University of Southern Queensland

Faculty of Health, Engineering and Sciences

# Comparison between robotic total station reflector-less measurement and terrestrial laser scanning for building modelling.

A Dissertation submitted by

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# Abstract

This project intends to test the accuracy of both a terrestrial three-dimensional laser scanner and a total station with reflector-less measurement for accurately positioning and creating 3D building models. The instruments that were used for this project are a FARO Focus 3D S series 120 terrestrial laser scanner and a Trimble S7 total station.

Laser scanning technology has the ability to increase the efficiency of the way surveyors complete conventional survey task. The total station, until recent years has been used for capturing the positions of buildings. The field testing for this project was completed on a two-story rectangular building at Concannon college in Toowoomba. A control network was established and measurements from both instruments captured from the same positions to control the variables. The project compares the differences between the points captured on the walls, eaves and gutters by both methods of measurement.

The results from the data capture were processed using terramodel and Autodesk for the total station data and FARO Scene for the laser scanning data. Using the data, two 3D models were produced. The 3D model that was developed from the reflector-less measurements was a simple wireframe model created by connecting all the captured points. It showed the external wall brick face, gutter and eave positions. The model created in FARO Scene was made up of 525 million points and produced a detailed model of the building and all its surrounding features. It was found that there was an average difference between the two models in easting of 9.8mm, northing of 10.4mm and elevation of 10.7mm. The distance difference between the two models was calculated to be 17.9mm.

It was recommended that the laser scanner be used for completing projects where three-dimensional modelling of buildings is required. This was recommended because of the substantial point cloud that can be acquired efficiently compared to the total station's reflector-less measurement. It was also noted that the accuracy of the laser scanner was less of that of the total station. For projects with high accuracy requirements, the total station data should be incorporated into the 3D model.

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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.

Matthew Kevin Copley

[redacted]

[redacted] Signed

17/10/2019 Date

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# Chapter 1 Introduction

## 1.1 Background

The surveying industry has been around for over a thousand years and over this time the role of the surveyor has evolved enormously. The evolution of the industry has always been driven by the need for higher accuracy and higher quality measurement. The equipment and techniques that the surveyor uses have also changed over time as well. The accuracy and reliability of this technology is continuously in the spotlight as the question is asked whether the drive for this technology had shifted to faster productivity of quality. In more recent years the productivity and time efficient technology advancements have been leading the way in new measurement processes within the survey industry.

The need for accurately positioning the exterior of buildings and structures is required for all different types of construction work. These range from positioning a house on a parcel of land for additional construction or checking boundary issues, to checking the position of buildings post construction and completing detailed surveys to create 3D models. This task has traditionally been undertaken by conventional survey methods, such as total station measurement using prism on a pole and offsetting the measurement.

## 1.2 Project Idea

The idea for this project was formed through several experiences in the workplace were the question was being asked, how could this be done to the same accuracy in a more efficient way. One was a project being completed for Queensland transport and main roads, where the road surface was to be captured with a laser scanner. This was an interesting concept and so it was questioned to what other projects the scanner could be applied to. When completing a detailed survey of a newly constructed industrial storage shed complex, the exterior building format was required to be captured using a total station. This was completed using the reflector-less measurement technique within the total station. This was not without hassle as the instrument was struggling to capture a distance measurement to certain corners of the building due to the angle and material of the surface. This is where the idea came from to compare the accuracy of the reflector-less measurements from the total station to the model that could be captured from a laser scanner. The idea of the project was to also determine the efficiency of the laser scanner versus the reflector-less measurement.

## 1.3 Project Justification

The project intends to research, test and identify the different accuracy's of both the total station reflector-less measurement and terrestrial laser scanning data to create a best practice solution. The results of this project will allow the surveyor to make an informed decision when deciding on which instrument to use for a given projects' accuracy requirement. There has not been a study to directly compare these two systems for the same project and so it is important to provide a complete study to inform the surveyor.

## 1.4 Project Aims and Objectives

The aim of this project is to design a methodology to accurately test both a total station and laser scanner for measurement of an exterior building to create a building model. The project aims to compare the results for both instruments being tested and be able to provide to surveyors recommendations regarding the time for completing projects with either instrument. There are three main objectives for this project;

- Firstly, create a building model using the data collected from both the terrestrial laser scanner and total station.
- Secondly, compare and analyse the two models created to determine the accuracy of each instrument.
- Thirdly, provide recommendations in regard to best survey practice.

# Chapter 2 Literature Review

## 2.1 History of Surveying Equipment

The first surveyors have been measuring angles and distances since the construction of the great pyramids in ancient Egypt. The Egyptians first used a set length of rope marked by knots to measure a distance and this is seen to be true from the consistent size of the rock used to build the pyramids. The first tool that the Egyptians used to measure angles was the groma. The groma was made of a wooden frame in the shape of a cross with a plumb line on each end. This tool was used to set out lines perpendicular to other lines. The Romans later used this tool as well as dioptra which was similar, but it had a marked plate at the centre that had set marked angles. It wasn't until the 1570's that the theodolite was introduced by a man named Leonard Digges (NOAA, n.d.). This was two shaped pieces of metal with a compass at the centre. The Theodolite evolved in the 1700's when the telescope was integrated.

### 2.1.1 Theodolite, Chains and Tapes

The theodolite was the first instrument that was able to measure both the horizontal and vertical angles. The theodolite in the 1800's had a round metal plate at the centre that was marked with angles. The theodolite also had a telescope that increased the accuracy of angle observations as reading to objects further away could be seen clearer (Encyclopaedia Britannica n.d).

A chain was one of the early measuring tools for a surveyor. The chain was invented by a man named Edmund Gunter and so it is also referred to as a Gunter's chain. The chain was introduced to surveyors in the late 1600's. The chain was an arbitrary measurement tool used primarily for surveying property boundaries. This unit of measurement is still seen on many cadastral boundaries plans today. A chain was made up of 100 links, where a link is equal to 20.1cm, and so 1 chain is equal to 20.1168m. A common chain measurement was 10 square chain which defined an acre (Encyclopaedia Britannica n.d).

Tapes were introduced to the surveyor around the 1870's when a man named Daniel M. Wheeler perfected the measurement tool for practical use (Encyclopaedia Britannica n.d). Tapes were generally made from steel and ranged in length, but the first tapes were 100ft long. Tapes however did need to be used with caution. Steel tape measurements were exposed to different types of error that required mathematical correction. These where expansion and contraction due to temperate, and sag in the tape which increased over distance.

### 2.1.2 Total Station

The total station is the leading piece of equipment for any surveying work and has been used by surveyors since it was developed in 1971. The total station was built from the same principles as the theodolite, that included a telescope and angle measurement. The total station was the first piece of equipment that was able to record and measure both angles and distances in the one instrument (Hoffman, A 2013). Figure 1 shows a modern total station that would be used in this project.

*Figure 1 Is a Trimble S7 Total Station (Trimble Inc., 2019)*

The total station can accurately measure horizontal and vertical angles between points and is built with an electric distance meter. Total stations are still evolving to this day with the most recent instruments having integrated laser scanning technology. The software that is being run within total stations allows for complete compatibility between office computers and field controllers. Many surveying tasks that used to require a 2 or 3-man survey party can now be completed by 1 surveyor with the total stations having robotic control.

### 2.1.3 EDM

EDM or Electric distance measurement is found in every modern-day total station. The first EDM instrument that was invented was called a geodimeter and is a geodetic distance meter. This instrument was first developed in the late 1940's in Sweden (Arjun, N n.d). This instrument worked using visible light, then the distance could be calculated using the time that the light took to travel to a target and be reflected back to the EDM. The second major development for the EDM took place in Africa in 1957 when the measurement style shifted to using modulated microwaves. Before the integration of EDM technology into the total station, the EDM was a large heavy instrument by itself. As the EDM was perfected and developed they did become smaller to the point at which they were able to be mounted on top of theodolites (Arjun, N n.d). EDM's in current theodolites calculate the slope distance from the station to the reflective target. The onboard computers within the total station will then use the angle information to display the horizontal and vertical distances to the target.

### 2.1.4 Terrestrial Laser Scanning

Terrestrial laser scanning is scanning that takes place on the ground of ground objects and at a higher accuracy than airborne laser scanning. A laser scanner is in instrument that captures and models three dimensional surfaces. A laser scanner measures and captures distances from the position of the scanner to the 3D surfaces in its un-obstructed field of view. To be able to measure and position an object a laser scanner will generally have to be used multiple times to capture all the surfaces from a few different positions. Laser scanners first started being used in the mid 1960's (Ebrahim, M 2014). This technology was very limited to smaller objects and the accuracy was not of a high quality. In the late 1980's laser scanners were using white light, lasers and shadowing to measure an object. Figure 2 shows a modern laser scanner that would be used in this project.


*Figure 2 Is a FARO Focus $^{3D}$ S Series Laser Scanner (FARO, 2018)*

Modern terrestrial laser scanners used for surveying are a tripod-mounted light radar that uses Light Detection and Ranging (LiDAR) to create 3D images and models of a surface. Modern laser scanners use a prism that reflects the lasers at different vertical angles from the scanner, at which point the laser beam bounces back off the object being scanned. Sensors within the laser scanner are then used to receive the reflected laser beam to measure a distance. Laser scanners will generally capture and measure 1 million points per second for the determined field of view (Ebrahim, M 2014). The points captured after laser scanning has been completed are known as a point cloud, which is used to create a model.

## 2.2 Reflector-less EDM

Reflector-less EDM is the focus of this report, so it is important to deeply understand the concepts behind how reflector-less measurement is possible. Reflector-less EDM measurement was integrated in total stations to be able to measure to a point or object that is unreasonable or impossible to set a reflective target up over. The word laser stands for Light Amplification by Stimulated Emission of Radiation (Key, H 2005).

In a total station for surveying, lasers are generally used for two things; visualising a line or point through a constant laser being emitted from the instrument, or range measurement which is the reflector-less EDM measurement. There are two principle types of laser measurement that are emitted from a total station. These are time of flight and phase shift distance measurements (Key, H 2005).

### 2.2.1 Time of Flight Distance Measurement

Time of flight measurement or pulse laser distance measurement, as it is otherwise known, is where the radiation beam is emitted from the total station to a point at which it is reflected on a parallel path to the instrument. This method uses the velocity of the radiation beam that is being emitted and the time it takes for the signal to return to the instrument. The beam that is emitted from the instrument is a short intense pulse of radiation. The equation to calculate the distance between the target and instrument is as follows;

$$D = c\Delta t/2$$

Where; D= the distance between the instrument and point light is being reflected off, c= velocity of the radiation beam, and t= is the time of flight from instrument to target and back to instrument (Key, H 2005). When using this method to calculate the distance theoretically only one pulse of radiation would be required to calculate the distance. However, this would produce poor quality results and so the instrument will generally send out up to 20,000 pulses per second, to give a more accurate distance.

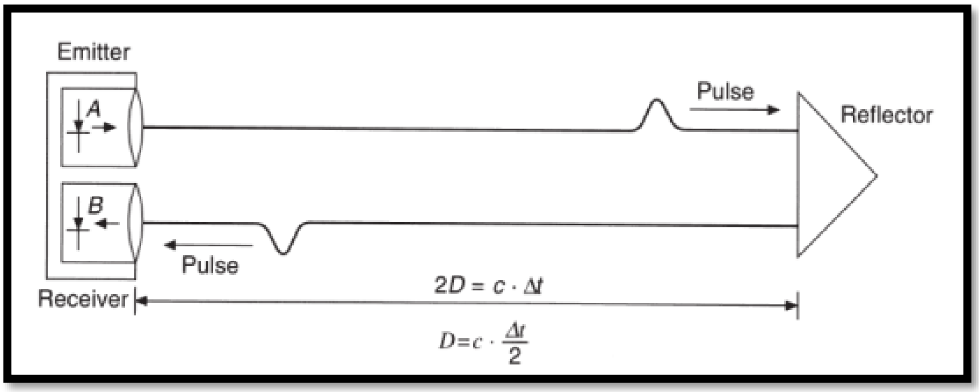



*Figure 3 Time of Flight Method (Reda, A, Bedada, B 2012)*

The time of flight method is used more often for reflector-less measurement because the power of the pulse is much stronger than that of the phase shift method. As the pulse beam is more powerful it means it's able to bounce back off man-made materials or natural features to have a return signal. This also means that the maximum distance this method can emit a signal to is larger than that of the phase shift method.

## 2.2.2 Phase Shift Distance Measurement

Phase shift is measured in full cycles and half cycles of a phase. A phase is measured in degrees and a full cycle is 360 degrees. Phase shift is determined by whether the received signal returns at the same angle as the emitted signal. If this is the case, then there has been no phase shift and the phase is locked. When the received signal returns and the phase angle is different to when it was emitted, then there has been a phase shift.

The phase shift distance measurement method is more suited to shorter distances and considered to be more accurate than the time of flight method. This is because it uses a narrow beam that's range is limited. When using the phase shift method, it is important to record distances multiple times so that the ambiguity can be solved (Key, H 2005).

The signal being received from the reflected point is converted to an electric signal by the EDM. This allows for the receiving and emitted phases to be compared. The distance for this method is calculated using the formula;

$$D = 1/2(n\lambda + d)$$

Where; D= the distance between the instrument and point light is being reflected off, n= the number of wavelengths in the double path, d= the phase difference and λ= wavelength (Key, H 2005). This is shown in the following figure;

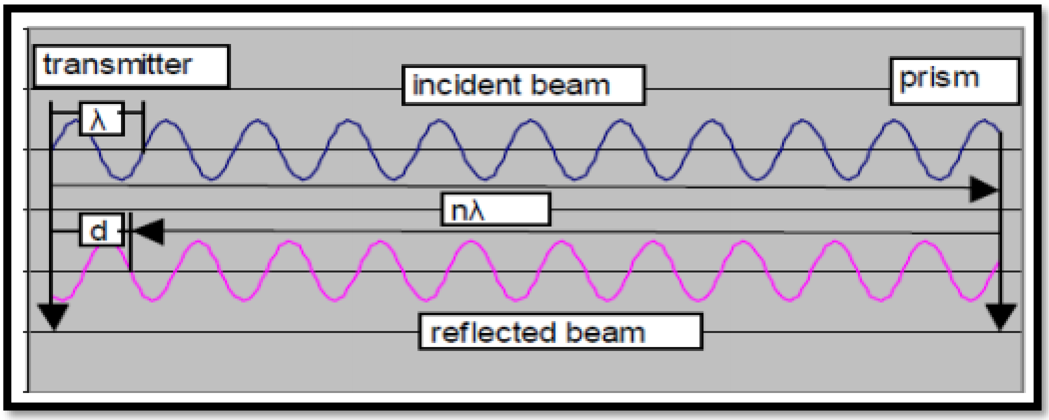



*Figure 4 Phase Shift Method (Reda, A, Bedada, B 2012)*

## 2.3 Properties of a Laser Scanner

The 3D laser scanners that are used for surveying use the Non-Contact active technique. This is where the scanner emits light, radiation of x-ray to be able to measure an object. There are three methods of using the non-contact active techniques; these are time of flight, phase shift and laser triangulation (Ebrahim, M 2014). As like reflector-less EDM discussed above a laser scanner uses the same principle methods for measuring an object, the difference is that a total station measures a single point and a laser scanner measures millions of points in its' field of view.

