University of Southern Queensland
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Terrestrial Laser scanning for Building Information Model (BIM) Development and Application

A dissertation submitted by

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ABSTRACT

Terrestrial laser scanners (TLS) offer the ability to collect highly accurate high density 3D point clouds. This dissertation looks into errors evident in TLS scans, such as edge effects, ranging errors, noise, and effect of surface reflectivity with the project scanner (which is a Trimble TX5). It then goes on to analyse the magnitude of these errors and ultimately concludes that the TLS is a suitable tool for use in Building Information Modelling (BIM)

It then analyses the suitability of the Revit add-on called Scan To Bim for use in creating Revit elements from TLS point clouds, and concludes that care needs to be taken, and identifies more research is required to determine accurate methods. It also highlights the difficulties inherent in creating complex building elements such as columns, windows, doors, and ducting which are many and varied.

University of Southern Queensland
Faculty of Health, Engineering and Sciences
ENG4111/ENG4112 Research Project

LIMITATIONS OF USE

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CERTIFICATION OF DISSERTATION

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

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

B Light

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CHAPTER 1 – INTRODUCTION

1.1 Introduction

Building information model (BIM) provides detailed information on building components, geometry, spatial relationships, and other properties in three-dimensional (3D) space. BIM helps understand geometric properties of buildings and provides the base for a number of forms of functional analysis and has many applications in areas such as facility management, maintenance, heritage protection, deformation monitoring, town planning and the support of construction decisions. The key idea behind a BIM is to obtain accurate 3D building data in order to adequately describe the buildings structure.

Terrestrial laser scanners (TLS) offer the ability to collect highly accurate high density 3D point clouds. Applications of TLS in BIM have not yet been extensively tested. Moreover, effective methods and workflows for efficiently extracting building structure information from large TLS data sets have yet to be developed.

This project aims to analyse the advantages and disadvantages of a TLS over conventional surveying techniques, it will aim to assess the accuracies of each method and then develop workflows to extract geometric and structural information from laser scanning point cloud data, and test these applications in building information modelling.

1.2 The problem

Terrestrial laser scanners have not been a technology that has caught on very quickly in the more conventional side of the surveying industry. With historically high startup costs for field equipment, and the very high demands on computing power required to process the immense data sets. Surveyors have been put off delving into this realm for quite a while.

Building information modelling has been the realm of the architects and engineers since its inception in in the late 1970's (Epstein 2012). Surveyors have been reluctant to enter into this new field, opting to stay with the more familiar CAD arena and three dimensional cad modelling.

1.4 Research Objectives

This project aims to analyse the advantages and disadvantages of a TLS for use within a BIM. It aims to assess the accuracies of TLS and then develop workflows to extract geometric and structural information from laser scanning point cloud data, then test these applications in building information modelling.

CHAPTER 2 – LITERATURE REVIEW

2.1 Introduction

This chapter will review the literature for both Building Information Modelling and Terrestrial Laser Scanners in order to obtain an understanding of the two and how they might be used together. It will look at an understanding of these two relatively new technologies and what is being done to use these technologies and streamline the process of collecting and processing data.

2.2 Building Information Modelling

The term 'Building Information Model' is one that is starting to be thrown around a lot in surveying circles in recent times. Whilst the Building Information Model (BIM) is something that has been adopted by Architects and Engineers for many years in the design and conceptualization of new projects. It is something that surveyors as a profession have been slow to adopt and understand. Over recent years there has been an ever increasing interest in Building Information Models due to its many benefits(Volk, Stengel & Schultmann 2014). This has resulted in the necessity for surveyors to adopt these new techniques or be left behind in this technological age. In fact a 2008 survey found that 45% of architects, engineers, contractors and building owners surveyed used BIM on 30% or more of their projects(Steel, Drogemuller & Toth 2012).

2.1.1 Definition

In ISO 29481-1:2010 the International Standards Organisation defines a building construction information model as:

> *Shared digital representation of physical and functional characteristics of any built object (including buildings, bridges, roads, etc.) which forms a reliable basis for decisions.*

This is a very vague and broad reaching definition. One that seems to recur endlessly when researching the topic of BIM.

Essentially when looking at the definition, is it seems that BIM reflects the change from the use of analog tools to digital ones (Epstein 2012). Perhaps the most important thing to take from the inability to find a definitive definition of BIM is that it is many different things to many people. To a surveyor the BIM should be whatever the end client desires, not what the surveyor wants to create.

2.1.2 BIM for existing buildings

Building Information processes for new buildings and concepts are well recognized in the industry. Commercial software packages such as Tekla Structures, Autodesk Revit, and Trimble's SketchUp have all cemented themselves as excellent packages for BIM. However, all of these packages have one thing in common, they are all primarily aimed at BIM for new buildings from their initial conception. Whilst they all have tools, add-ons or extra packages that can be used to handle point clouds and as-built data from existing buildings. Most of them are still in their infancy and still have a very heavy feeling of an 'add-on' and are not as intuitive to use as when creating a building information model from an all new design.

2.1.3 INDUSTRY FOUNDATION CLASSES

Industry Foundation Classes (IFC) provide software applications in the field of architecture, engineering and construction that are IFC compliant with a platform for the exchange of information (Bazjanac & Crawley 1997). Whilst an important, and widely discussed topic, it is outside of the scope of this project. The only thing we need to consider is, when choosing a software package later in the project, it is important that the package be IFC compliant in order to ensure maximum compatibility with potential clients.

2.1.4 LEVEL OF DEVELOPMENT

Level of development (LOD) framework from www.bimforum.org addresses a number of issues with BIM that arise when it is used as a communication and collaboration tool (BIMForum 2013). The framework identifies 6 different fundamental levels of LOD, which are outlined in (Figure 1)

LOD 100	The Model Element may be graphically represented in the Model with a symbol or other generic representation, but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements.
LOD 200	The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 300	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element.
LOD 350	The Model Element is graphically represented within the Model as a specific system, object, or assembly in terms of quantity, size, shape, orientation, and interfaces with other building systems. Non-graphic information may also be attached to the Model Element.
LOD 400	The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element.
LOD 500	The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements.

Figure 1- Fundamental LOD Definitions - BIMForum.org

For the purposes of this research project LOD will not be considered, however it is important that the purpose of this project is to investigate construction building information models at a level that will include simple architecture such as walls, floors, and ceilings. In addition it will look at modelling locations of things like windows and doors. It will not look into modelling accurate models of individual components from TLS point clouds such as light fittings, furniture, or other detailed information.

2.2 Terrestrial Laser Scanners

Terrestrial Laser Scanners (TLS) are fast becoming the new must have tool for surveyors and other industry professionals in the architecture, engineering and construction (AEC) sector. In relatively recent times, TLS were considered expensive, over the top and with the resultant large data sets, extremely hard to process data.

Historically, this was probably correct, with TLS costing in the multiple hundreds of thousands of dollars and the processing power required to handle such large datasets costing similarly prohibitive amounts. This has resulted in TLS being slow to be embraced by the general surveying industry, and as such remained the domain of some of the larger more specialized architectural, engineering and construction companies.

Vast leaps in technology has brought the computer power required to handle the large datasets into the realm available in normal office PC's. At the same time the cost of TLS is now in similar price brackets to the more conventional survey equipment like RTK GPS' and Robotic Theodolites. Such that many surveyors are starting to look to this equipment to deliver their end customers with new and exciting products.

2.2.1 Types of Terrestrial Laser Scanner

Terrestrial laser scanners can be broken up into two broad categories based on the method with which they determine the distance to the point being scanned. These are known as time-of-flight laser scanners and phase-shift laser scanners (Vandezande, Krygiel & Read 2013).

