of the options for data collection. For the exterior scanning scanner could be mounted on a mobile platform like a car or bicycle, and for interior scans person can carry scanner on its back.

In absence of mobile scanner, static scanning with Faro Focus scanner can be continued but with slightly different approach. Recommendation would be to lower the quality and resolution of the scans but to increase number of scanning positions. By lowering quality and resolution time needed for individual scan is significantly reduced and by increasing number of scanning positions coverage is maximized. Benefits of that approach are time efficiency and expanded point coverage. Overall data quality would not be compromised because the lower resolution and quality would be compensated by more overlapping data generated in increased number of scanning positions.

Before any further object reconstruction recommendation would be to search for 2D drawings showing the floor plan and building layout of the building being modelled. Those drawings can be of great help where there is no adequate scan data, i.e. position of the wall cannot be accurately determined due to fact that there is overgrown vegetation on the walls. Also, other software packages for registration and data processing as well for 3D modelling could be looked to see if they offer easier and simpler workflow.

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Appendix A

Project Specification

University of Southern Queensland
Faculty of Health, Engineering and Science
The School of Civil Engineering and Surveying

ENG4111/4112 Research Project

Project Specification

For: Antonio Jelacic
Title: Terrestrial Laser Scanner for 3D Modelling of USQ Toowoomba Campus
Major: Surveying
Supervisor: Dr. Xiaoye Liu
Enrolment: ENG4111 – ONC S1, 2016
ENG4112 – ONC S2, 2016
Project Aim: To investigate how the collected data of the built environment (buildings, trees, etc.) can be modelled into 3D model, to create photorealistic model of the buildings by combining data from different sources, and to create 3D model that can be used in web based applications (e.g. Google earth)

Programme: Issue A, 6th March 2016

1. Research the background information about terrestrial laser scanner technology, data collections methods, and information about processing and modelling data into 3D model.
2. Design the procedure for field measurement which includes:
 - a. Determining scan locations and required number of scans.
 - b. Designing a layout for reference marks.
 - c. Conducting the scans.
 - d. Determining the coordinates of the scan stations using GNSS.
3. Process the acquired data which includes:
 - a. Combining multiple scans into one coordinate system.

- b. Removing bad or unnecessary scans.
 - c. Creating surfaces from point cloud.
 - d. Further cleaning of the data and animation.
4. Evaluate the amount of details that can be acquired by using this technology.
5. Creation of the model that can be incorporated in Google Earth.

As time permits:

1. Expand the scanned area to inside of the buildings.
2. Create complete 3D model of the buildings by combining outer and inner building scans.

Appendix B

Risk Assessment

Every project carries the potential risks, whether risks of injury, equipment damage, or negative impact on environment. To minimize the risks of this events occurring pre-start risk assessment is needed. If risk is identified in this phase measures can be applied that will control the processes and it will ensure that health and safety requirements are met.

Project site is situated in pedestrian only zone so there is no immediate risk of traffic. However, it is highly populated pedestrian zone so there is a potential high risk of equipment being damaged. Also there are some potential risks involving working with laser scanner. LASER stands for Light Amplification by Stimulated Emission of Radiation, and its coherency, monochromatic and ability for extreme powers means that people dealing and working with laser should have good understanding of the potential risks. The International Electrotechnical Commission (IEC) sets out standards for safety of laser products and classifies the laser based on potential risks. For this project Faro Focus 3D will be used and its laser is classified as 3R class under the IEC, what means that the laser can be potentially hazardous for eyes if direct viewing in beam is involved. To minimize the risks while working with class 3R lasers in surveying IEC sets out following procedures: Only qualified person should use the equipment, appropriate warning sign should be posted in working area, preventing the direct intra-beam viewing and preventing the laser beam to be directed at mirror like surfaces. Laser scanner itself weighs around 5 kilograms, and although the weight shouldn't present potential risk for the operator, precaution should be taken when handling the scanner. Furthermore, when working outside care needs to be regarding the protection from the sun.

Major portion of completing this project will involve desk work, so to minimize the risk of strain injuries ergonomics and correct computer setup are essential and regular breaks from sitting are advisable.

There are also some potential risks that can affect the completion of the project. So in planning phase of the project availability of the equipment needs to be discussed with personnel in charge as well as working order of the equipment needs to be insured. Next risk involves data collection and data management. To minimize that proper site planning needed as well as proper execution. To prevent the risk of potential data loss, due to computer failure, multiple copies should be stored.