### 2.3.1 Time of Flight Distance Measurement

The time of flight method is the same for both the reflector-less EDM and the laser scanner. The laser range finder that's within the laser scanner is what is used to measure the distance to the object by emitting the laser beam. In the laser scanner the laser range finder can only measure to one point at a time. This means that when the laser scanning is scanning it is measuring one point at a time, the direction of the laser range finder is changed by using a constant rotating mirror to scan all the points in the view of the laser scanner. A laser scanner using the time of flight method can generally measure the distance of 100,000 points per second (Ebrahim, M 2014). The method can scan larger arounds due to it having a higher range as the laser is stronger. However, this method is limited due to distance being affected by noise. Noise is created by the time of flight being affected when it bounces off an object either increasing or decreasing the speed which in turn will produce an inaccurate distance.

### 2.3.2 Phase Shift Distance Measurement

The phase shift method is again the same for the laser scanner as it was for the reflector-less EDM as the phase is determined by whether the received signal returns at the same angle as the emitted signal. Distance measurement is refined when using the phase shift technique in a laser scanner. This is because the time of flight is not measured but calculated using the phase shift which is the difference between the emitted wavelength and received wavelength. Using the phase shift method, the range distance is a lot shorter than the time of flight as it is limited to approximately 80m (Ebrahim, M 2014).

## 2.4 Systematic and Random Errors

There are different types of errors that occur in the surveying industry that are seen mainly through the way in which data is collected. Measurements are the main source of data that a surveyor will collect. Any anomaly in a measurement must firstly be categorised into either an error or a mistake. A mistake is a type of error that cannot be predicted or fixed after it takes place. Mistakes are compensated for by using best practice for the work being completed. Error however is the difference between the true value of a measurement and the actual measured value. (Ref Chap2 Measurement PowerPoint Minnesota University)

Errors can then be broken down into systematic and random errors. A systematic error is an error that looks to be constant in both its' direction and magnitude. An example of a systematic error is an instrument error, e.g. (temperature, pressure, humidity), these errors are mitigated by calculation. Most total stations these days have on board computers that calculate the error adjustment for systematic errors automatically. Random errors are generally an error associated with the way the measurement was taken. A singular random measurement cannot be fixed. Random errors are usually calculated by averaging several measurements. (Ref Chap2 Measurement PowerPoint Minnesota University)

## 2.5 Previously Conducted Research

There have been multiple studies conducted on the accuracies of laser scanners and the accuracies of total station reflector-less measurement. A study that has not been completed is a comparison between the two instruments for the same project. Previous studies that have been conducted in the field of Total station reflector-less and terrestrial laser scanning measurements can assist in developing a methodology for this project.

### 2.5.1 Total Station Reflector-less Measurements

Studies have been done on the different properties of total station reflector-less measurement for different types of surveys. One study looked at the accuracy of the reflector-less measurement within the total station for structural surveillance, by testing and comparing the angle of incidence for both horizontal and vertical angles (Hosking, A 2009). Another study looked at the focus on the variety of materials that reflector-less measurement is affected by. This study tested the 12 different types of material, 6 different weather conditions, 10 different colours and different angles of target incidence (James, J 2016). Another study compared the affect that different materials and different types of shapes have on the reflector-less measurement, while again looking at how the reflector-less measurement is affected by the angle of incidence (Coaker, L 2009).

These studies used multiple total stations to compare any differences between makes and models. One study focused on the comparison between the Trimble S6 and Trimble S8 total stations (Coaker, L 2009). One study tested the total stations at 4 different distances with different angles of incidence (Hosking, A 2009).

The results and conclusions that were drawn from these studies are important to note for further comparison of this project. One study found that as the angle of incidence increased and distance away from the target increased, the error in distance the recorded proportionally up until axis rotation for 30°. This same study showed a spike of error in distance results between 30° and 50° for horizontal and vertical axis rotation. The study showed that the Topcon total station would not return a measurement in standard reflector-less measurement after a distance of 100m (Hosking, A 2009). Another study found that over a short distance, targets with angles of incidence up to 60° degrees can be measured for survey accuracy. Although for longer distances the weather condition will affect the measured distance. A cold target was found to produce constant quality results. The study also found that brighter coloured surfaces will have a better return signal to the instrument and provide a more accurate distance measurement (James, J 2016). Another study found similar results in regard to the way the reflector-less measurement is affected by the angle of incidence and material. The study found that the angle on incidence paired with a dark material greatly affects the measurement quality outside the manufacturers specification. These studies generally concluded by stating that controlling the quality of measurements is best done through strict and regulated procedure. The studies suggested that all measurements that require a strict accuracy be checked thoroughly (Coaker, L 2009).

These studies are important to note so that when forming a methodology for the project and conducting fieldwork for the project, steps can be taken to reduce error and ensure that best practice for distance measurement is used. When formulating the methodology, it will be important to note the surfaces of the material being measured, to relate any error. It is also important to note the angle of incidence for each measurement and a constant procedure for each measurement is adhered to.

### 2.5.2 Terrestrial Laser Scanning Measurements

Terrestrial laser scanners have been used to look at the benefits of creating a three-dimensional model of a section of the USQ campus in Toowoomba. The study looked at the possible accuracy's for creating a model using a laser scanning data for web-based applications, such as google earth (Jelacic, A 2016). Terrestrial laser scanners have also been used to test the work flow benefits and safety for a surveyor within an open cut mine site. This study discussed the cost effectiveness of a laser scanner compared to conventional survey methods (Wall, A 2009).

The studies involved an in-depth look at the potential errors in measurement when using the laser scanner for different scenarios (Jelacic, A 2016). The studies also compared 3 different laser scanners for the types of data that can capture and the types of mining surveys they are able to undertake (Wall, A 2009). These studies found that the laser scanner is an effective tool that can be used to measure and model building information of a certain area (Jelacic, A 2016). The studies also found that the scanner is capable of undertaking mining surveys to a competent accuracy, and be a time effective instrument (Wall, A 2009).

The results and conclusions from these studies found that the process for scanning a large area can be refined with good planning and that a good knowledge of expected quality and accuracy allows for limitations to be controlled.

Techniques and methods used in these studies are keys pieces of information that will be used to formulate the methodology for the project. The data collection method is very similar for the project being completed and so a combination of methods will be used. It's also important to note from these studies the outcomes; the efficiency of the laser scanner in these studies compared to traditional surveying methods. Comparison between the outcomes of these studies and the project will be an important component of the analysis.

### 2.5.3 Previous Study Case #1:

Combined 3D building surveying techniques – terrestrial laser scanning (TLS) and total station surveying for BIM data management purposes by Mill, T, Alt, A & Liias, R.

In this study a building at the University of Applied Sciences in the city of Estonia required an updated source of informative spatial data. The building was built in the 1950's and had had many renovations during its life time and included many intricate features. This case used Building Information Tools to be able to model the buildings' current structure.

In this case the following procedure was carried out to model both the interior and exterior of the building. Firstly, a survey traverse was established inside and around the building, followed by planning and execution of the exterior laser scanning of the building, planning and execution of the total station work for the interior of the building and then data processing and combing the two different models.

The problems that were found in this case were the interior measurements of the building's rooms using the total station as some corners of the room were in accessible. An electronic distance meter was needed, and that information had to be added to the model later. Another problem was during the processing phase of the project where the two different sets of point cloud data had to be combined. The point cloud software did not support survey coordinate systems.

This case in comparison to my project uses both the terrestrial laser scanner and the total stations reflector less measurement capability but does not compare the same set of data for both instruments. In my project I aim to merge the point cloud data that is captured with laser scanner to a survey coordinate system by completing scans from known points with known points as reference objects. The project which I will be undertaking will not use the two sets of data in combination to create the one model but use the data from each instrument to create their own model for comparison.

### 2.5.4 Previous Study Case #2:

3D Laser Scanner and Reflector less Total Station: A Comparative Study of the Slots of El-Khazneh at Petra in Jordan by Naif Haddad and Fawwas Ishakat.

In this case study the El-Khazneh meaning 'the treasury' at Petra in Jordan, was chosen as the subject building for comparison between a 3D laser scanner and a total station with reflector less measurement capabilities. The El-Khazneh is a monument carved of stone which is to be spatially modelled. The aim of this project was to model the slots that are on either side of the El-Khazneh which have no documented measurements or reasoning for their existence.

Laser scanning of the monument was undertaken from 3 different positions and scanned either in the morning or before sunset as this is when there was the least amount of shade. The laser scanner performs better when it is unaffected by heavy shadows. The total stations measurements for this projected however were completed in the afternoon when the monument was in full shade as the laser from the total station was easier to follow. The scanning for this project took approximately 2 hours in total compared to the total station that needed a full day's work to capture 500 points.

This study found that it had difficulties using reference objects when completing the 3D scanning as they were unable to attach anything to the monument. The results of this study conclude that the laser scanner was able to measure the points to the same needed accuracy as the total station. The study found the difference between the points of the two sets of data to be 2mm to 20mm in difference.

This study shows some similarities to the project which I will be undertaking as it directly compares the 3D laser scanner to the total station reflector-less measurements for the same model. However, this study did not aim to create a model using the total station data, rather just a set of dimensions for the slots. This study only concentrated on a specific section of the monument, as the project I aim to conduct will look at the model and features of an entire building.

## 2.6 Instrument Specifications

The instruments that will be used in the research project are a Faro Focus 3D laser scanner and a Trimble S7 total station.

### 2.6.1 Faro Focus S Series 150


*Figure 5 Faro Focus $^{3D}$ S Series 120 (FARO, 2018)*

The specifications for the Faro scanner are as follow;

| | |
|---|---|
| Range at 90% Reflectivity | 0.6m – 120m |
| Range at 2% Reflectivity | 0.6m – 20m |
| Ranging Error | ±2mm at 10m and 25m |
| Angular Accuracy | 19 arcseconds for both horizontal and vertical |
| Measurement Speed | 122,000 / 244,000 / 488,000 / 976,000 (pts/sec) |
| Colour Resolution | 70-megapixel colour |
| Laser Class | Class 1 |
| Field of View | 300° Vertical and 360° Horizontal |
| Wavelength | 905nm |
| Weight | 5kg |
| Battery Life | Up to 5 Hours |
| Max Scan Speed | 97Hz |

*Table 1 Faro Focus $^{3D}$ S Series 120 Specifications (FARO, 2018)*

## 2.6.1 Trimble S6 Total Station

*Figure 6 Is a Trimble S7 Total Station (Trimble Inc., 2019)*

The specifications for the Total Station are as follow;

| | |
|---|---|
| Angle Accuracy | 2” |
| Automatic Level Compensator Accuracy | 0.5” |
| Distance Accuracy, Prism, Standard | 2mm + 2ppm |
| Distance Accuracy, Prism, Tracking | 4mm + 2ppm |
| Distance Accuracy, Reflector-less (DR), Standard | 2mm + 2ppm |
| Distance Accuracy, Reflector-less (DR), Tracking | 4mm + 2ppm |
| Measuring Time, Prism, Standard | 1.2 Seconds |
| Measuring Time, Prism, Tracking | 0.4 Seconds |
| Measuring Time, Reflector-less (DR), Standard | 1-5 Seconds |
| Measuring Time, Reflector-less (DR), Tracking | 0.4 Seconds |
| Range, Prism, Longest | 2500m (Long Range Mode 5500m) |
| Range, Prism, Shortest | 0.2m |
| Range, DR, Good Conditions, (90% Reflective) | 1300m |
| Range, DR, Good Conditions, (18% Reflective) | 600m |
| Range, DR, Extended Range Mode, Accuracy | 10mm +2ppm |
| Range, DR, Shortest | 1m |
| EDM Light Source, Laser Class | Class 1 |
| EDM Laser Pointer, Laser Class | Class 2 |
| Laser Scanning, Range | 1m – 250m |
| Laser Scanning, Speed | 15 points/ second |
| Laser Scanning, Accuracy | 10mm at less than or equal to150m |

*Table 2 Trimble S6 Total Station Specification (Trimble Inc., 2019)*

# Chapter 3 Methodology

## 3.1 Study Area

The project intends to take place on Residential Colleges Toowoomba campus. The project will use D Block on Concannon College which is a two-story rectangular building. The buildings on the Toowoomba residential colleges campus are gradually being renovated and so this data could be supplied to the colleges for future planning.

## 3.2 Equipment and Resources Required

The project intends to borrow equipment and materials from the University of Southern Queensland faculty of engineering and surveying and student equipment.

The following equipment and materials will be needed for the completion of the project;

| **Resource** | **Quantity** | **Purpose** | **Borrowed/ Purchased** |
|---|---|---|---|
| Faro Focus $^{3D}$ S Series 120 Laser Scanner | 1 | Field Measurements | Borrowed from USQ Survey Store |
| Reference Object Orbs for laser scanning | 6 | Field Measurements | Borrowed from USQ Survey Store |
| Tribraches, and Reference Orb Adapters | 6/6 | Field Measurements | Borrowed from USQ Survey Store |
| Safety Cones/ Barrier Tape Dispensers | 10/4 | Field Measurements | Borrowed from USQ Survey Store |
| Trimble S7 Total Station with TSC3 Controller | 1/1 | Field Measurements | Borrowed from USQ Survey Store |

| | | | |
|---|---|---|---|
| Tripod Legs | 3-5 | Field Measurements | Borrowed from USQ Survey Store |
| Trimble Traversing Kit (Includes 2 Targets) | 1 | Field Measurements | Borrowed from USQ Survey Store |
| Mini Prism (Trimble +2mm 360° Prism with, with mini pole attachment) | 1 | Field Measurements | Borrowed from USQ Survey Store |
| Trimble R10 GPS with TSC3 Controller | 1/1 | Field Measurements | Borrowed from USQ Survey Store |
| Trimble Rover Pole and Adapter/ Controller brackets | 1/1/1 | Field Measurements | Borrowed from USQ Survey Store |
| Control Marks, (e.g. Nails, Dumpy Pegs, Screws) | As Needed | Field Measurements | Supplied by student and USQ Survey Store |
| Basic Survey Tools, (e.g. Hammer, Tape measure) | As Needed | Field Measurements | Student Equipment, or Borrowed from USQ Survey Store |
| Trimble Business Centre Software | 1 Version | Data Processing | Access to USQ Computers |
| Faro Scene 3D Software | 1 Version | Data Processing | Access to USQ Computers |
| Computer with Microsoft Office Programs, (e.g. Word, Excel) | 1 Version | Writing Dissertation | Student Equipment |

*Table 3 Equipment needed for Project*

## 3.3 Data Collection Method

The data collection for this project can be broken down into 3 main parts. Installation and traversing of control marks, total station reflector-less measurement and 3D terrestrial laser scanning. The steps for this process are as follows;

1.0 Place control marks (these are dumpy pegs and nails that will have GDA94 co-ordinates) around the building. These marks will be placed in relation to where the laser scanner will need to be set up, so each scanning station has a set of 3 dimensional coordinates.