Time of Flight Laser Scanner

Time of flight laser scanners as the name suggest, use the time of flight method to determine the distance from the scanners sensor to the point being measured. The instrument sends out a pulse of light and measures the time it takes for the pulse to return to the optical sensor. Time of Flight laser scanners have a very long range, with units like the Reigl VZ-4000(Riegl 2013) and Maptek(Maptek 2013) stating on their brochures that they are capable of distances into the multiples of kilometers with precisions of approximately 8-10mm.

Scanning rates for time of flight laser scanners are generally considered slower than those of phase based laser scanners, however the speed of time of flight scanners is rapidly increasing, with the Reigl VZ-4000 capable of up to 220,000 points per second (Riegl 2013).

Phase Shift Laser Scanner

Phase shift laser scanners measure the shift of phase between an emitted laser pulse compared to the light that it receives back to the sensor once it has bounced off the target being measured (Vandezande, Krygiel & Read 2013). When compared to time of flight laser scanners, the distance ranges are considerably shorter. With ranges of 120m for the Leica ScanStation P20 (Leica-Geosystems 2013) out to 330m for the Faro Focus3D X 330 (Faro 2013).

Scan rates for phase shift laser scanners are a lot higher than for those of time of flight scanners, with measurement rates nearing 1 million points per second typical in this class of scanner.

Another area where phase shift laser scanners excel over time of flight scanners is in accuracies. With the Faro Focus3D X330 claiming an accuracy of a couple of millimeters (Faro 2013) and the Leica ScanStation offering similar accuracies (Leica-Geosystems 2013).

As a quick comparison of the different laser scanners and their specifications, see the Table 1 – Comparison of different Laser Scanners below.

Table 1 – Comparison of different Laser Scanners

	Faro Focus 3D	Leica ScanStation P20	Maptek I-Site 8810	Riegl VZ-4000
Method of Measurement	Phase Shift	Phase Shift	Time of Flight	Time of Flight
Accuracy	±2mm	±2mm	8mm	15mm
Range	0.6m-120m	0.4-120m	2.5-1400m	5-4000m
Points Per Sec	976,000	1,000,000	40,000	220,000

2.2.3 ACCURACY OF LASER SCANNERS/POTENTIAL ERRORS

Before using a laser scanner in a BIM situation a surveyor must first fully understand the errors and limitations inherent in a laser scanner. This is because the surveyor must fully understand the data the laser scanner and its software outputs, so that it can be utilized correctly.

As with any survey instrument, the pamphlets and specifications stated by manufacturers can seem very daunting and hard to understand. Specifically to laser scanners, accuracy specifications given are not directly comparable (Boehler, Bordas Vicent & Marbs 2003). The accuracies given are general and are given for very specific conditions, which normally aren't replicated when using the instrument in real world applications.

Studies into the Accuracy of Laser Scanners

There have been many investigations into the accuracy of laser scanners and the way they perform under different conditions.

Boehler, Bordas Vicent, & Marbs (2003) investigated the accuracy of laser scanners extensively. They looked into a number of errors and accuracies inherent in laser scanners. They investigated such potential errors as angular accuracy, range accuracy, resolution, edge effects, and surface reflectivity. Their analysis of the laser scanners available at the time of the study was extensive and well laid out, however these results may potentially no longer be applicable with the advances in scanner technology over the last decade. This will be investigated later on in the practical section of this project.

Tucker (2002) tested the accuracies of a Cyrax 2500 (also known by many as the Leica HDS 2500). Whilst they did not look into how this laser scanners errors were produced. It considered whether the accuracies stated by the manufacturer, were within those specified by the manufacturer. Similar methods will be discussed and used later in the practical section of this project.

Angular Accuracy

In a terrestrial laser scanner the laser pulse is deflected by a small rotating device (Figure 2- Faro Laser Scanner with rotating mirror highlightedsuch as a mirror or prism and sent to the object being measured, the second angle is usually changed by a mechanical axis or other optical device. These two angles, similar to a conventional total station are used to compute the three dimensional coordinates. Any errors inherent in the laser scanners angular measurement, will obviously be extrapolated perpendicular to the pulse (Boehler, Bordas Vicent & Marbs 2003).

Figure 2- Faro Laser Scanner with rotating mirror highlighted

Range Accuracy

As previously stated, terrestrial laser scanners compute their range using either time of flight or phase comparison principles. When scanners don't have a defined reference point as is often the case when using modern scanners, then it is not possible to measure direct range errors of the instrument. It is only possible to measure range differences between targets (Boehler, Bordas Vicent & Marbs 2003).

Resolution

Resolution of a laser scanner is quoted differently by manufacturers and their respective products, it generally a variable setting, up to a maximum value. Maximum resolution of a terrestrial laser scanner is essentially a function of the minimum angular increment possible by the instrument between consecutive points, and the size of the laser spot being produced by the instrument (Boehler, Bordas Vicent & Marbs 2003).

Edge Effects

Edge effects occur when the focused laser spot hits an object edge. Since the laser has a finite size, part of the laser is reflected by the object and part of it reflected by the surface behind the edge, or nothing at all. As depicted in Figure 3- Edge Detection. This can produce incorrect points being calculated as part of a scan. The

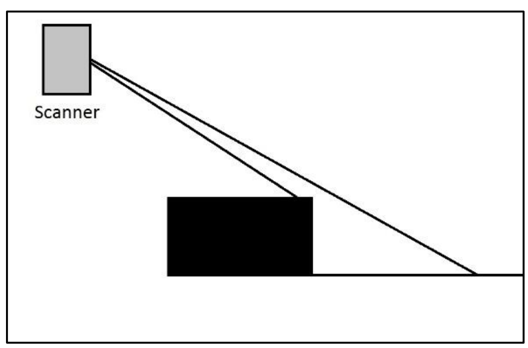

Figure 3- Edge Detection

range error in these points can vary in magnitude from a fraction of a millimeter to several decimeters (Boehler, Bordas Vicent & Marbs 2003).

Effect of Surface Properties

Much like the reflector-less measurement of a total station, laser scanners rely on the laser pulse they emit to be reflected back from the surface they are measuring. The strength of the return of this pulse is dependent on many factors including distance, atmospheric conditions, angle of incidence, and the reflective properties of the object being scanned (Boehler, Bordas Vicent & Marbs 2003).

Environmental Considerations

As mentioned previously, atmospheric conditions play a part in the accuracy of a terrestrial laser scanner. The environmental conditions can also play a part in accuracy of the scanner.

As with any other high accuracy electronic equipment, scanners will only work when used within a specific temperature range (Boehler, Bordas Vicent & Marbs 2003). For example the Faro Focus 3D is stated to work in an ambient temperature range of 5º - 40 ºCelcius (Faro 2013).

Similar to other optical distance measurements such as those from total stations, the speed of light is affected by temperature and pressure variations. Generally, for short distances this affect is generally negligible (Boehler, Bordas Vicent & Marbs 2003).

2.2.4 Combining BIM with Terrestrial Laser Scanners

There already exists research and studies into the automatic extraction of building features from point cloud data sets that have been created by terrestrial laser scanners.

More traditional methods (not utilizing terrestrial laser scanners) for as-built building information modelling mainly involve creating a two dimensional manual reconstruction of the layout from conventional surveying techniques. Then simply elevating this to a certain height to create a three dimensional model (Pu & Vosselman 2006).

Automatic Feature Reconstruction

A number of studies have been carried out regarding automatic extraction of features from laser scanned point clouds. The idea of as-constructed building information models is now a possibility with the rise of cost effective terrestrial laser scanners (Tang et al. 2010).