Risk can be calculated as product off probability (how likely is to happen) and consequences (how severely it hurts somebody-if it happens). After the likelihood and consequences has been determined risk factor can be established. If the risk factor is moderate or higher appropriate control measures needs to be applied to lower the risk factor to low.

Figure 6.1 shows example of risk assessment matrix.

Probability			CONSEQUENCES				
			How severely it hurts someone (if it happens)?				
How likely is it to happen?			Insignificant (No injuries)	Minor (First aid treatment only)	Major (Medical treatment)	Severe (Extensive injuries)	Catastrophic (Death)
			1	2	3	4	5
Almost Certain	Expected in most circumstances	5	5	10	15	20	25
Probable	Will probably occur in most circumstances	4	4	8	12	16	20
Moderate	Might occur at some time	3	3	6	9	12	15
Unlikely	Could occur at some time	2	2	4	6	8	10
Rare	May occur, only in exceptional circumstances	1	1	2	3	4	5
7-9: Moderate - Follow management instructions			13-25: Acute - Danger - ACT NOW - Urgent - Requires immediate attention from Management				
1-6: Low - OK - record and review if any changes			10-12: High - Management to be Consulted				

Figure 6.1 Risk Assessment Matrix (NorthGroup Consulting 2011)

Appendix C

Faro Focus 3D Datasheet

DATASHEET



GENERAL SPECIFICATIONS

PERFORMANCE SPECIFICATIONS

Ranging Unit

Unambiguity Interval > 130 m
 Range Focus^{1D} X 130 0.6 m - 130 m indoor or outdoor with upright
 Incidence to a 90% reflective surface
 Measurement speed (pts/sec) 122,000 / 244,000 / 488,000 / 976,000
 Ranging error¹ ±2mm

Ranging noise ²	@10m	@10m - noise compressed ³	@25m	@25m - noise compressed ³
⊙ 90% reflectivity	0.3 mm	0.15 mm	0.3 mm	0.15 mm
⊙ 10% reflectivity	0.4 mm	0.20 mm	0.5 mm	0.25 mm

Color Unit

Resolution Up to 70-megapixel color
 Dynamic colour feature Automatic adaption for brightness
 Parallax Co-axial design

Deflection Unit

Field of view (vertical/horizontal) 300°/360°
 Step size (vertical/horizontal) 0.009° (40,960 3D-ptxel on 360°)
 /0.009° (40,960 3D-ptxel on 360°)
 Max. vertical scan speed 5,820 rpm or 97 Hz

Laser (Optical Transmitter)

Laser Class Laser Class 1
 Wavelength 1550 nm
 Beam divergence Typical 0.19 mrad (0.011°, 1/e, halfangle)
 Beam diameter at exit Typical 2.25 mm (1/e)

Data Handling and Control

Data storage SD, SDHCTM, SDXCTM; 32 GB card Included
 Scanner control Touch-screen display and WLAN
 New WLAN access Remote control, and scan visualization
 are possible on mobile devices with Flash[®]

Multi-Sensor

Dual axis compensator Accuracy: 0.015°, Range: ± 5°
 Height sensor Via an electronic barometer, the height relative
 to a fixed point can be detected and added to a scan
 Compass⁴ The electronic compass gives the scan
 geographic orientation. A calibration feature is Included
 GPS Integrated GPS receiver

HARDWARE SPECIFICATIONS

Power Supply Voltage 19 V (external supply) 14.4 V (Internal battery)
 Power Consumption 40 W and 80 W (while battery charges)
 Battery Life 4.5 hours
 Ambient Temperature 5° - 40° C
 Humidity Non-condensing
 Cable Connector Located in scanner mount
 Weight 5.2 kg
 Size 240 x 200 x 100 mm
 Maintenance/Calibration Annual

1 Ranging error is defined as a systematic measurement error at around 10 m and 25 m, one sigma.
 2 Ranging noise is defined as a standard deviation of values about the best-fit plane for measurement speed of 122,000 points/sec.
 3 A noise-compression algorithm may be activated, thereby compressing raw data noise by a factor of 2 or 4.
 4 Ferromagnetic objects can disturb the earth's magnetic field and lead to inaccurate measurements.

Specifications subject to change without notice.

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