2.0 These control marks will be traversed using the Trimble S7 total station. The traverse will commence from PSM12890 located on the corner of Baker street and Platz Street. The planned traverse network is shown in figure 7 and figure 8 below.

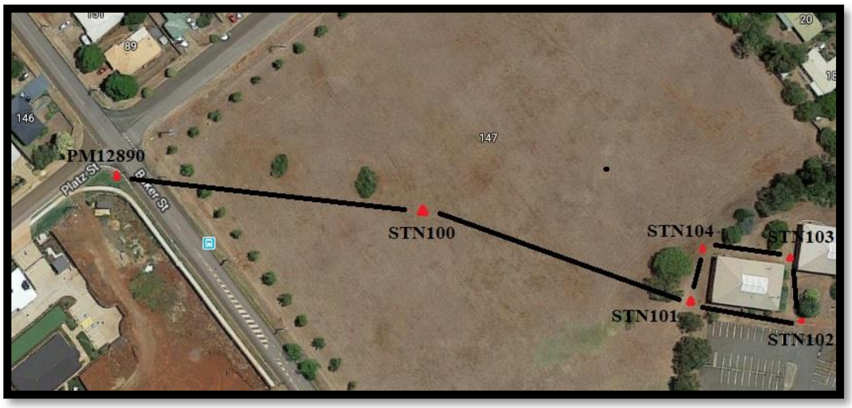



*Figure 7 Planned Primary Traverse Network (Google Maps, 2019)*

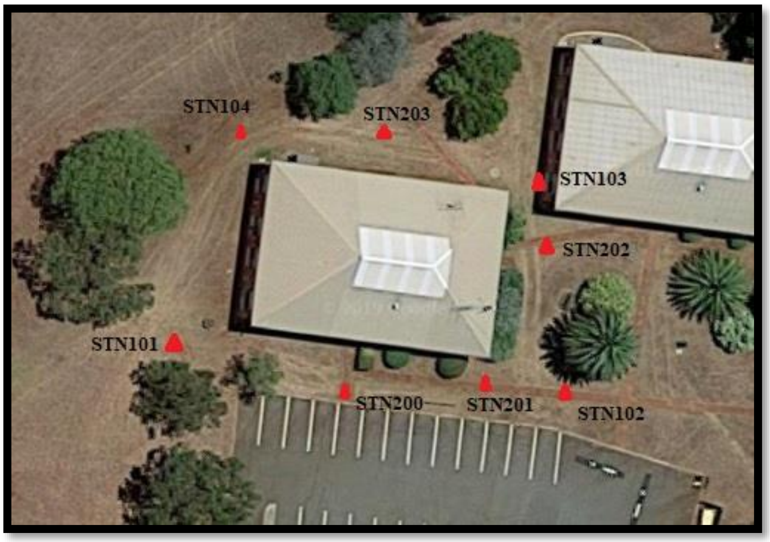



*Figure 8 Primary and Secondary Instrument Stations (Google Maps, 2019)*

- The first instrument setup will take place on PM12890 and a backsight recorded to STN100. A check shot will also be measured to a PM26162 across the road for a post-processed check.
- The second instrument setup will be at STN100 and a set of 4 rounds will be observed to the backsight PM12890 and foresight STN101 using the onboard function of the S7 total station. Topographic shots will also be recorded as a check.
- The process in the step above will continue until the instrument has been set up on each of the primary instrument stations.
- At STN101, Both STN200 and STN201 will be shot using the Trimble 360° mini prism.
- At STN102, STN200 and STN201 will be staked-outed and checked for accuracy and have topographic shots measured to these points.
- At STN 102, STN202 will be shot in using the Trimble 360° mini prism.
- At STN 103, STN202 will be staked-outed and checked for accuracy and have topographic shots measured to this point. STN203 will also be shot in using the Trimble 360° mini prism.
- At STN 104, STN203, STN101 and STN100 will be staked-outed and checked for accuracy and have topographic shots measured to this point.

3.0 Using the Trimble R10 GPS Rover connected to the USQ base station, a check shot on PM40403 which is close to the base station will be completed, as well as a check shot on PM40832. Then the PM12890 and STN100 that were used in the traverse will have 2 x 60 epoch shots, to obtain a set of GDA94 coordinates to be able to swing the traverse and project onto datum.

4.0 Reflector-less total station measurement will be conducted from the traverse stations that were previously placed. The total station will capture measurements along the wall on the edge of each brick column at 5 points vertically. The total station will also capture the eaves and gutters of the building. The points that the total station plans to capture are shown in figure 9 below.

*Figure 9 Points captured by the Total Station*

5.0 Three-dimensional terrestrial laser scanning will be conducted using the FARO scanner. The building will be scanned from all the traverse stations apart from STN102, as it will not be required. The building will be scanned at 2x quality and 1/2 resolution, and vertical parameters will be set at -60° to 90°. The horizontal parameters will differ at each set up but will not exceed 0° to 220°. Each scan at 2x quality depending on the angle of the horizontal will take approximately 10 minutes. The reference object orbs will be used to tie the different scans together. The heights of both the laser scanner and reference objects that have been set up over control points in the network will be measured and recorded. The heights of the scanner and reference objects will be used to create a coordinate for the central axis of the scanner which will be used to position the scan data in the software. The planned positions for the reference orbs are shown in figure 10, 11, 12, 13, 14, 15 and 16 below.

*Figure 10 Proposed Laser Scanning Setup at STN101 with Reference Orbs (Google Maps, 2019)*

*Figure 11 Proposed Laser Scanning Setup at STN200 with Reference Orbs (Google Maps, 2019)*

*Figure 12 Proposed Laser Scanning Setup at STN201 with Reference Orbs (Google Maps, 2019)*

*Figure 13 Proposed Laser Scanning Setup at STN202 with Reference Orbs (Google Maps, 2019)*

*Figure 14 Proposed Laser Scanning Setup at STN103 with Reference Orbs (Google Maps, 2019)*

*Figure 15 Proposed Laser Scanning Setup at STN203 with Reference Orbs (Google Maps, 2019)*

*Figure 16 Proposed Laser Scanning Setup at STN104 with Reference Orbs (Google Maps, 2019)*

6.0 The data can then be processed using a combination of software. The traverse network will be processed using tereamodel and the reflector-less data will then be added to this file to produce both a plan of the building and a set of coordinates for the buildings' position. The reflector-less total station measurements will be modelled in Autodesk, a free student version of AutoCAD which allows points to be imported into the program and viewed as a three-dimensional model. The laser scanning data will be processed using FARO Scene which will place the scans together to create and view the three-dimensional model.

## 3.4 Benefits and Expected Results

The benefits of this project and the testing of both the laser scanner and the total station are that the outcomes produced can be used to educate and inform the surveyor about best practice. The benefits are also that the project will produce a building format plan and model that can be given to residential colleges to use for future planning. The surveyor will be able to make an informed decision knowing which method will produce the required accuracy. This in turn will improve efficiency of the survey and produce cost savings.

The expected accuracy results for this project are that the laser scanning data will produce a more comprehensive model for each of the buildings. It is also expected that the processing time for the laser scanning data will be much longer than that of the reflector-less data measurements. This being due to the large point cloud of data that needs to be checked. However, the field procedure for the laser scanning will be much quicker than that of the total station measurements. The reflector-less measurements will not produce a 3D model that looks nice to the eye but from the measured point a building footprint will be able to be drawn. It's expected that the reflector-less measurement will be the more accurate instrument for measurement but the least efficient.

# Chapter 4 Results

## 4.1 GPS Results for Orientation of Traverse Network

The results of the GPS checks on the permanent survey marks used in the traverse were unexpected at first. When the starting traverse mark PM12890 was checked it was showing a horizontal misclose distance of 2.435m at 355°11'36''. The check across the road to PM26162 was also showing a horizontal misclose of 3.374m at 356°11'38''. This can be seen in tables 4 and 5 below.

| PM12890 (GDA94) | Form 16 Coordinates | GPS Coordinates | Difference (m) |
|---|---|---|---|
| Easting | 393948.740 | 393948.536 | 0.204 |
| Northing | 6946721.800 | 6946724.226 | -2.426 |
| Elevation (AHD) | 683.935 | 683.918 | -0.017 |

*Table 4 Difference in Form 16 Coordinates for PM12890*

| PM26162 (GDA94) | Form 16 Coordinates | GPS Coordinates | Difference (m) |
|---|---|---|---|
| Easting | 393961.440 | 393961.216 | 0.224 |
| Northing | 6946736.900 | 6946740.267 | -3.367 |
| Elevation (AHD) | n/a | 684.424 | n/a |

*Table 5 Difference in Form 16 Coordinates for PM26162*

These results required more investigation into the horizontal uncertainty of these marks. When looking at the form 16 for both these marks the horizontal uncertainty was seen to be Class E with No Order and fixed by cadastral surveying. It was realised that these coordinates for these marks have been digitalised for the purpose of creating an online record for the Survey Control Database (SCDB). To be able to confirm the GPS coordinates captured for PM12890 and PM26162, another two permanent survey marks where required to be captured and checked. Below in table 6 and 7 are the differences between the form 16 coordinates and GPS coordinates for PM40403 and PM40832.

| PM40403 (GDA94) | Form 16 Coordinates | GPS Coordinates | Differences (m) |
|---|---|---|---|
| Easting | 394940.421 | 394940.402 | 0.019 |
| Northing | 6945984.527 | 6945984.558 | -0.031 |
| Elevation (AHD) | 684.598 | 684.542 | 0.056 |

*Table 6 Differences in Form 16 Coordinates for PM40403*

| PM40832 (GDA94) | Form 16 Coordinates | GPS Coordinates | Differences (m) |
|---|---|---|---|
| Easting | 394133.752 | 394133.764 | -0.012 |
| Northing | 6946292.745 | 6946292.807 | -0.062 |
| Elevation (AHD) | 691.963 | 691.900 | 0.063 |

*Table 7 Differences in Form 16 Coordinates for PM40832*

PM40403 has a horizontal uncertainty of 9mm and PM40832 has a horizontal uncertainty of 10mm. Misclose for these two points was under 65mm in both the horizontal and vertical. This then assures that the GPS coordinates that were captured for PM12890 and PM26162 are alright to use for orientation of the traverse network.

The resulting coordinates from the GPS unit for STN100 are shown below in table 8.

| STN100 (GDA94) | GPS Coordinates |
|---|---|
| Easting | 394067.449 |
| Northing | 6946698.352 |
| Elevation (AHD) | 688.647 |

*Table 8 GPS Coordinates for STN100*

## 4.2 Traverse Processing and Final Coordinates

The traverse network was processed using the program terramodel, the GPS points were imported into a new working file and points checked against Form 16 information. The traverse data was then imported into the file and using the move, rotate and mirror tools, the traverse was orientated into position. The GPS coordinates of PM12890 were established as the starting point of the traverse and then the traverse points were rotated so that the bearing of the GPS coordinates PM12890 to STN100 was the same bearing as the traverse points from PM12890 to STN100. A check between the traverse point and GPS point of STN100 could then be calculated to a misclose of 73mm, which was accepted. A check on the orientation of the traverse was also done by calculating a misclose bearing a distance between the GPS coordinates and traverse coordinates of PM26162, which was 25mm at 355°34’21’’.

*Figure 17 Traverse work being completed around Concannon*

Below is a screenshot of the traverse in the software program where the main traverse lines are shown in red and the check shots and measurements to secondary instrument stations are shown in purple.

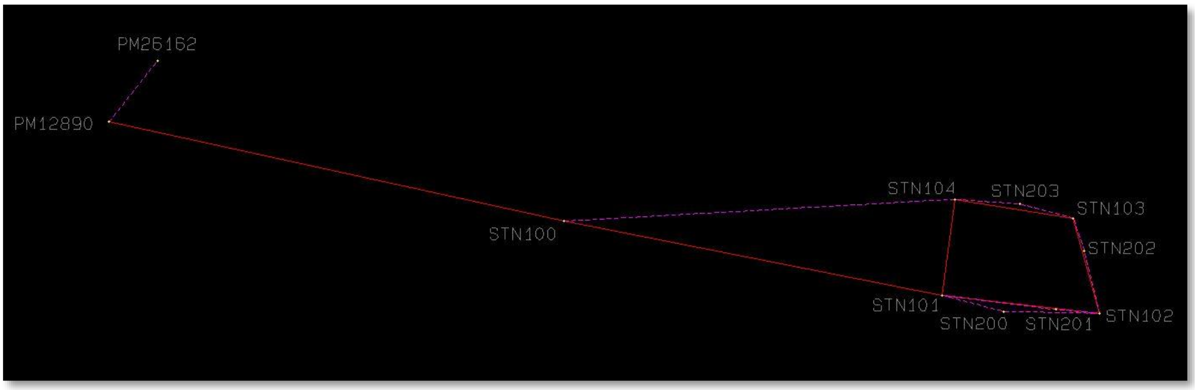



*Figure 18 Traverse Network from PM12890*

Using the program, a list of coordinates was then generated for all the points in the traverse. This can be seen in table 9 below. This set of coordinates was then used for completing the reflector-less measurement work.

| Point Name (GDA94) | Easting | Northing | Elevation (AHD) |
|---|---|---|---|
| PM12890 | 393948.536 | 6946724.226 | 684.154 |
| PM26162 | 393961.214 | 6946740.292 | 684.655 |
| STN100 | 394067.519 | 6946698.336 | 688.877 |
| STN101 | 394166.413 | 6946678.947 | 691.576 |
| STN102 | 394207.561 | 6946674.274 | 692.611 |
| STN103 | 394200.657 | 6946699.143 | 692.961 |
| STN104 | 394169.664 | 6946704.055 | 693.154 |
| STN200 | 394182.558 | 6946674.741 | 692.284 |
| STN201 | 394196.038 | 6946675.250 | 692.457 |
| STN202 | 394203.547 | 6946690.657 | 692.962 |
| STN203 | 394186.693 | 6946702.814 | 692.309 |

*Table 9 Coordinates List for Network*

## 4.3 Reflector-less Total Station Processing and Results

The results for the reflector-less total station data were processed first using terramodel. The points were imported into the software program and swung onto the already processed traverse coordinates. The reflector-less points were captured from six of the ten control stations in the network. The data was imported into the program one station at a time and swung onto the processed traverse network using the backsight measurement and then checked using the check measurement taken in the field. In total from the six stations, 443 reflector-less points were captured that consisted of gutter, eave and brick points. Out of the 443 points that were captured, there were 10 points that did not import properly and could not be used to create the three-dimensional model. In the figure below the reflector-less points are presented in terramodel. The point colours in the figure correspond with the station in which the point was captured from.