There currently exist a number of methods for reconstructing many geometric profiles like those found in buildings. For linear structures like mouldings, pipes, conduits, rafter, and beams then a cross section can be created by joining points in the scan and then sweeping the cross section along a path to form the desired model object (De Luca, Véron & Florenzano 2006). Or for more indepth structures such as decorative carvings or ornaments, they may require non-parametric modelling using triangle meshes or the use of databases of known object models (Campbell & Flynn 2001).

CHAPTER 3 –METHODOLOGY

3.1 The Laser Scanner

The research component of this project is going to involve investigating the accuracy and suitability of a terrestrial laser scanner for building information modelling. For this project I will be using a Trimble TX5 Laser Scanner (Figure 4) which has been generously supplied by Ultimate Positioning. The TX5 Scanner uses a phase shift measurement technique, has a stated ranging error of ±2mm and can measure point at rates up to 976,000 per second (Trimble 2012). The TX5 does not require an external data collector or laptop and holds its battery within itself. Which makes for a very small, and light unit, weighing only 5.0kg,

Figure 4- Trimble TX5 Laser Scanner - http://www.trimble.com/3d-laser-scanning/3d-scanners.aspx

3.2 Accuracy Testing

For the purposes of this project, we are not interested in testing every accuracy criteria as discussed earlier as some, such as resolution and angular accuracy, are extremely time consuming to test and not really relevant to this project.

The errors we will be considering as a part of this research will be:

- Ranging – in order to determine potential errors in measuring distances between object in scans. This is important as it will give an indication of potential error in room sizes, wall thicknesses, and any other measurements created as part of the BIM.
- Noise – this will be an important error to get an understanding of, it will give an indication of deviations from a plane we can expect when modelling surfaces.
- Edge Effects – important to consider as it will directly affect calculations when trying to calculate edges such as building walls and corners.
- Surface reflectivity – important to consider, as in any building site, there will be many different surface to scan and it will be important to gain an understanding of the effect of surface reflectivity on accuracy of measurements.

3.2.1 Ranging

To test the ranging accuracy of the laser scanner, a simple scan was carried out that included three spherical targets mounted on solid mounts. These were scanned using a number of various levels of accuracy within the scanner to see if this had any effect. These three targets were then swapped standard reflector style targets and coordinated with a calibrated and adjusted Trimble S6 total station from the same station as the scanner and then again from an independent station. These measurements were then put into the Liscad SEE adjustment package to gain coordinates and error ellipses for each of the stations for comparison with the results from the laser scanner.

Two of the targets within the homestead scan were also coordinated with the total station from two points and adjusted to calculate horizontal and vertical distance for comparison to the TLS data.

3.2.2 Noise

Noise At A Distance

The test for noise in scanned data was carried out by scanning a flat piece of wood, approximately 300mm wide and 3.6m long. The scanner was set up at distance of approximately 10 metres away, approximately square out from the centre of the wood.

To test for variances in quality setting (and consequently scan speed) versus noise in the point cloud the scan was carried out a number of times on various different quality setting within the scanner (x2, x3, x4, x6, x8) to ascertain if there were any differences to the noise produced within a scan.

Noise Up Close

To test for noise variances, up close and to determine whether angle of incidence plays any part in the noise present within the point cloud the same piece of wood was scanned as was used in the distance noise test. However, this time the scanner was set up approximately 3 metres from the scanner, square out from one end of the piece of wood.

The reason for setting up like this was that for a section of the scan the surface of the wood would be perpendicular to the beam from the scanner, but at the other end of the wood, the beam would then be at approximately 45º to the beam. This is in order to get a good indication of noise that can be expected at varying angles of incidence within a scan. Also, as with the noise at a distance scan, it was carried out at a number of different quality setting within the scanner to ascertain whether this would affect the noise evident within the scan.

3.2.3 EDGE EFFECTS

In order to get an idea of edge effects that are evident within a scan, a similar test to the one of Boehler et al (2003) was used. A small piece of wood was mounted in front of larger piece of wood. This board was mounted roughly perpendicular to the laser scanner and scanned at varying levels of accuracy within the scanner (x2, x3, x4, x6) to see whether this would significantly affect whether this would affect edge effects within the scanned point cloud. If there were no edge effects were evident within the scan, then visual inspection of the scan should show only two flat surface, with no extraneous points between the two.

3.2.4 SURFACE REFLECTIVITY

To test the effect of surface reflectivity on the TX5 a flat board was setup approximately 2.5m from the scanner facing approximately at the scanner. On the board were a number of different colour sections to ascertain the effect of colour and surface reflectivity on the accuracy and noise of the laser scanner. The different surface colours were (from right to left). Matt black, gloss black, silver, grey, white, and finally retro-reflective yellow (Figure 5).

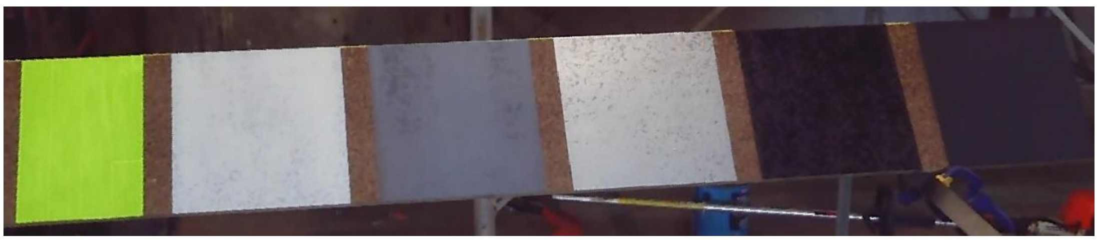

Figure 5- Colour Test Board

Once the board was setup, the board was scanned at quality settings x1, x2, x3, x4, and x6 to test if there was any correlation between colour, reflectivity, and scanner accuracy with respect to noise in the scan. The results were then using Faro's Scene software to calculate the standard deviation of the distance of points within the scan from the calculated plane (Reinhard Becker 2014).

3.3 Building Information Modelling Software

There are many building information modelling packages available on the market today. With offerings ranging from Graphisoft's Archicad, Trimble's Tekla, Bentley's Buildings, Autodesk's Revit, and many more it is very difficult to choose a package to use. When considering which package to use for this project I was looking for one that was going to be cheap to implement for the life of the project. It would also have to be IFC compliant, have plenty of assistance available online, and have powerful point cloud tools available.

I took the obvious choice in my opinion, Autodesk's Revit. Not only does Autodesk offer free three year software licenses to students, have masses of online forums, tutorials and help desks. It is also IFC compliant and has a number of available plugins to handle point cloud data as well as its own point cloud engine.

Whilst researching software for this project and hardware requirements, it became very evident that when handling even medium to small size data sets that computer speed, processing cores, memory and solid state drives are very important handle the datasets in reasonable timeframes. Faro recommends 2.5GHz 64bit Multicore-processors, 16GB or more of RAM, and solid stated hard drives (Faro). For the sake of completeness, all point cloud processing will be carried out using on a system running the following:

- Intel Core i7-3770 CPU @3.40GHz (4 physical – 8 virtual processing cores)
- 16GB Ram
- 128GB Samsung 840 Pro Solid State Hard Drive
- 3.0TB Conventional Hard Drive

- Nvidia GeForce GT 640 Graphics Card
- Windows 8.1

3.4 The Sites

For this project, I have selected 3 different sites to try and analyse work flows and the suitability of terrestrial laser scanners in building information modelling. Each one is quite different and has been selected to present common scenarios that are given to a surveyor when carrying out surveys.

3.3.1 SITE 1 – MODERN OFFICE BUILDING

The first site that has been chosen is a typical office building. It has been chosen due to its simple architecture, and the fact that it is a modern building, built to industry standards and it is expected that the walls, floors and ceilings will be relatively square and plumb. This will make extracting data from the point clouds a reasonably simple exercise.

3.3.2 SITE 2 – INDUSTRIAL SHED

The second site that has been chosen for this project is a medium sized industrial shed. It has been chosen due to its industrial design, and the fact that it has all of its structural elements clearly visible for the scanner to measure. The idea here is that I hope to be able to use the software to model not only things like walls, floors and ceilings, but also the structural supports, purlins, and possibly parts of the electrical system.

3.3.3 SITE 3 – HOMESTEAD

The third and final site chosen for this project is an old stone homestead known as Strathneath. It was built circa 1860. It has thick stone walls, a full return verandah, a valleyed roof and lots of non-standard (in today's terms at least) architecture, making it near on impossible to model accurately with more conventional survey methods. With pressed tin ceilings and many walls and features that are not quite square it should present quite a challenge to turn the laser scan point cloud into a suitable building information model. This site is also surrounded by a number of trees, and lush garden which will have the potential to make it difficult to get adequate scans of the outside of the building.

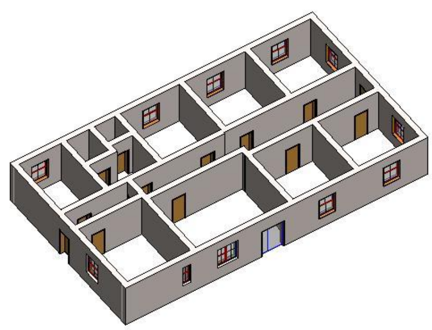

Figure 6- Manual Survey BIM of Strathneath Homestead

CHAPTER 4 – RESULTS AND ANALYSIS

4.1 Accuracy Testing

4.1.1 RANGING

Ranging testing went very simply, with the least squares adjustment carried out in the least squares module of Liscad and coordinates calculated for comparison. The results from angle readings can be found in Appendix 2 as an ISO Rounds report and the results from the least squares adjustment can be found in Appendix 3.

The traverse layout for the ranging test can be seen in Figure 7. In order to calculate a least squares adjusted solution, and to gain an orientation, the bearing from base 1 to sphere 1 was fixed, and all analysis done from here. This meant that distance only can be compared for sphere 1, and angle and distance can be compared on spheres 2 and 3.Diagrammatic representation of the error ellipse and the calculated position for each of the spheres from each accuracy setting can be seen in Figure 8 and Figure 9.

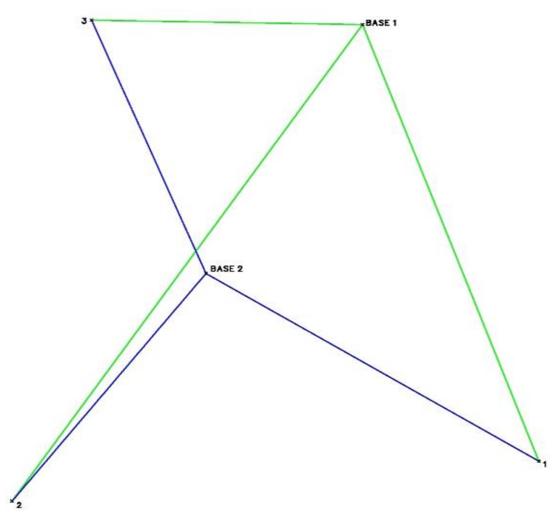

Figure 7. Angle Testing - Traverse Layout

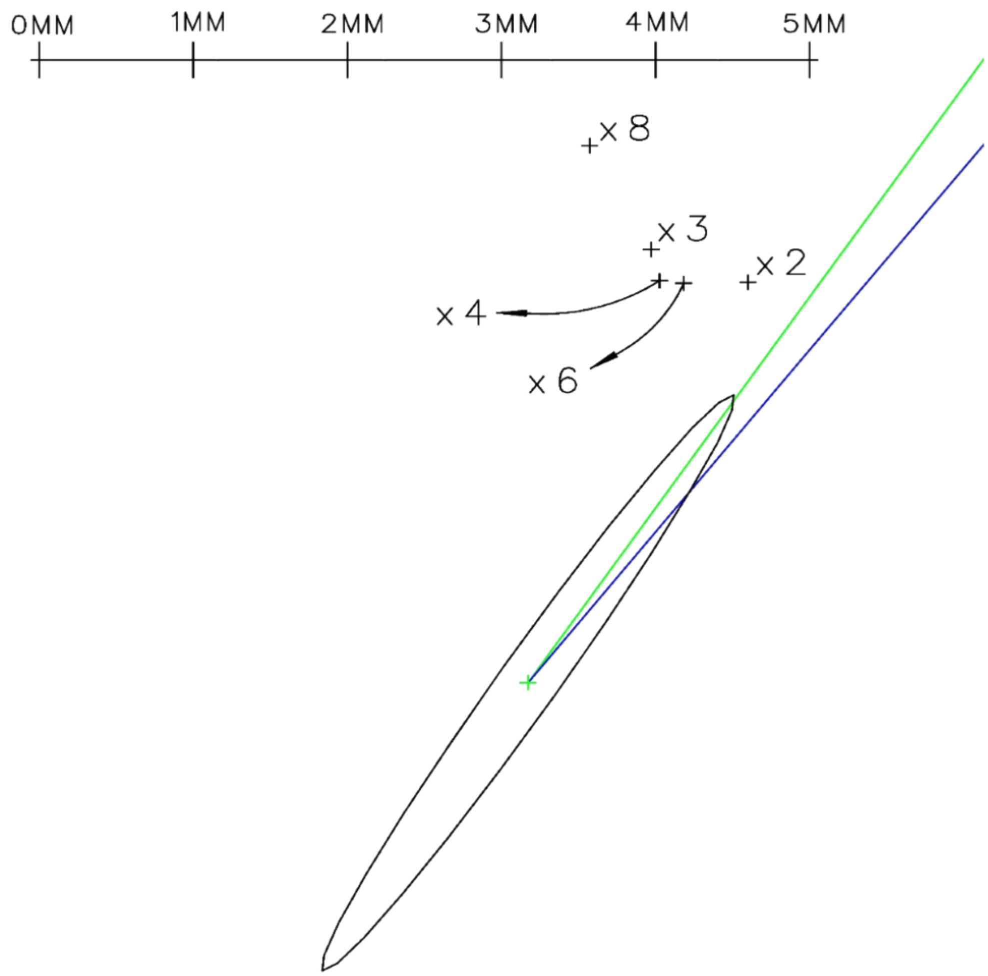

Figure 8. Angle Testing - Sphere 2

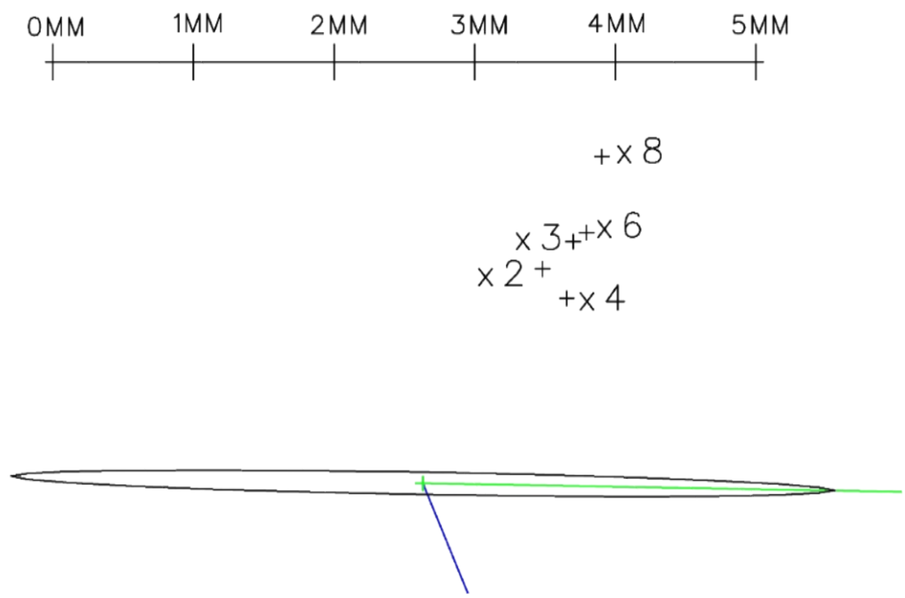

Figure 9. Angle Testing - Sphere 3

As can clearly be seen by the diagrams none of the calculated coordinates fell within the error ellipses from the total station observations. There are also no readily obvious patterns in the errors produced when the accuracy of the TLS is increased. Direct linear differences between the least square adjusted point and the points from the TLS can be seen in Table 2 - Difference between Least Squares and TLS Scanned Point.