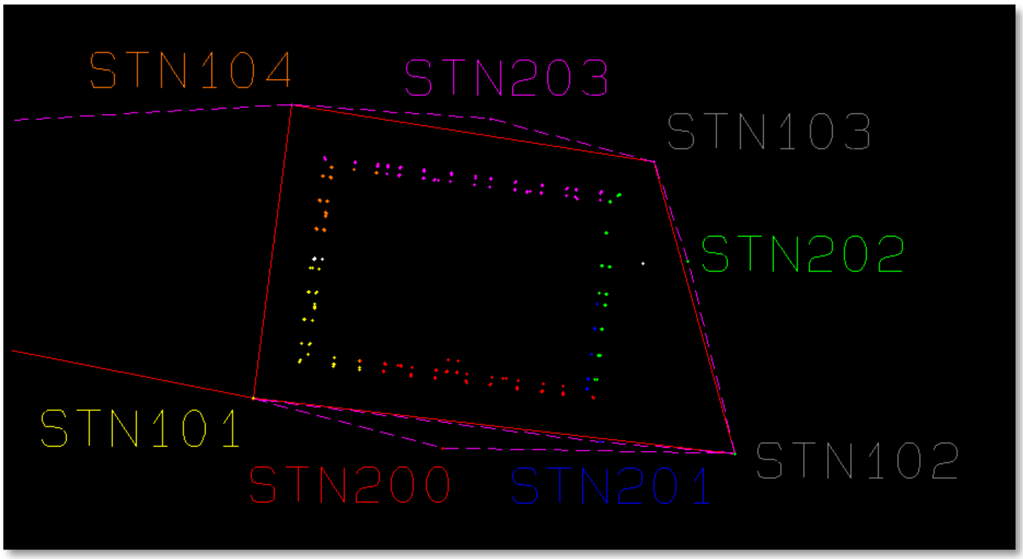



*Figure 19 Reflector-less points presented in terramodel*

The points coloured white in the figure above are the outlying points that were not used to create the model. The points were then strung together in respect to their position on the building, i.e. Top of gutter, Bottom of gutter, Top of eave, Bottom of eave, Bottom of building, Bottom of ground floor window, Top of ground floor window, Bottom of second floor window and top of the brick. The front door to the building is recessed in and these points were also strung together to show this. The figure below presents the points strung together in terramodel.

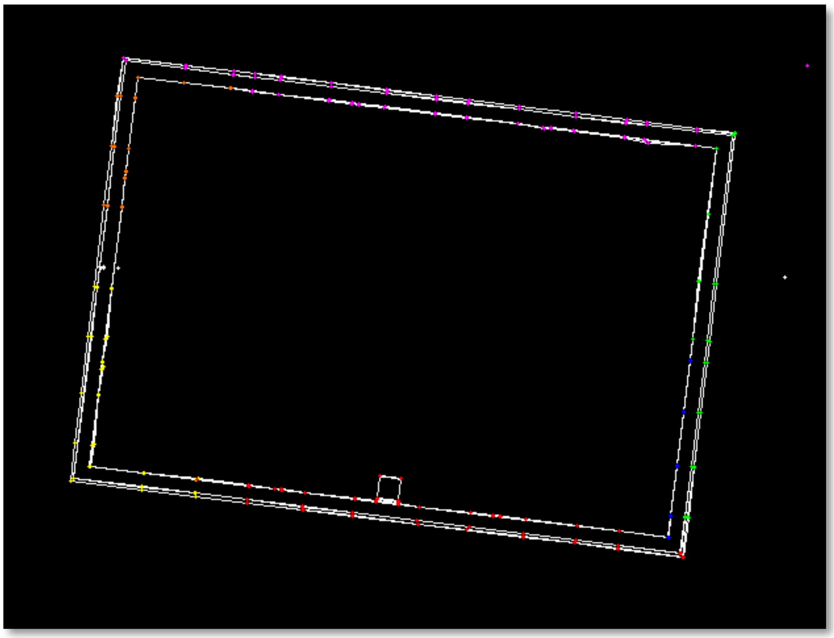


*Figure 20 Reflector-less points strung together in terramodel*

The results from the reflector-less measurements then needed to be presented as a three-dimensional model. This function cannot be completed in terramodel and so the data needed to be exported to another software. The software that was used to present the reflector-less data as a three-dimensional model was Autodesk. For the data to be easily imported in to the program it firstly needed to be exported in drawing exchange format from terramodel. The figure below shows the three-dimensional model that was produced in Autodesk to represent the total station data.

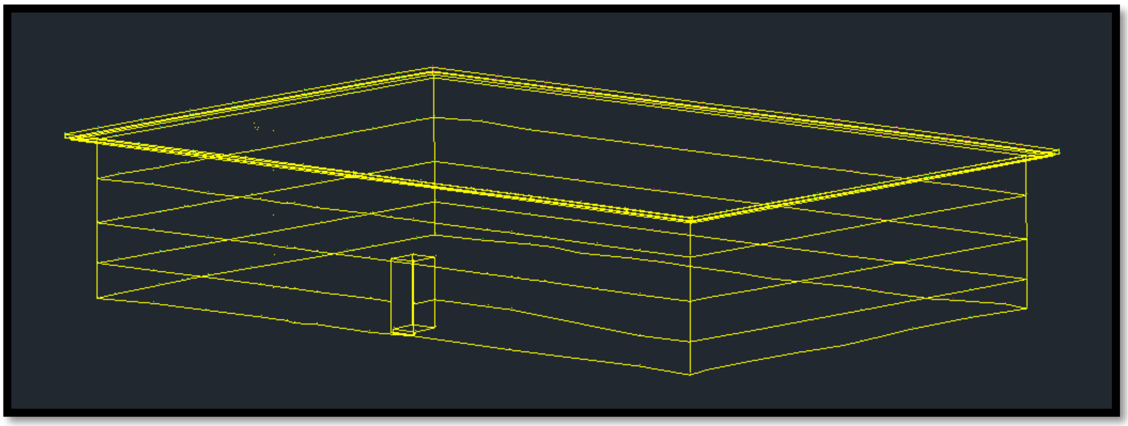


*Figure 21 Total station data as a 3D model*

The software is only able to produce a simple wireframe model with the three-dimensional points that were captured. The model created serves the purpose of the project to be able to compare the model created by that of a total station to that of the laser scanner.

The reflector-less points that were captured at the four corners of the building were compared for vertical accuracy to check for irregularity in measurement. Using excel the differences in the easting and nothing of the gutter points, eave points and building points were compared. As the building should be vertical the points captured above each other should have the same easting and northing. The four tables below present the average difference in both easting and nothing for the gutters, eave and building at each of the 4 corners.

| **North-East Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | -0.0090 | 0.0080 |
| **Eave Difference** | -0.0090 | 0.0120 |
| **Building Average Difference** | 0.0072 | 0.0070 |
| **Total Average Difference** | 0.0084 | 0.0090 |
| **Avg East and North Difference** | | 0.0087 |

*Table 10 TS Easting and Northing comparison NE building corner*

| **North-West Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | -0.0040 | 0.0010 |
| **Eave Difference** | 0.0060 | 0.0020 |
| **Building Average Difference** | 0.0108 | 0.0056 |
| **Total Average Difference** | 0.0069 | 0.0029 |
| **Avg East and North Difference** | | 0.0049 |

*Table 11 TS Easting and Northing comparison NW building corner*

| **South-West Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | -0.009 | -0.009 |
| **Eave Difference** | -0.005 | -0.003 |
| **Building Average Difference** | 0.004 | 0.0048 |
| **Total Average Difference** | 0.006 | 0.0056 |
| **Avg East and North Difference** | | 0.0058 |

*Table 12 TS Easting and Northing comparison SW building corner*

| **South-East Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | -0.002 | -0.001 |
| **Eave Difference** | -0.010 | -0.005 |
| **Building Average Difference** | 0.002 | 0.006 |
| **Total Average Difference** | 0.0048 | 0.0039 |
| **Avg East and North Difference** | | 0.0043 |

*Table 13 TS Easting and Northing comparison SE building corner*

The results from these calculations found that the mean average difference in vertical position for the reflector-less measurements at the corners of the building was 5.9mm.

The results of the total station data from both terramodel and Autodesk are compared with the laser scanning data to complete a point to point comparison in the following sections.

## 4.4 Laser Scanning Processing and Results

The results from the laser scanning field work, were derived from the software program that was used, which was FARO Scene 3D. After completion of the field work for the laser scanning the scan files were imported into the software.

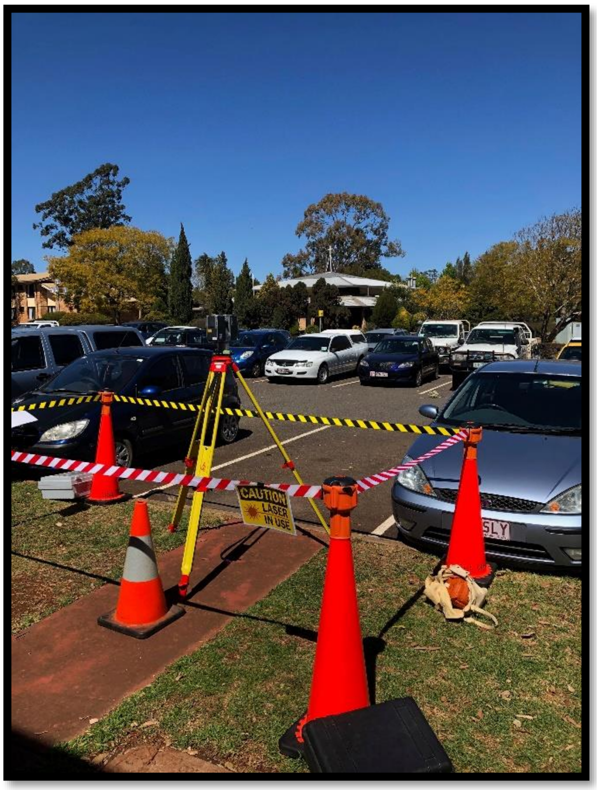



*Figure 22 Laser Scanning work being completed around Concannon*

The first scans initially had to undergo a pre-processing operation. In this operation the program applies pictures and colour to the scan images, detects any artificial reference spheres and places the scans together to create a preliminary model. The figure below shows the model of the building in the software after the first iteration of pre-processing.

*Figure 23 Post Pre-processing of laser scanning data in SCENE*

The next stage of the processing was to check the residuals for the placement of the scan data. The scans placed themselves together during pre-processing by using the common reference objects (white spheres) and produced residuals of 0.030m. The scans being locked into position, irrelevant data could be clipped from the scans and the point cloud could then be generated. The figure below show the model after the clipping of some of the irrelevant data and the generation of the point cloud.

*Figure 24 Post point cloud generation and clipping of irrelevant data*

To be able to compare the model of the laser scanning data to the reflector-less measurements captured by the total station, a point to point comparison was derived. To be able to complete this comparison the points that were measured to with the total station would have to be extracted from the model in FARO Scene. The process for extracting points from the laser scanning model within FARO Scene is a time-consuming process and so only 72 points from the model were extracted. The points that were extracted from the model were the building corners, eaves and gutters where the reflector-less measurements were captured as well as 5 building points, 2 eave points and 2 gutter points at the middle of each side of the building. To determine where the points that were captured by the total station were in relation to the laser scanning model, a comma separated values file containing the easting, nothings and elevations of the total station data was exported from terramodel. The file was then imported into FARO scene to begin the processing of point extraction. The figure below shows the planar view of the scan captured from STN101 with the imported total station points shown in pink.

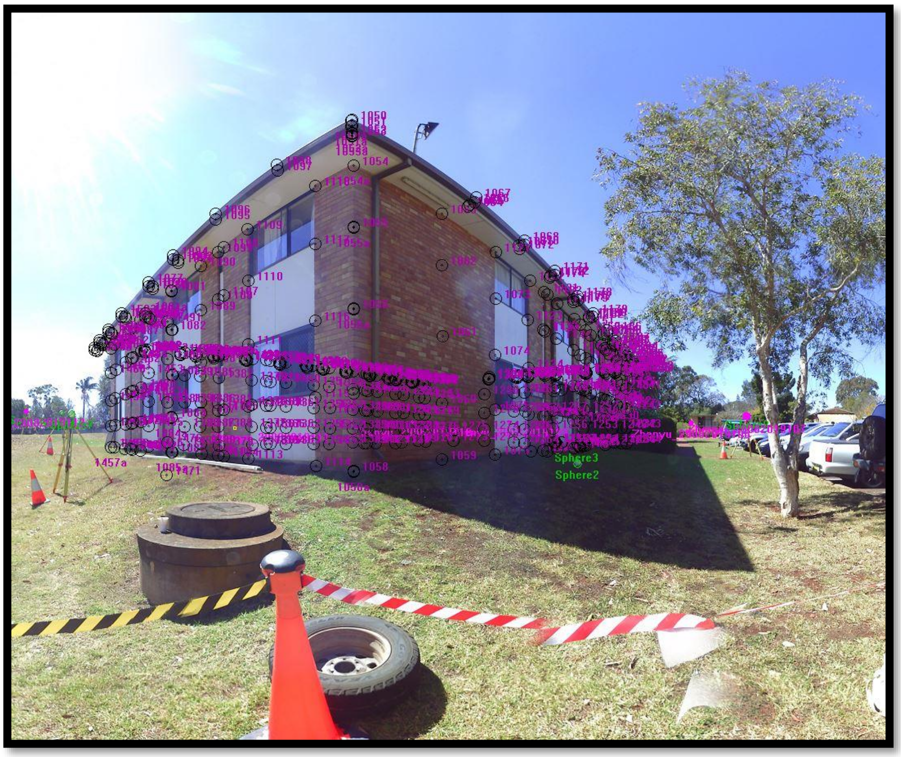


*Figure 25 Planar scan view at STN101*

FARO Scene does not allow for imported points to be viewed in the three-dimensional view of the model or create points while viewing the model in 3D. This is the reason for the extensive time taken to extract similar points because points can only be seen and created in the planar view. To extract a point in Scene you must use the ‘mark scan point tool’ in the planar view. The points were extracted by using this tool in the planar view, for example clicking the top corner of the gutter, and then selecting around the point and viewing the selection in 3D view. This can be seen in the two figures below.