	SPHERE 1	SPHERE 2	SPHERE 3
X2	4.8mm	3.2mm	1.7mm
X3	4.8mm	3.2mm	2.0mm
X4	4.0mm	1.7mm	3.0mm
X6	4.4mm	3.0mm	2.1mm
X8	4.8mm	3.2mm	2.6mm

Table 2 - Difference between Least Squares and TLS Scanned Point

the TLS can be seen in Table 2 - Difference between Least Squares and TLS Scanned Point.

	SPHERE 1	SPHERE 2	SPHERE 3
X2	4.8mm	3.2mm	1.7mm
X3	4.8mm	3.2mm	2.0mm
X4	4.0mm	1.7mm	3.0mm
X6	4.4mm	3.0mm	2.1mm
X8	4.8mm	3.2mm	2.6mm

Table 2 - Difference between Least Squares and TLS Scanned Point

Further analysis of the result, shows that the accuracy of the scanner is quite reasonable but in this case, not quite at the same accuracy as stated from Trimble. However, to ascertain if this was always the case more testing would be required. It is also clear from these results, that increasing the accuracy of the TLS does not necessarily increase the accuracy of points calculated from scanned spheres.

The house traverse ISO Rounds reports can be found in Appendix 5 and the Least Squares adjustment is in Appendix 6. The distance calculated from the total station was 33.094m in the horizontal and 0.674m in the vertical. In comparison, the distances calculated from the point cloud were 33.100m in the horizontal and 0.678m in the vertical, this is a difference of only 6mm in the horizontal and 4mm in the vertical. For the purposes of this project and BIM in general this is perfectly acceptable, however it is something that needs to be kept in mind when carrying out scans and creating building models. If more accurate or more extensive buildings are being scanned then one would need to consider coordinating a number of control stations with a total station.

4.1.2 NOISE

Noise Testing at a Distance

Field testing for noise went without a hitch. In order to test the amount of noise evident when scanning the surface, initial results were gained by selecting a region within the scan point cloud and using the Scene software to get standard deviations of the distance scan points from the calculated plane. The results from this can be seen in (Figure 1010).

The reason for manually selecting an area in from the edges of the board, rather than letting Scene automatically grow a region, is I wanted to ensure that edge effects from the scanner were not going to affect the results.

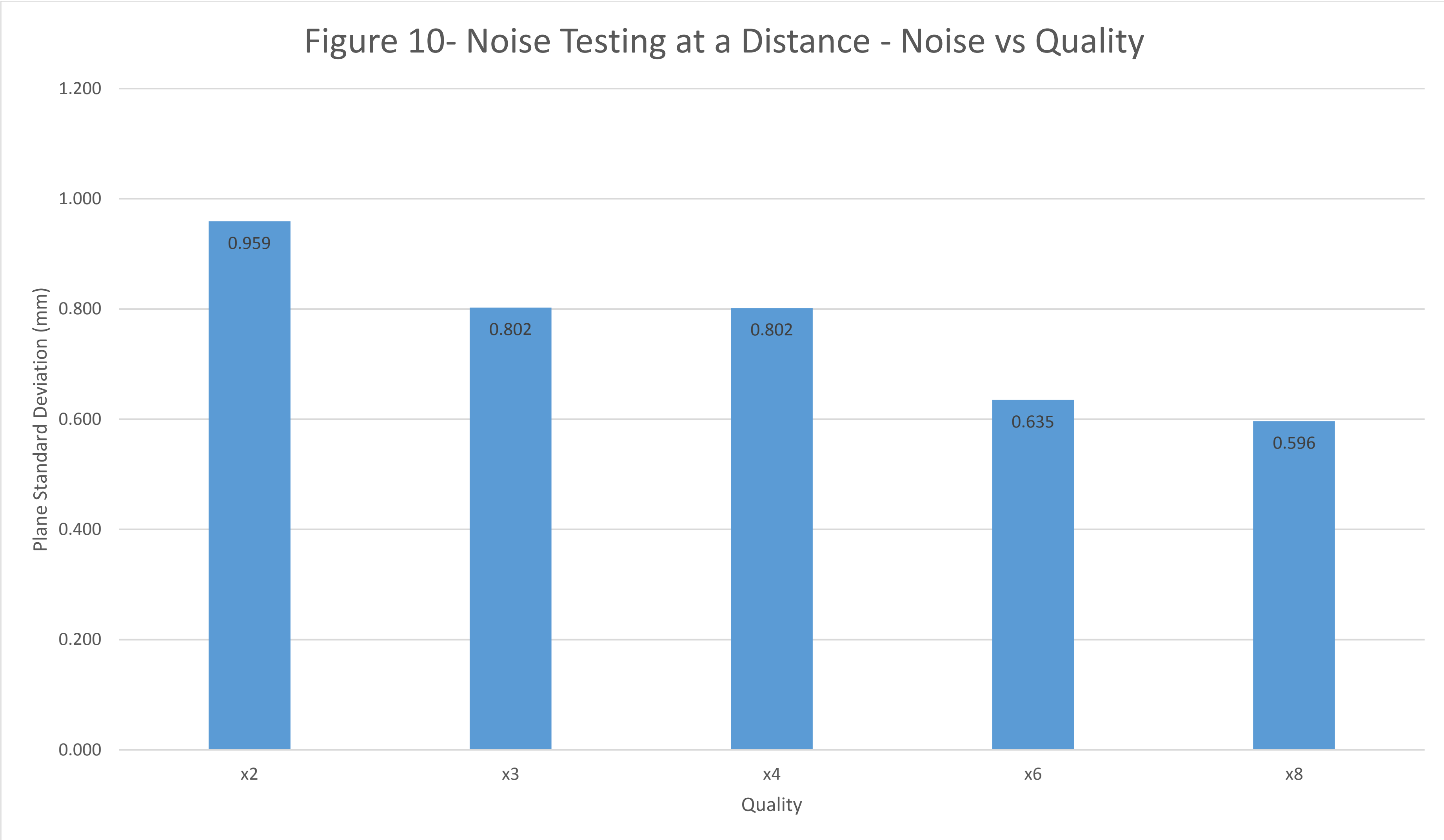
Figure 10- Noise Testing at a Distance - Noise vs Quality
Plane Standard Deviation (mm)
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.959
0.802
0.802
0.635
0.596
x2
x3
x4
x6
x8
Quality

Noise Testing Up Close

Noise testing up close went exactly as expected, scans were carried out and data imported to Scene software. Once the data had been verified, the points within the cloud that were on the plane under scrutiny, were exported separately to the engineering calculation package Liscad SEE for modelling and comparison.

In Liscad, the point clouds which were not normalized to any particular plane were normalized so that the length and width of the board were the X and Y axes respectively and therefore the noise could be modelled and visually analyzed for any patterns by simply creating a terrain model and seeing if any patterns emerge. The results of this modelling can be seen in (Figure 11).