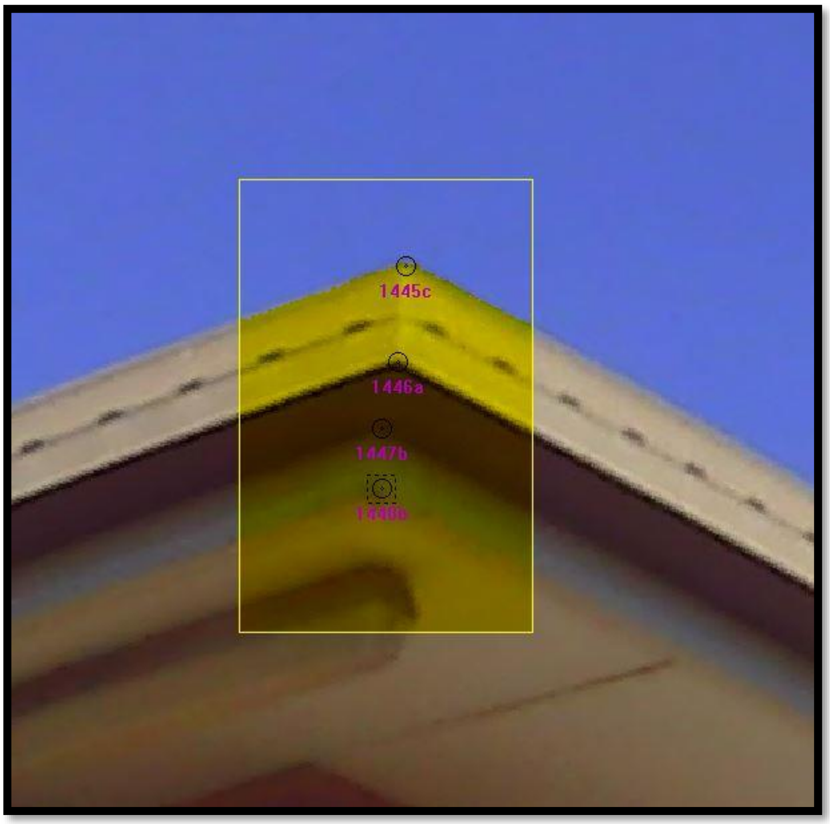



*Figure 26 The marked scan points created in the planar view*

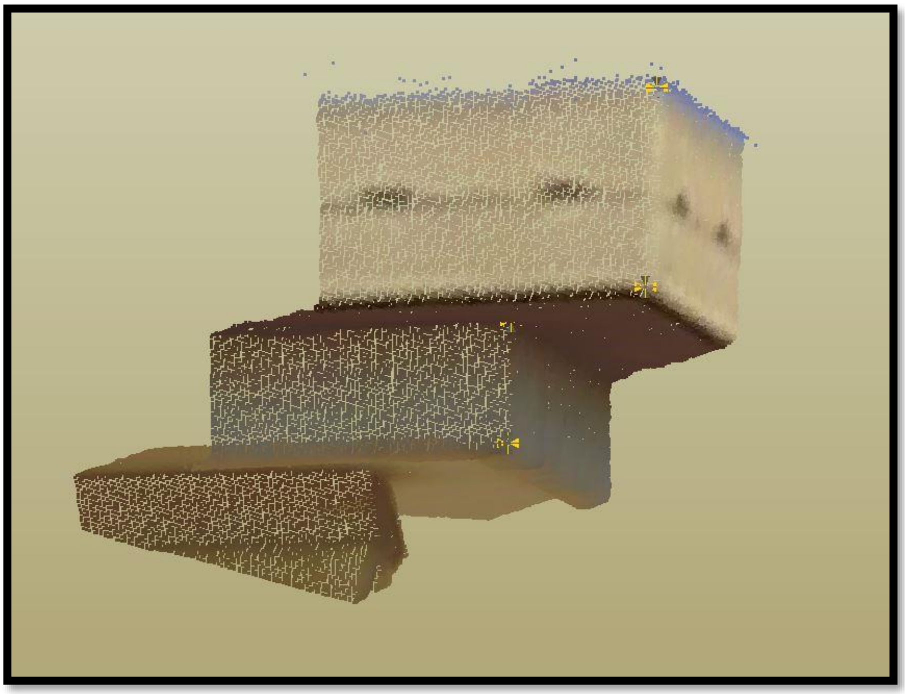


*Figure 27 The marked selection in figure 26 shown in three-dimensional view*

The point created in the planar view is then visible in the 3D view as a yellow and black marker seen in the figure above. Using the zoom and rotate functions this process is repeated until the yellow and black point marker is positioned on the top corner of the gutter in the 3D view. Once the correct point has been selected the coordinate can be viewed and entered into the excel spread sheet. The table below displays the easting, northing and elevations for the points extracted from the model.

| **South-West Corner** | | | | **Middle - Right West Side** | | | |
|---|---|---|---|---|---|---|---|
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | -1.2757 | 4.8774 | 666.1385 | **Top Gut** | -8.1548 | 9.0270 | 666.1396 |
| **Bot Gut** | -1.2784 | 4.8882 | 666.0209 | **Bot Gut** | -8.1572 | 9.0408 | 666.0121 |
| **Top Eave** | -1.3167 | 5.0469 | 666.0248 | **Top Eave** | -8.1161 | 9.1534 | 666.0160 |
| **Bot Eave** | -1.3182 | 5.0531 | 665.9659 | **Bot Eave** | -8.1090 | 9.1568 | 665.9469 |
| **Build 1** | -1.5011 | 5.8465 | 665.9830 | **Build 1** | -7.7927 | 9.6582 | 665.9512 |
| **Build 2** | -1.4950 | 5.8507 | 664.7393 | **Build 2** | -7.7913 | 9.6661 | 664.7184 |
| **Build 3** | -1.4936 | 5.8510 | 663.3602 | **Build 3** | -7.7906 | 9.6694 | 663.3339 |
| **Build 4** | -1.4901 | 5.8490 | 662.1074 | **Build 4** | -7.7923 | 9.6693 | 662.0766 |
| **Build 5** | -1.4928 | 5.8550 | 660.9960 | **Build 5** | -7.7808 | 9.6636 | 661.0611 |

| South-East Corner | | | | Middle - Left South Side | | | |
|---|---|---|---|---|---|---|---|
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | 11.8829 | 26.5910 | 666.1334 | **Top Gut** | 4.7865 | 14.8516 | 666.1536 |
| **Bot Gut** | 11.8860 | 26.5824 | 666.0079 | **Bot Gut** | 4.7769 | 14.8530 | 666.0358 |
| **Top Eave** | 11.7139 | 26.5434 | 665.9382 | **Top Eave** | 4.6713 | 14.9065 | 666.0392 |
| **Bot Eave** | 11.7232 | 26.5296 | 665.9846 | **Bot Eave** | 4.6684 | 14.9117 | 665.9676 |
| **Build 1** | 10.8959 | 26.3530 | 665.9702 | **Build 1** | 4.1842 | 15.2488 | 665.9867 |
| **Build 2** | 10.8976 | 26.3493 | 664.7388 | **Build 2** | 4.1902 | 15.2501 | 664.7535 |
| **Build 3** | 10.8999 | 26.3514 | 663.3581 | **Build 3** | 4.1923 | 15.2528 | 663.3729 |
| **Build 4** | 10.9019 | 26.3502 | 662.0934 | **Build 4** | 4.1944 | 15.2552 | 662.1180 |
| **Build 5** | 10.8998 | 26.3493 | 661.0673 | **Build 5** | 4.1941 | 15.2518 | 661.0937 |
| **North-West Corner** | | | | **Middle - Right East Side** | | | |
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | -16.2520 | 13.9468 | 666.1351 | **Top Gut** | 4.2624 | 31.1962 | 666.1310 |
| **Bot Gut** | -16.2530 | 13.9551 | 666.0094 | **Bot Gut** | 4.2601 | 31.1995 | 666.0046 |
| **Top Eave** | -16.0910 | 13.9935 | 666.0107 | **Top Eave** | 4.2102 | 31.0855 | 666.0040 |
| **Bot Eave** | -16.0856 | 13.9941 | 665.9332 | **Bot Eave** | 4.2052 | 31.0766 | 665.9343 |
| **Build 1** | -15.2744 | 14.1875 | 665.9592 | **Build 1** | 3.8945 | 30.5800 | 665.9581 |
| **Build 2** | -15.2703 | 14.1899 | 664.7182 | **Build 2** | 3.8918 | 30.5736 | 664.7243 |
| **Build 3** | -15.2683 | 14.1924 | 663.3418 | **Build 3** | 3.8944 | 30.5721 | 663.3443 |
| **Build 4** | -15.2672 | 14.2009 | 662.0770 | **Build 4** | 3.8978 | 30.5751 | 662.0797 |
| **Build 5** | -15.2530 | 14.1940 | 661.0589 | **Build 5** | 3.8712 | 30.6009 | 661.1236 |
| **North-East Corner** | | | | **Middle - Left North Side** | | | |
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | -3.0965 | 35.6450 | 666.1157 | **Top Gut** | -8.8443 | 26.2241 | 666.1463 |
| **Bot Gut** | -3.1005 | 35.6436 | 666.0100 | **Bot Gut** | -8.8335 | 26.2139 | 666.0201 |
| **Top Eave** | -3.0707 | 35.4820 | 666.0027 | **Top Eave** | -8.7234 | 26.1597 | 666.0254 |
| **Bot Eave** | -3.0680 | 35.4805 | 665.9499 | **Bot Eave** | -8.7181 | 26.1573 | 665.9450 |
| **Build 1** | -2.8645 | 34.6667 | 665.9726 | **Build 1** | -8.2245 | 25.8361 | 665.9733 |
| **Build 2** | -2.8645 | 34.6697 | 664.7402 | **Build 2** | -8.2247 | 25.8290 | 664.7399 |
| **Build 3** | -2.8648 | 34.6733 | 663.3620 | **Build 3** | -8.2221 | 25.8285 | 663.3566 |
| **Build 4** | -2.8674 | 34.6759 | 662.1052 | **Build 4** | -8.2228 | 25.8258 | 662.0983 |
| **Build 5** | -2.8644 | 34.6726 | 661.1863 | **Build 5** | -8.2132 | 25.8247 | 661.0676 |

*Table 14 Coordinates of laser scanning points*

A comparison for the vertical accuracy of the points captured by the laser scanner was also completed the same way the reflector-less points were compared. Using excel the differences in the easting and nothing of the gutter points, eave points and building points were compared. As the building should be vertical the points captured above each other should have the same easting and northing. The easting and northings for the points at the corners of the building were extracted from the laser scanning model by clicking points on the building that the total station took measurements to. The four tables below present the average difference in both easting and nothing for the gutters, eave and building at each of the 4 corners.

| **North-East Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | 0.0110 | 0.0050 |
| **Eave Difference** | 0.0150 | 0.0030 |
| **Building Average Difference** | 0.0013 | 0.0044 |
| **Total Average Difference** | 0.0136 | 0.0062 |
| **Avg East and North Difference** | | 0.0099 |

*Table 15 LS Easting and Northing comparison NE building corner*

| **North-West Building Corner** | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | -0.0020 | -0.0030 |
| **Eave Difference** | 0.0020 | 0.0070 |
| **Building Average Difference** | 0.0092 | 0.0062 |
| **Total Average Difference** | 0.0066 | 0.0081 |
| **Avg East and North Difference** | | 0.0073 |

*Table 16 LS Easting and Northing comparison NW building corner*

| South-West Building Corner | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | 0.0040 | -0.0120 |
| **Eave Difference** | 0.0010 | -0.0050 |
| **Building Average Difference** | 0.0029 | 0.0019 |
| **Total Average Difference** | 0.0039 | 0.0094 |
| **Avg East and North Difference** | | 0.0067 |

*Table 17 LS Easting and Northing comparison SW building corner*

| South-East Building Corner | | |
|---|---|---|
| **(Meters)** | **Easting** | **Northing** |
| **Gutter Difference** | 0.0000 | -0.0020 |
| **Eave Difference** | 0.0010 | -0.0110 |
| **Building Average Difference** | 0.0048 | 0.0038 |
| **Total Average Difference** | 0.0029 | 0.0084 |
| **Avg East and North Difference** | | 0.0057 |

*Table 18 LS Easting and Northing comparison SE building corner*

The results from these calculations found that the mean average difference in vertical position for the laser scanning measurements at the corners of the building was 7.4mm.