Visual analysis of this reveals a number of interesting observations in relation to noise created within the scan. Initial visual perusal indicates as the accuracy of the instrument is increased the noise that is evident in the scan decreases (as would be expected). It also initially appears that as the angle of incidence of the beam increases the amount of noise in the scan decreases significantly. Visual inspection of the models however does not tell the whole story. Point density also needs to be considered. To the far left of the scan, point spacing's are approximately 1mm along the Y axis and as small as 0.5mm along the X axis. This resulted in a much higher impact of noise on the model when compared to the point spacing's to the far right of the scan, where spacing in the Y axis was around 3mm and spacing of around 7mm along the X axis created a much lower point density.

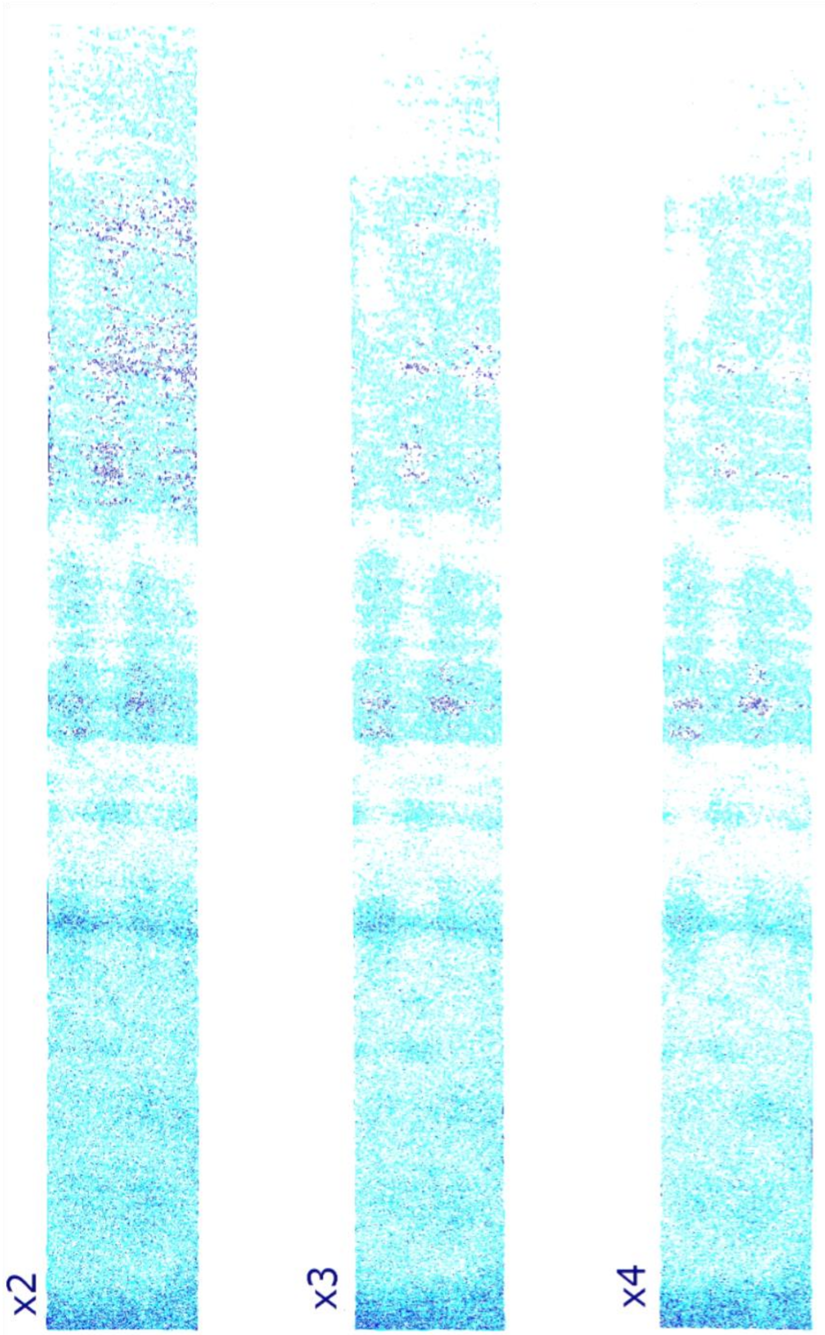

Figure 11- Noise Testing up Close

Visual analysis of this reveals a number of interesting observations in relation to noise created within the scan. Initial visual perusal indicates as the accuracy of the instrument is increased the noise that is evident in the scan decreases (as would be expected). It also initially appears that as the angle of incidence of the beam increases the amount of noise in the scan decreases significantly. Visual inspection of the models however does not tell the whole story. Point density also needs to be considered. To the far left of the scan, point spacing's are approximately 1mm along the Y axis and as small as 0.5mm along the X axis. This resulted in a much higher impact of noise on the model when compared to the point spacing's to the far right of the scan, where spacing in the Y axis was around 3mm and spacing of around 7mm along the X axis created a much lower point density.

Without further testing of the effect of the angle of incidence on the noise within a scan it is difficult to say with complete certainty what the effect is. However for the purposes of this project it can be concluded that the angle of incidence has no significant effect on the noise seen within a point cloud.

4.1.3 Edge Effects

Edge effects are well documented and expected result when working with point clouds created from modern day TLS as discussed by Boehler. Testing of edge effects with the Faro went smoothly with scans taken at accuracy settings at x2, x3, x4, and x6. Initial visual inspection of the point clouds can be seen in the following edge effect figures: Figure 12, Figure 13, Figure 14, and Figure 15.

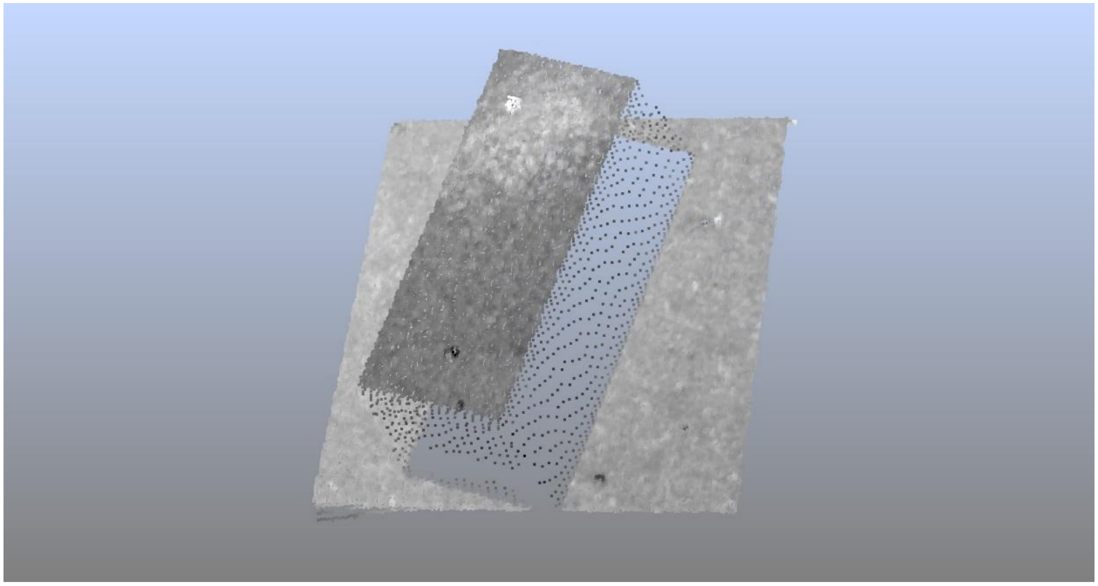

Figure 12- Edge Effect - Accuracy x2

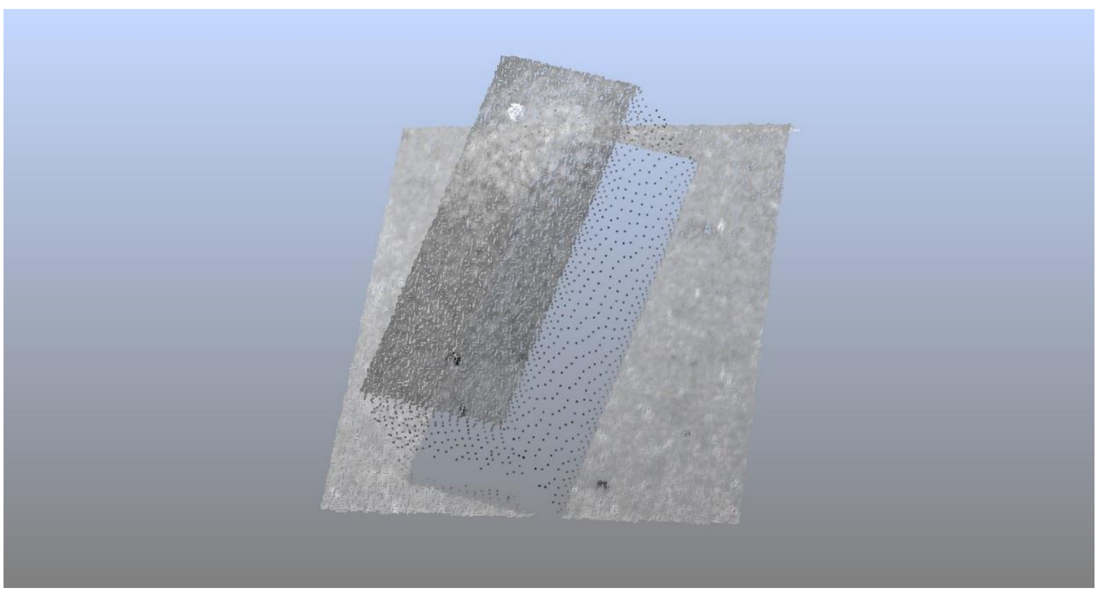

Figure 13- Edge Effect - Accuracy x3

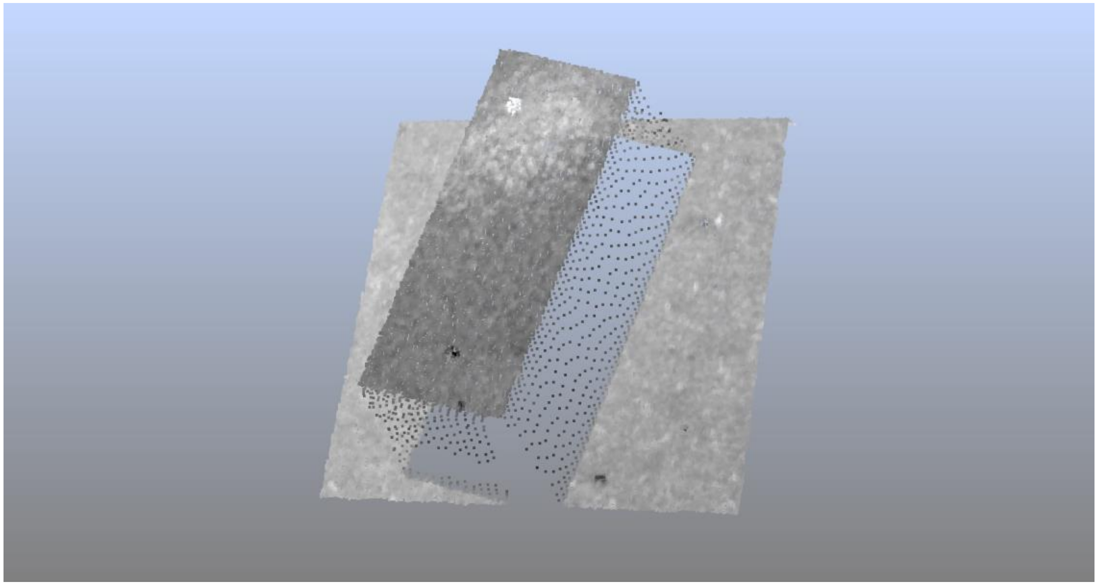
Figure 14- Edge Effect - Accuracy x4

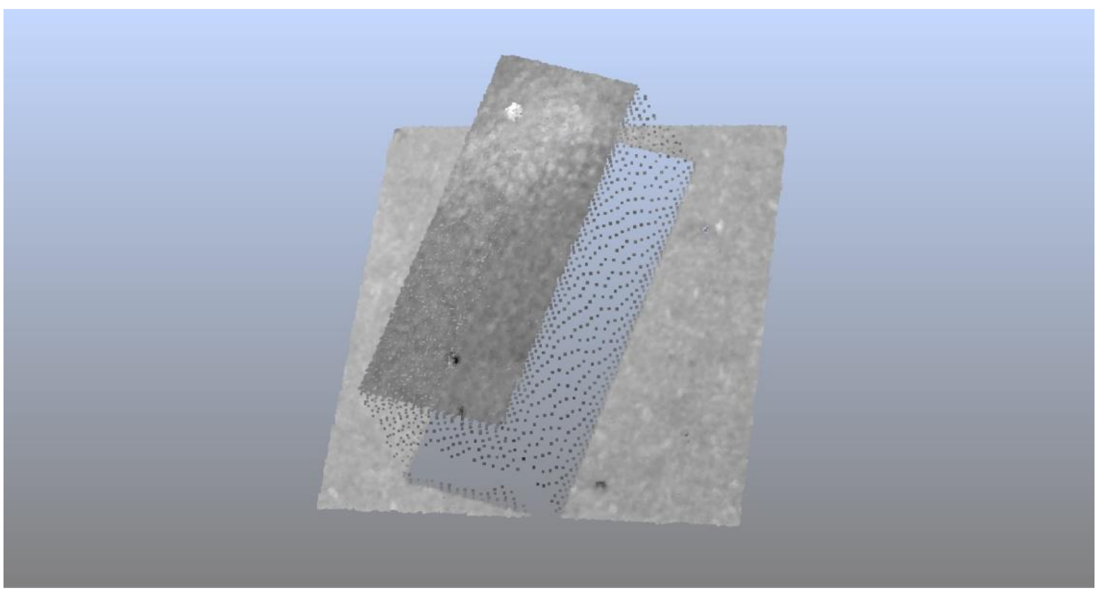
Figure 15- Edge Effect - Accuracy x6

This initial visual inspection gives the distinct impression that increasing the accuracy of the scanner has little or no effect on reducing edge effect problems within the scan. Further analysis of the number of erroneous points which don't fall on either of the scanned planes confirms the results from the initial visual inspection. These results can be seen in Table 3 - Erroneous Points in Edge Effect Scan.

ACCURACY SETTING	APPROX NUMBER OF POINTS
X2	1092
X3	1141
X4	1105
X6	1190

Table 3 - Erroneous Points in Edge Effect Scan

Analysis of the above table shows that the average number of erroneous points within the different scans is 1132. With the highest variance from the average only 5%, and the fact there is no clear reduction in erroneous points as the accuracy is increased. It is clear that the increase in accuracy of the TX5, has no significant effect on the edge effects evident within a TLS point cloud.

4.1.4 SURFACE REFLECTIVITY

Going into surface reflectivity, I initially had some preconceived notions about the results that were to be expected. Based on previous experiences with reflectorless electronic distance measurement techniques. The different surfaces were placed in roughly the order that the accuracy was expected. With the expected most accurate surface being the retro reflective yellow on the far left and the worst the matt black on the far right.