## 4.5 Data Comparison Results

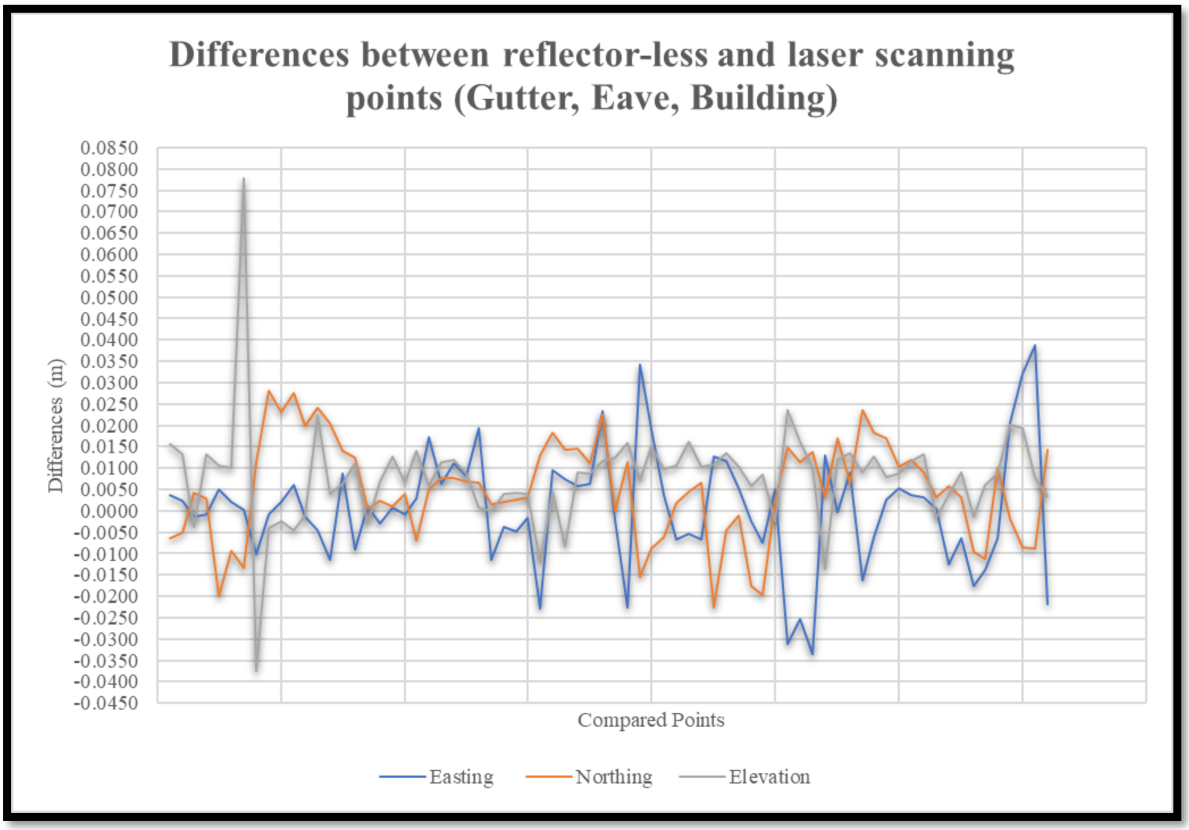
The comparison results were compiled in excel by comparing the difference in easting, northing and elevation of a point on the building captured by both the total station and the laser scanner. A total of 72 points were compared and consisted of measurements to the gutter, eave and brick wall. The results for the differences between the two methods of point capture are shown in the table below.

| **South-West Corner** | | | | **Middle - Right West Side** | | | |
|---|---|---|---|---|---|---|---|
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | 0.0037 | -0.0064 | 0.0155 | **Top Gut** | -0.0022 | 0.0000 | 0.0124 |
| **Bot Gut** | 0.0024 | -0.0052 | 0.0131 | **Bot Gut** | -0.0228 | 0.0113 | 0.0159 |
| **Top Eave** | -0.0013 | 0.0041 | -0.0038 | **Top Eave** | 0.0341 | -0.0154 | 0.0070 |
| **Bot Eave** | -0.0008 | 0.0029 | 0.0131 | **Bot Eave** | 0.0190 | -0.0088 | 0.0151 |
| **Build 1** | 0.0011 | 0.0006 | -0.0030 | **Build 1** | 0.0037 | -0.0061 | 0.0098 |
| **Build 2** | -0.0031 | 0.0023 | 0.0067 | **Build 2** | -0.0067 | 0.0019 | 0.0106 |
| **Build 3** | 0.0006 | 0.0010 | 0.0128 | **Build 3** | -0.0054 | 0.0046 | 0.0161 |
| **Build 4** | -0.0009 | 0.0040 | 0.0066 | **Build 4** | -0.0067 | 0.0067 | 0.0104 |
| **Build 5** | 0.0028 | -0.0070 | 0.0140 | **Build 5** | 0.0128 | -0.0226 | 0.0109 |
| **South-East Corner** | | | | **Middle - Left South Side** | | | |
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | 0.0051 | -0.0200 | 0.0106 | **Top Gut** | 0.0115 | -0.0046 | 0.0134 |
| **Bot Gut** | 0.0020 | -0.0094 | 0.0101 | **Bot Gut** | 0.0051 | -0.0010 | 0.0103 |
| **Top Eave** | 0.0001 | -0.0134 | 0.0778 | **Top Eave** | -0.0023 | -0.0175 | 0.0058 |
| **Bot Eave** | -0.0102 | 0.0114 | -0.0376 | **Bot Eave** | -0.0074 | -0.0197 | 0.0084 |
| **Build 1** | 0.0171 | 0.0051 | 0.0058 | **Build 1** | 0.0118 | 0.0012 | 0.0113 |
| **Build 2** | 0.0064 | 0.0077 | 0.0112 | **Build 2** | -0.0312 | 0.0149 | 0.0235 |
| **Build 3** | 0.0111 | 0.0076 | 0.0119 | **Build 3** | -0.0253 | 0.0112 | 0.0161 |
| **Build 4** | 0.0081 | 0.0068 | 0.0086 | **Build 4** | -0.0334 | 0.0138 | 0.0101 |
| **Build 5** | 0.0192 | 0.0067 | 0.0007 | **Build 5** | 0.0129 | 0.0032 | -0.0136 |
| **North-West Corner** | | | | **Middle - Right East Side** | | | |
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | -0.0010 | 0.0282 | -0.0041 | **Top Gut** | -0.0004 | 0.0168 | 0.0120 |
| **Bot Gut** | 0.0020 | 0.0229 | -0.0024 | **Bot Gut** | 0.0089 | 0.0065 | 0.0134 |
| **Top Eave** | 0.0060 | 0.0275 | -0.0047 | **Top Eave** | -0.0162 | 0.0235 | 0.0090 |
| **Bot Eave** | -0.0014 | 0.0199 | -0.0012 | **Bot Eave** | -0.0061 | 0.0184 | 0.0127 |
| **Build 1** | -0.0116 | 0.0015 | -0.0002 | **Build 1** | 0.0025 | 0.0170 | 0.0079 |
| **Build 2** | -0.0037 | 0.0021 | 0.0038 | **Build 2** | 0.0052 | 0.0104 | 0.0087 |
| **Build 3** | -0.0047 | 0.0026 | 0.0042 | **Build 3** | 0.0036 | 0.0119 | 0.0117 |
| **Build 4** | -0.0018 | 0.0031 | 0.0040 | **Build 4** | 0.0032 | 0.0089 | 0.0133 |
| **Build 5** | -0.0230 | 0.0130 | -0.0119 | **Build 5** | 0.0298 | -0.0029 | 0.0054 |
| **North-East Corner** | | | | **Middle - Left North Side** | | | |
| | **Easting** | **Northing** | **Elevation** | | **Easting** | **Northing** | **Elevation** |
| **Top Gut** | -0.0045 | 0.0240 | 0.0223 | **Top Gut** | -0.0127 | 0.0059 | 0.0037 |
| **Bot Gut** | -0.0115 | 0.0204 | 0.0040 | **Bot Gut** | -0.0065 | 0.0031 | 0.0089 |
| **Top Eave** | 0.0087 | 0.0140 | 0.0063 | **Top Eave** | -0.0176 | -0.0097 | -0.0014 |
| **Bot Eave** | -0.0090 | 0.0125 | 0.0111 | **Bot Eave** | -0.0139 | -0.0113 | 0.0060 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Build 1** | 0.0095 | 0.0183 | 0.0044 | **Build 1** | -0.0065 | 0.0099 | 0.0087 |
| **Build 2** | 0.0075 | 0.0143 | -0.0082 | **Build 2** | 0.0207 | -0.0020 | 0.0201 |
| **Build 3** | 0.0058 | 0.0147 | 0.0090 | **Build 3** | 0.0321 | -0.0085 | 0.0194 |
| **Build 4** | 0.0064 | 0.0111 | 0.0088 | **Build 4** | 0.0388 | -0.0088 | 0.0077 |
| **Build 5** | 0.0234 | 0.0224 | 0.0117 | **Build 5** | -0.0218 | 0.0143 | 0.0034 |

*Table 19 Differences in Easting, Nothing and Elevation of compared points*

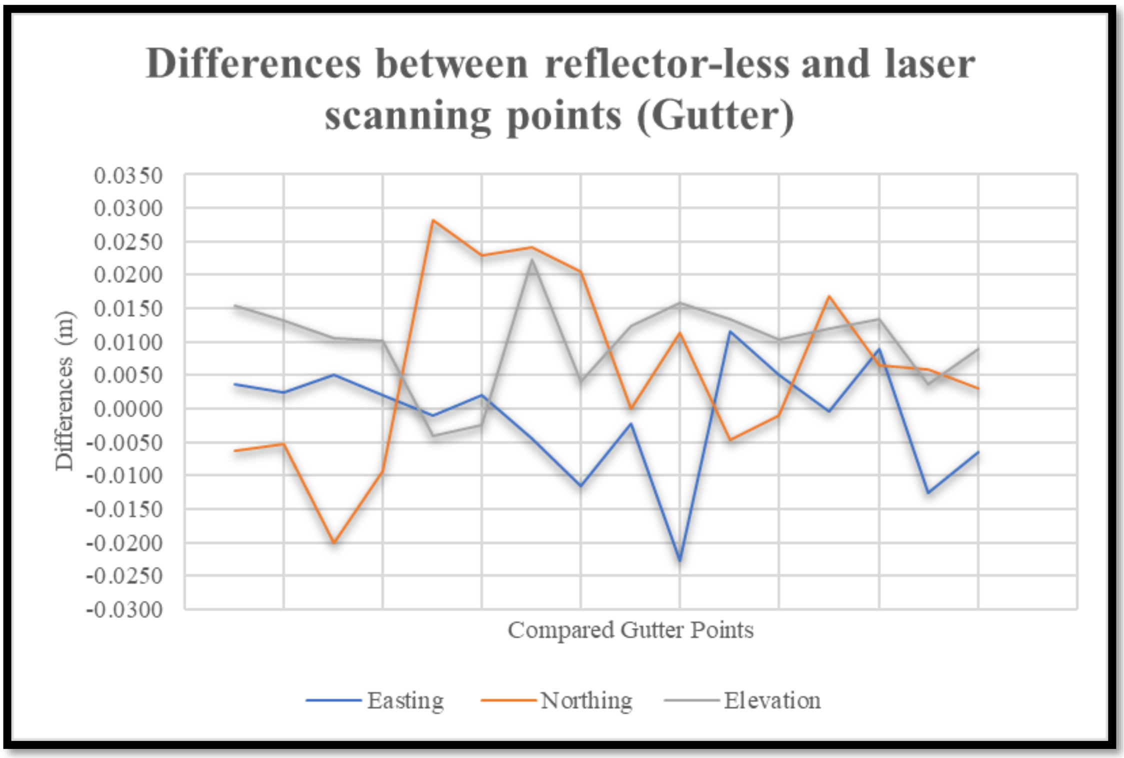
The differences between the selected comparable points were graphed to visually compare the data and then the average difference in easting, northing and elevation calculated. This was also displayed as an average distance misclose. The data was then broken down into the differences in gutter points, eave points and wall points to be graphed and averages calculated. This data is represented in the tables and graphs below.




*Graph 1 Difference between reflector-less and laser scanning points (Gutter, Eave, Building)*

| (Meters) | Number of Points | Sum of the Differences | Average | Sum of the Averages | Average Difference Total |
|---|---|---|---|---|---|
| **Easting** | 72 | 0.7024 | 0.0098 | | |
| **Northing** | 72 | 0.7499 | 0.0104 | | |
| **Elevation** | 72 | 0.7669 | 0.0107 | 0.0308 | 0.0103 |

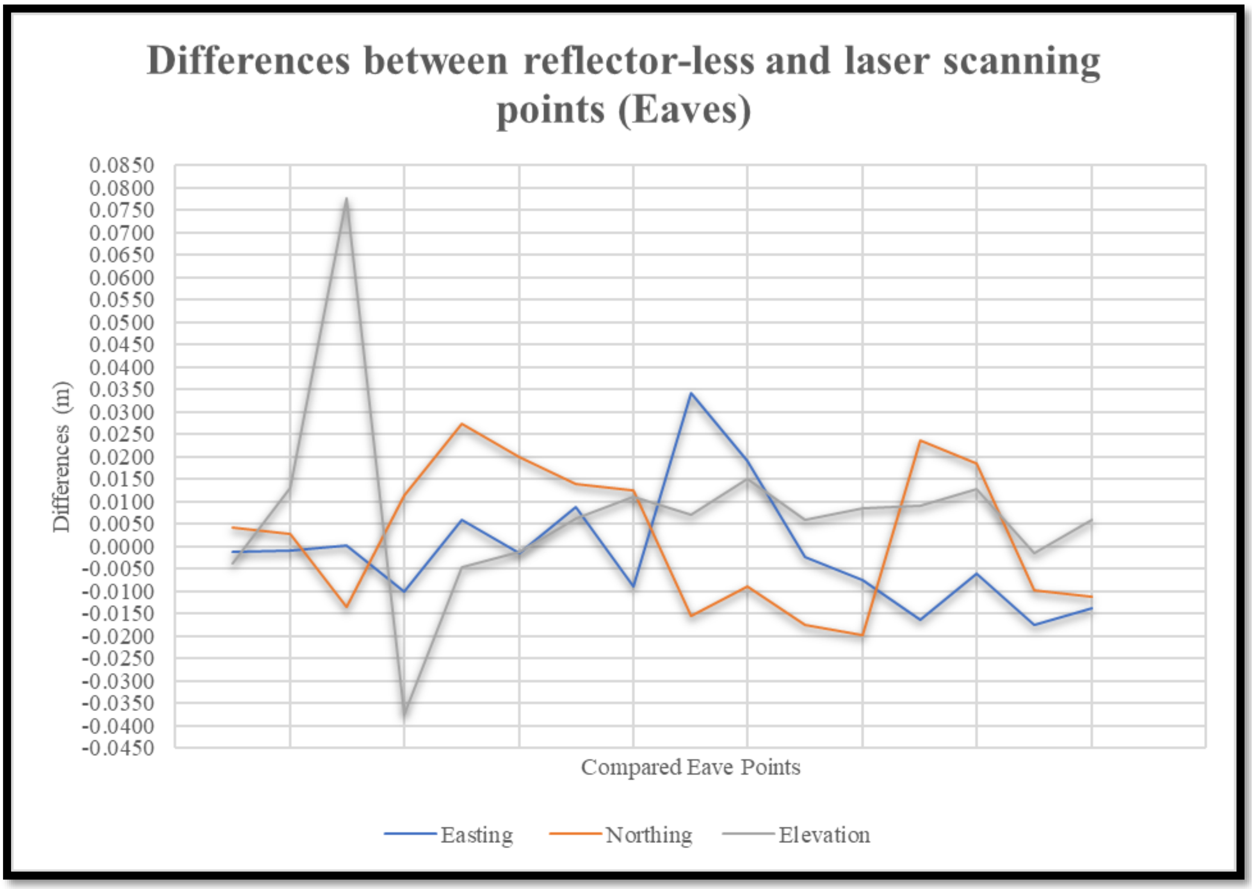
*Table 20 Averages of all compared points*




*Graph 2 Differences between reflector-less and laser scanning points (Gutter Only)*

| (Meters) | Number of Points | Sum of the Differences | Average | Sum of the Averages | Average Difference Total |
|---|---|---|---|---|---|
| **Easting** | 16 | 0.1023 | 0.0064 | | |
| **Northing** | 16 | 0.1857 | 0.0116 | | |
| **Elevation** | 16 | 0.1720 | 0.0108 | 0.0288 | 0.0096 |

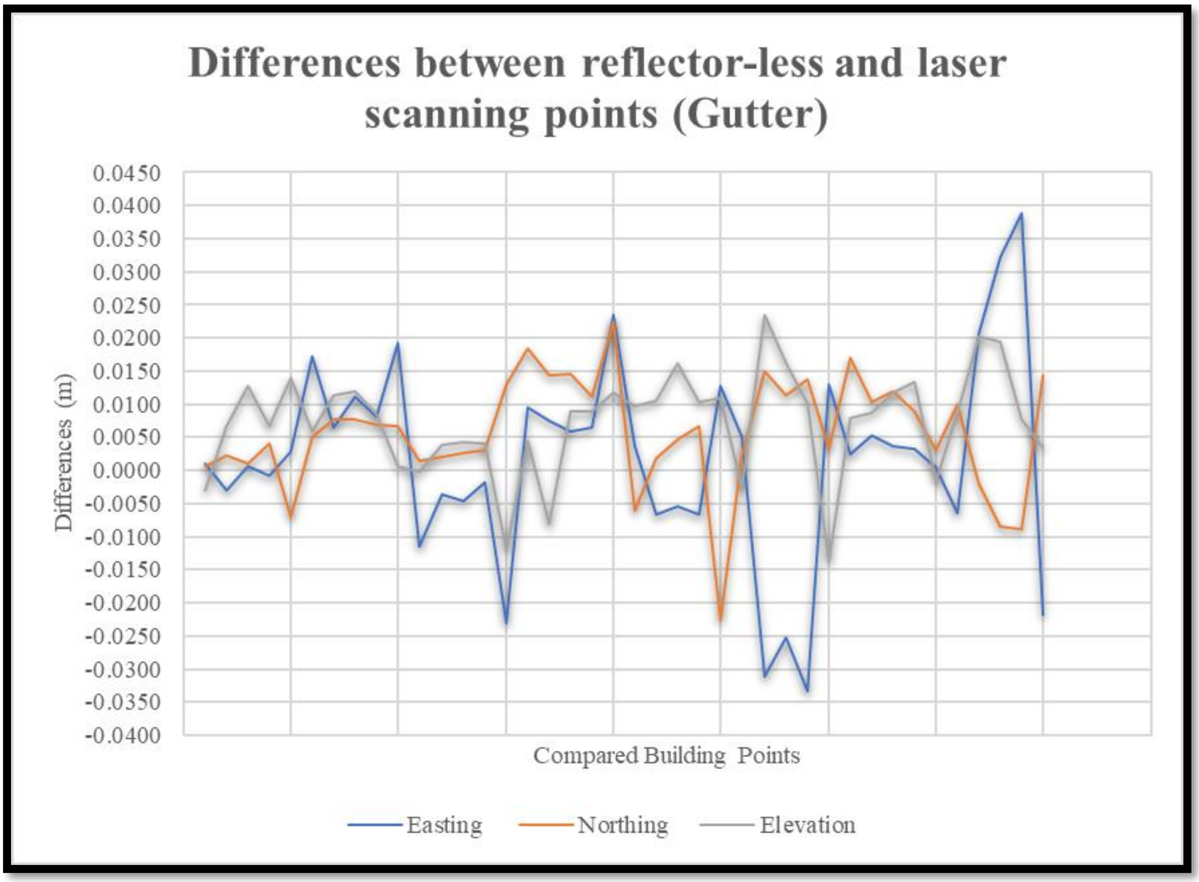
*Table 21 Averages of compared gutter points*




*Graph 3 Differences between reflector-less and laser scanning points (Eaves Only)*

| (Meters) | Number of Points | Sum of the Differences | Average | Sum of the Averages | Average Difference Total |
|---|---|---|---|---|---|
| **Easting** | 16 | 0.1542 | 0.0096 | | |
| **Northing** | 16 | 0.2301 | 0.0144 | | |
| **Elevation** | 16 | 0.2210 | 0.0138 | 0.0378 | 0.0126 |

*Table 22 Averages of Compared eave points*




*Graph 4 Differences between reflector-less and laser scanning points*

| (Meters) | Number of Points | Sum of the Differences | Average | Sum of the Averages | Average Difference Total |
|---|---|---|---|---|---|
| **Easting** | 40 | 0.4459 | 0.0111 | | |
| **Northing** | 40 | 0.3341 | 0.0084 | | |
| **Elevation** | 40 | 0.3738 | 0.0093 | 0.0288 | 0.0096 |

*Table 23 Averages of compared wall points*

As shown in the tables and graphs above the average difference for northing, easting and elevation was calculated to be 10.3mm.

# Chapter 5 Discussion

## 5.1 Analysis of comparison results

The differences between the easting, northing and elevation of the compared points in Chapter 4.5 above where calculated to have an average of 10.3mm in either direction. The average three-dimensional distance difference between the two methods of measurement is calculated to be 17.9mm. The total number of points collected on the building by the total station was 443, once it had been realised that the only way of comparing the data collected by the two methods was to manually extract points in the 3D model. It was realised that it would be impractical and take extensive time to compare all 443 points. Firstly, the gutter, eave and wall points at the corners of the building were compared. The mean result of difference in either easting, northing or elevation was ll.4mm. Secondly, the gutter, eave and wall points for 1 vertical line in the middle of each side of the building were extracted and added to the originally compared points. This, like stated above calculated an average of 10.3mm in either E, N, E direction. By doubling the sample size of the data there was only a change of 1.1mm in the difference in direction but the three-dimensional distance difference was reduced by 1.9mm.

Before any measurements with the total station or the laser scanner were completed, the building was measured using a tape measure. The dimensions of the building were then calculated using the data captured by the total station and laser scanner. The difference in the results are shown in the figure below.

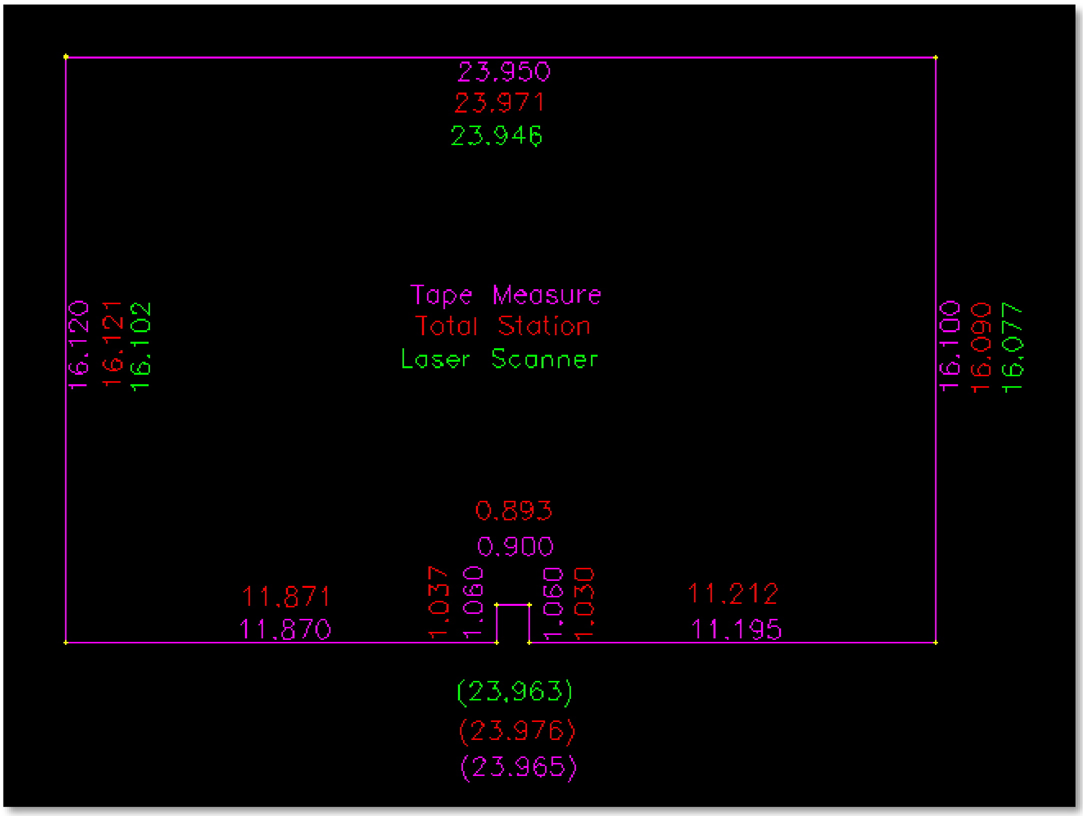



*Figure 28 Differences in dimensions of the building*

It can be seen in the figure above that the distances calculated between the three methods of measurement for the building dimensions are relatively similar. The average difference between the tape measure and total station was 12.3mm, tape measure and the laser scanner was 11.8mm and total station and laser scanner was 17.5mm. The distance difference that was calculated above from the average differences in easting northing and elevation was 17.9mm. Comparing this difference with the difference in building dimensions, there is only 0.4mm difference, which at the level of accuracy for building modelling I was looking at is considered minor.

Referring to graph 1 that depicts the differences between the two methods, there is an outlier in the elevation difference of 80mm. Excluding this value from the data collected, the maximum difference values are plus or minus 40mm. The explanation for this possible outlier could be an error in the extraction of the points from the point cloud in FARO Scene. The outlying point was found to be a measurement to the top of the eave at one of the corners of the building. Once comparing the elevation of all the top of the eave points, it was found that the laser scanning point at that corner was significantly lower. It was concluded that the outlier was a result of mis-clicking the correct point when extracting data from the laser scanning model.

When the comparison points were broken down into gutter, eave, and building wall, there was no noticeable difference in the difference between the laser scanning points and the total station points. Gutter points and wall points were the same. The range of results also very consistent with both sets of data.

The vertical accuracy comparison produced a 5.9mm average difference between easting and northing for the total station and 7.4mm average difference for the laser scanning points. The difference between the vertical accuracy comparison for both measurement techniques is 1.5mm. This was seen to be an insignificant difference between the two results.

In comparing the two different models that were created from both the total station data and the laser scanning data, there are some significant differences. The three-dimensional model that was created in terramodel and Autodesk is a simplistic wire frame model that depicts the main structure of the building and accurately represents the position and characteristics of the gutters and eaves on the building. The total station model was created using 433 of the 443 points that were captured. The laser scanning model that was created, contained approximately 525 million points, of which approximately 70% were irrelevant. The model produced from the laser scanning data however is extensive and extremely detailed. The two figures below present a section from the total station model and the laser scanning model.

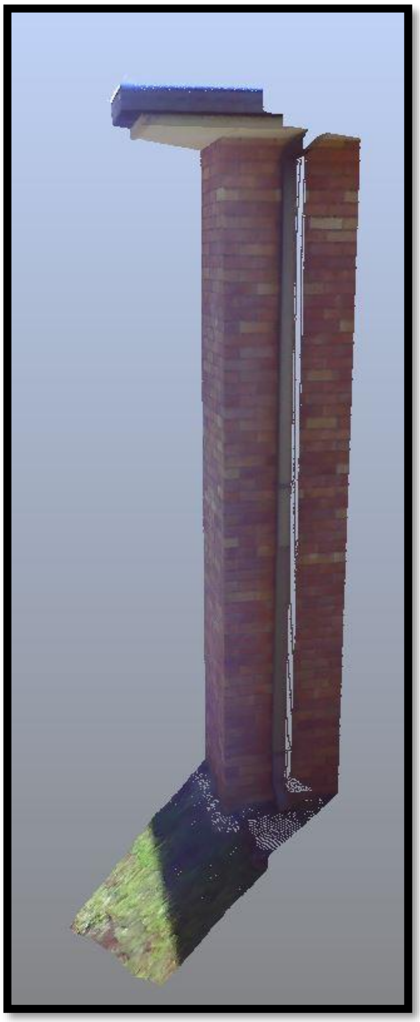


*Figure 29 SW Building corner snippet from FARA Scene*

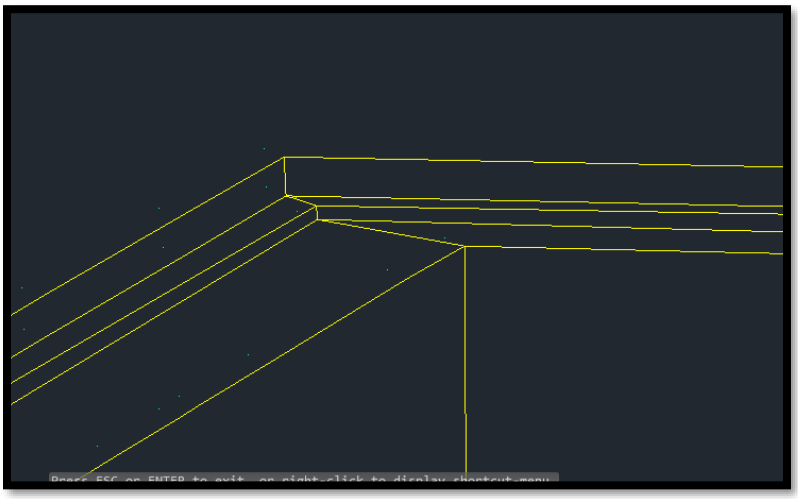


*Figure 30 SW Building corner snippet from Autodesk*

Comparing the two figures above, it is noticeable how much easier it is to establish what part of the building is being shown from the laser scanning model. This is due to the colour that has been assigned to each individual point to create an image and the large number of points that were reflected off the building. The second figure of the total station model shows the same corner of the building but focuses on the guttering and eave, which can be seen but needs explanation. This is the case for any sections of the model in both software. The laser scanning model can be interpreted by just scrolling through the program or looking at images from the model. The total station model however, requires explanation and or a description to be able to interpret what is being presented. The level of detail that the laser scanner is able to produce to show even the smallest feature of the model can be seen in the figure below.

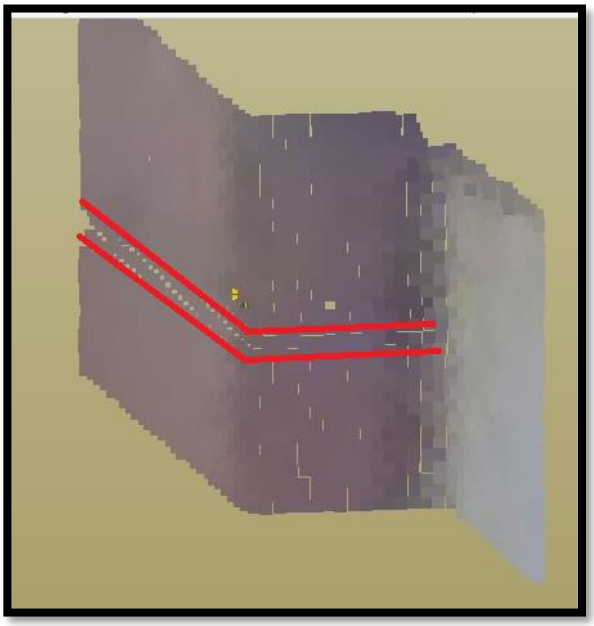


*Figure 31 Magnification of 3D model to define individual bricks*

This figure presents a magnified view of the bricks on the building. It shows how each brick can be visually defined by the indents in the point cloud where the mortar for the bricks are. The benefits of the laser scanning model compared to the total station model is also that it captures all the possible data that is within the scan parameters. The data collected from the total station relies on what was captured on the day. This means that if a client requires more data after the work has been completed, with the laser scanner this data would have already been collected. If using the total station however, there may be a need to revisit the site to collect additional data.

## 5.2 What didn't work

One of the goals of the project was to place the laser scanning data onto the GDA94 coordinate system. This goal was not achieved during the project as inexperience with the software did not allow for the scan stations to be moved onto imported coordinated points. The control network was established and imported into the model, but the scan stations could not be orientated to the network without compromising the residuals of the scan placement.

To still be able to compare similar points between the two methods of data capture, the local coordinates of the scan stations that had been assigned in the pre-processing stage were exported as a CSV. The total station data in terramodel was then orientated to fit the local coordinates of the scan stations. This allowed the points extracted from the three-dimensional model in Scene to be compared to the reflector-less points.

The goal of being able to overlay the two models and visualise a difference in points in the three-dimensional view was only somewhat achieved. The total station data was only able to be imported to the model and viewed in the planar view which did not allow for three-dimensional viewing comparison.

## 5.3 Time Analysis

The time that the project took including only aspects that a survey firm would complete for the two measurement methods can be seen in the table below.

| (Hours) | Total Station | Laser Scanner |
|---|---|---|
| **Office Planning** | 1 | 1.5 |
| **GPS Work** | 1 | 1 |
| **Traversing** | 4 | 4 |
| **Reflector-less Measurements** | 12 | N/A |
| **Laser Scanning Measurements** | N/A | 4 |
| **Processing Time** | 2 | 16 |
| **Total Time** | 20 | 26.5 |
| **Total Time for Laser Scanner without GPS and Traversing** | N/A | 21.5 |

*Table 24 Time taken for collecting and processing data*

As shown in the graph above the fieldwork for completing the total station data collection took a significant amount of time. This was due to the 443 reflector-less points that were captured. In a work place situation that number of points would be unrealistic to capture for the characteristics of the building as it is only rectangular in shape. The processing time for this data was relatively quick as the transformation and orientation of the data in terramodel was straight forward. However, the time it took to complete the laser scanning fieldwork was a third of that of the total station. Laser scanning in a more common work environment would also not include the time to traverse and set up a control network. This is because the laser scanner does not need to be set up over control points. The processing for this data did take a very extensive amount of time due to the lack of knowledge and experience surrounding the use of the program. The processing time for the laser scanning data cannot be used to accurately compare the time taken to collect data. This is because it is unknown how much quicker the process would have been with sound knowledge of the program. Taking out the time for unnecessary point capture for the total station and reducing the processing time for the laser scanning, then the time taken for both methods of measurement is relatively similar.

# Chapter 6 Conclusion

## 6.1 Introduction

The following chapter will discuss how the project met or did not meet the aims and objectives. The project will be summarised, and recommendations made in consideration of the results collected. Future work that could be completed to expand on the project will also be advised.

## 6.2 Conclusion

The aim of the project was to design a methodology to accurately test both a total station and laser scanner for measurement of an exterior building to create a building model. The project also aimed to compare the results for both instruments being tested and be able to provide to surveyors recommendations regarding the time for completing projects with either instrument. The three main objectives for this project were; create a building model using the data collected from both the terrestrial laser scanner and total station, compare and analyse the two models created to determine the accuracy of each instrument and provide recommendations in regard to best survey practice. The objective to provide recommendations in regard to time and best survey practice will be completed in chapter 6.3 of the conclusion.

The methodology that was designed allowed for both the laser scanner and the total station measurement methods to be compared with limited variables. Using the data that was captured from both instruments, two three-dimensional models were created. The results of the total station data was that a simple wireframe model with basic surface features and building dimensions was able to be produced. The results of the laser scanning data produced an extensive point cloud and a very detailed model of the building that was not able to be transformed onto the GDA94 coordinate system. A high level of knowledge is required for accurate and precise three-dimensional modelling of the laser scanning data. These results met the aim of the first objective for creating a 3D building model for both sets of data.

A point to point comparison was completed by extracting similar points from both sets of data. This comparison achieves the second objective, being able to compare the two models. The difference between the two models was found to be 17.9mm. This objective was only somewhat met as the model could not be overlaid for a visual comparison of all the captured points. A more extensive knowledge and experience of working with 3D software would have been able to a produce more comparative model.

## 6.3 Recommendations and Future work

Recommendations regarding the results that were collected for the comparison between the robotic total station and terrestrial laser scanner for building modelling are as follows. The total station reflector-less measurement function is only recommended for projects where relative position of a structure is required. The reflector-less measurement tool is not recommended for creating a three-dimensional model of buildings. To produce a model to the same quality and detail as a laser, the total station would have to capture an unreasonable number of points. The total station, however is still recommended for projects that require high accuracy positioning. The laser scanner is recommended for creating three-dimensional models because of its capability to capture a large number of points in a short period of time and present them as a data set that can be interpreted by any individual. The model of a building that the laser scanner is able to produce is extremely detailed for the time that it takes to complete a scan.

It is recommended that for large building modelling projects, the laser scanner be used as it can capture all relevant data faster than the total station. It should also be noted substantial time needs to be allowed for large data sets collected by the laser scanner. It is also recommended that for best practice when using the laser scanner, not only artificial reference objects should be utilised. External control like traverse points or GPS control points should be included to place and reference scan data.

Future work that could be completed regarding the comparison between the total station and the laser scanner are as follows. Research into the capability of the laser scanning function in the S7 total station compared to that of the FARO laser scanner or the Trimble SX10 total station. Further work could include the capability of the laser scanner for interior building modelling and combining interior and exterior laser scanning data. Finally, the use of different and more capable three-dimensional modelling software could be looked at, to investigate the way data can be manipulated.

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# Appendices

## Appendix A Project Specification

ENG4111/4112 Research Project
**Project Specification**

**For:** Matthew Kevin Copley

**Title:** Comparison between robotic total station reflector-less measurement and terrestrial laser scanning techniques.

**Major:** Surveying

**Supervisors:** Zhenyu Zhang

**Enrolment:** ENG4111 – ONC S1, 2019 ENG4112 – ONC S2, 2019

**Project Aim:** The aim of this project is to create a 3D model of a building using a 3D terrestrial laser scanner and a total station using the reflector-less measurement function. Compile and compare the accuracies of both the total station and laser scanner. Provide cost verse time analysis data for the use of everyday surveyors. Produce a building format plan and give overall recommendations for completing a project using either a laser scanner or reflector-less total station measurement.

**Programme: Version 1, 20th March 2017**

1. Research and compare different terrestrial laser scanners and total stations that would be available for testing.

2. Research the different software programs that could be used for processing data from the available instruments.

3. Review all choices and confirm which instruments and software programs will be tested and used. Book and confirm availability.

4. Communicate with USQ Residential Colleges to gain approval for survey work to be completed on two of the Steele Rudd College blocks.

5. Prepare a methodology for undertaking the fieldwork, including a procedure and timeline for each task.

6. Gather all materials and equipment and confirm that all equipment is working correctly and has been calibrated recently.

7. Position and install control marks around the buildings in appropriate locations for scanning to take place.

8. Traverse from a local PSM around the placed control marks and complete a level run over all control marks used.

9. Process traverse and level run data and assign coordinates to each control mark.

10. Complete reflector-less total station measurements of both buildings and use terrestrial laser scanner to scan both buildings.

11. Process the fieldwork data, by creating 3D models from both the laser scanning data and the reflector-less measurements. Create time vs cost analyses reports.

# Appendix B Risk Assessment

The following risk assessment plan has been filled out in accordance with USQ policy to be able to conduct the necessary field work required. The project does have the potential for some risk and hazards to occur, like many job sites. These however, can be mitigated using basic safety procedure.

The main risk in carrying out the fieldwork for this project is the laser emitted from both the laser scanner and the total station. This risk has been listed in the risk assessment below, but as the laser scanner only uses a class 1 laser no measures are need. The safety measures for conducting laser scanning on USQ property will be adhered to. These are, safety tape and barriers, warning signs and laser scanning safety glasses. However, the total station uses and class 1 and 2 type laser and so mitigation measure will be put in place. Waiting to use the class 2 laser until site is clear of the public.

University of Southern Queensland — Offline Version

USQ Safety Risk Management System

**Note**: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

| | | | |
|---|---|---|---|
| Safety Risk Management Plan – Offline Version | | | |
| Assessment Title: | Comparison between robotic total station reflector-less measurement and terrestrial laser scanning techniques for accurately positioning exterior building format | Assessment Date: | 25/03/2019 |
| Workplace (Division/Faculty/Section): | University of Southern Queensland | Review Date:(5 Years Max) | 6/03/2019 |
| Context | | | |
| **Description:** | | | |
| What is the task/event/purchase/project/procedure? | Laser Scanning and Reflector-less Total Station Measurement | | |
| Why is it being conducted? | Dissertation Requirement | | |
| Where is it being conducted? | Residential Colleges, Darling Heights, Toowoomba | | |
| Course code (if applicable) | ENG4111/4112 | Chemical name (if applicable) | |
| **What other nominal conditions?** | | | |
| Personnel involved | Two Students | | |
| Equipment | Terrestrial Laser Scanner (Faro Focus S Series 120), Total Station (Trimble S7) | | |
| Environment | Residential | | |
| Other | | | |
| Briefly explain the procedure/process | Both a laser scanner and total station will be set up in multiple positions around 2 different buildings to measure the exterior building format. | | |
| Assessment Team - who is conducting the assessment? | | | |
| Assessor(s) | Matthew Copley | | |

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

| Probability | Consequence: Insignificant<br>No Injury<br>0-$5K | Minor<br>First Aid<br>$5K-$50K | Moderate<br>Med Treatment<br>$50K-$100K | Major<br>Serious Injuries<br>$100K-$250K | Catastrophic<br>Death<br>More than $250K |
|---|---|---|---|---|---|
| Almost Certain<br>1 in 2 | M | H | E | E | E |
| Likely<br>1 in 100 | M | H | H | E | E |
| Possible<br>1 in 1000 | L | M | H | H | H |
| Unlikely<br>1 in 10 000 | L | L | M | M | M |
| Rare<br>1 in 1 000 000 | L | L | L | L | L |

**Recommended Action Guide**

| Recommended Action Guide |
|---|
| E=Extreme Risk – Task **MUST NOT** proceed |
| H=High Risk – Special Procedures Required (See USQSafe) |
| M=Moderate Risk – Risk Management Plan/Work Method Statement Required |
| L=Low Risk – Use Routine Procedures |

| Step 1 (cont) | Step 2 | Step 2a | Step 3 | | | | Step 4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Hazards:* From step 1 or more if identified | *The Risk:* What can happen if exposed to the hazard with existing controls in place? | *Existing Controls:* What are the existing controls that are already in place? | *Risk Assessment:* Consequence x Probability = Risk Level | | | | *Additional controls:* Enter additional controls if required to reduce the risk level | *Risk assessment with additional controls:* | | | |
| | | | Consequence | Probability | Risk Level | ALARP? Yes/no | | Consequence | Probability | Risk Level | ALARP? Yes/no |
| Tripod legs with instrument is blown/ knocked over | Equipment is expensive to replace | Use sandbags to secure tripod legs, and use safety cones to mark the tripod | Major | Possible | Low | Yes | | Minor | Unlikely | Low | Yes |
| High Traffic Area for pedestrians | Bystander may trip and fall over any equipment | Use safety cones or bollards if necessary to block off work area to the public, do not leave equipment lying around | Moderate | Unlikely | Low | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Laser beam from both laser scanner and total station | Direct contact with eyes can cause damage to the reinter. | Don't look directly at the laser when taking measurements from total station. Be aware of where the laser scanning is taking place.<br>Set up barriers and a perimeter around the scanner when in use for the public to stay clear. | Major | Unlikely | High | No | In a public place put signs up to tell people not to look directly at the laser scanner | Major | Unlikely | High | Yes |
| Temperature, Heat | Heat Stroke, Sunburn, Fatigue | Wear PPE to avoid the elements, includes long sleeves and long pants, drink lots of water | Moderate | Likely | Moderate | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Snakes and Insect bites | Allergic reaction, injury, death | Where protective clothing and be aware of surroundings | Major | Rare | High | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Driving a motor vehicle around the college | Injury, or death | Drive very slowly, use flashing light, be aware of surroundings | Major | Unlikely | Moderate | Yes | | Select a consequence | Select a probability | Select a Risk Level | Yes or No |
| Laser Scanning<br><br>Class 1 – safe – no measures required<br><br>Other than class 1 | VZ 400 Laser scanner Laser Class 1<br><br><br>Eye damage | Where other than Class 1 laser is used adhere to following :-<br>Eye Protection by natural aversion responses such as blinking, looking away from beam. Do not view directly into the laser beam.<br>Warning sign is to be placed at entrance to the Worksite indicating that a Laser is in use.<br>Notify Workers in the area. | Moderate | Unlikely | Moderate | Yes | | | | | |