Upon first inspection of the scans in the Scene software (Figure 5) it appeared all was well and that the processing could continue. However, a quick visual inspection of the three dimensional point cloud (Figure 163) quickly presented an obvious problem that the distance measured to the retro reflective tape was grossly in error and considerably outside of acceptable tolerances, in fact it was out by approximately 1m. Due to this large and unexpected error in the retro reflective surface results, it will be left out of any further result analysis in this portion.

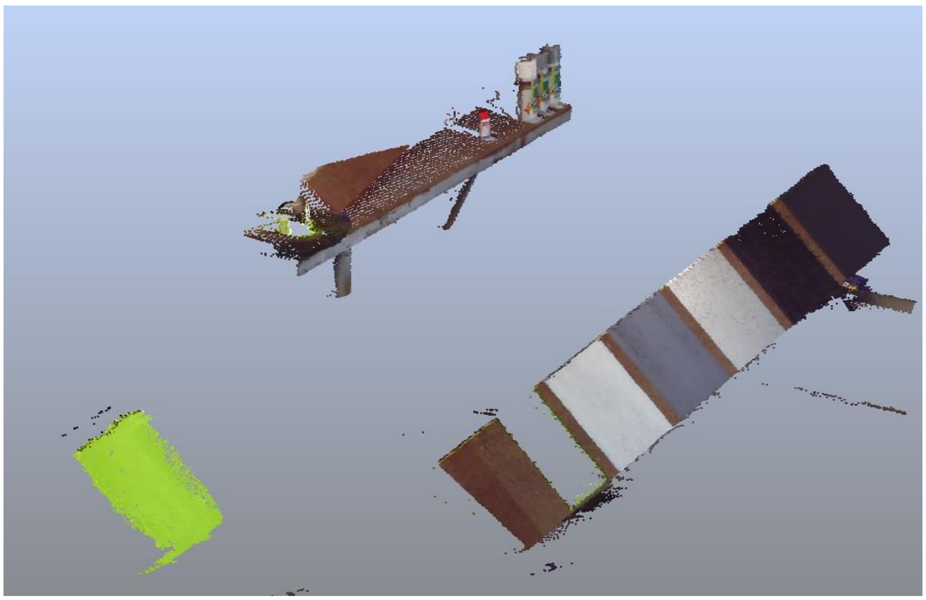
Figure 16- 3D View of Colour Test Board Scan

Following the complete discounting of the results of the scanning of the retro reflective surface, the scene software was used to fit a plane to each of the different coloured areas for each of the varying levels of scanner accuracy. These results can be seen in Figure 17.

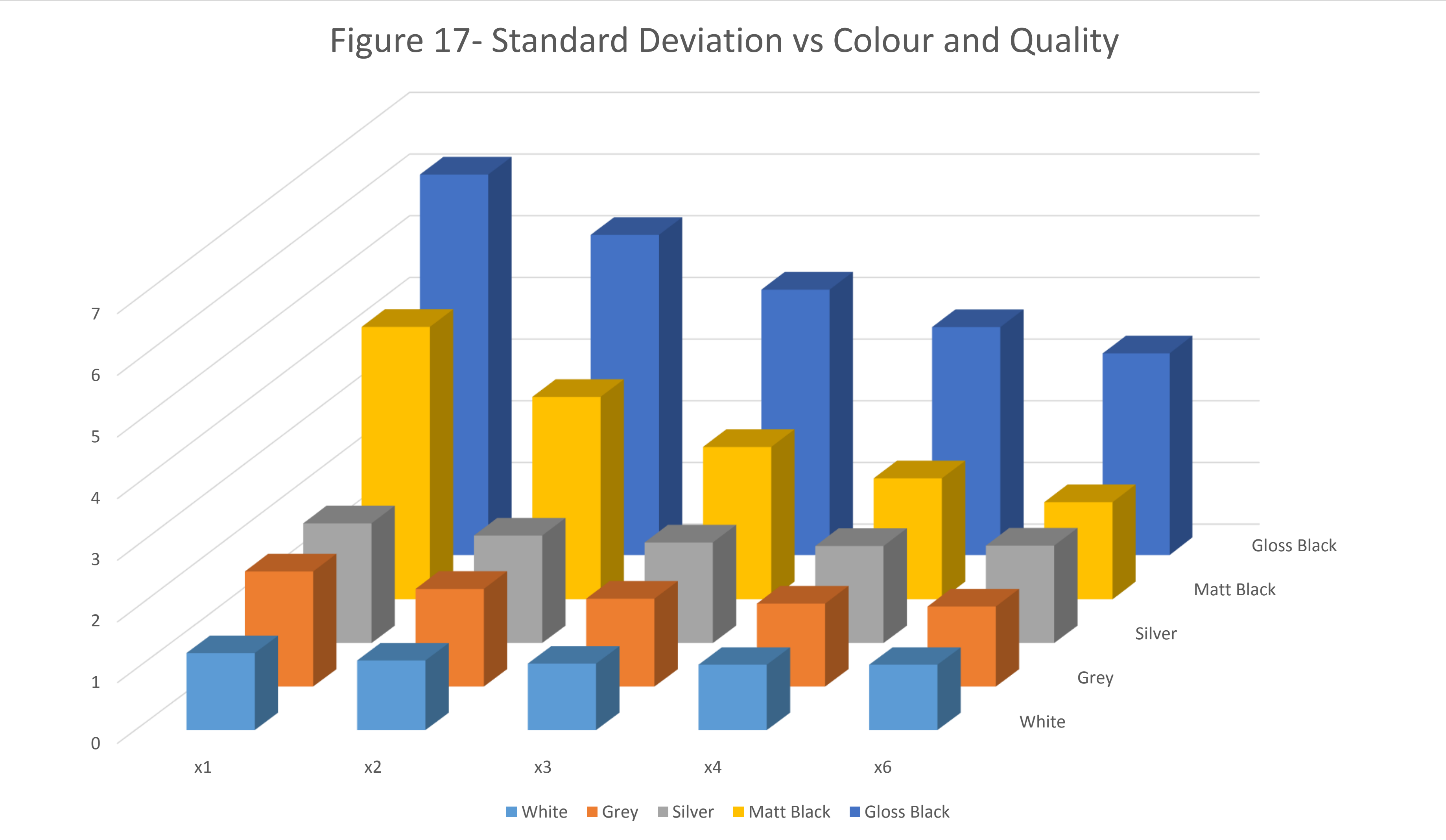

Figure 17- Standard Deviation vs Colour and Quality
0
1
2
3
4
5
6
7
x1
x2
x3
x4
x6
Gloss Black
Matt Black
Silver
Grey
White
White
Grey
Silver
Matt Black
Gloss Black

The results from this clearly show that there is a definite change in noise when either the colour (therefore reflectivity) being scanned or the accuracy of the scan varied. An observation that is supported by Boehler, Bordas Vicent and Marbs (2003).

In respect to its application to BIM using TLS, the data from this test is rather inconclusive. However, it does give an indication of how a TLS operator or someone using the point cloud to create a BIM would need to be aware of the varying accuracies from differing surfaces, and that highly reflective surfaces such as signs, mirrors, and windows would need to be treated with extreme caution. If not deleted entirely from point clouds, however this will be investigated later on in the project when we look at the results from actual building scans.

4.2 The Building Scans

The process of scanning the buildings in this project was an extremely intensive learning process. With no prior experience with TLS, BIM or the associated software, it was very much a trial and error progression.

Following the accuracy testing carried out in the previous sections, it was deemed that the suggested settings in the software for the TX5 were generally an excellent balance between accuracy and speed. Hence these settings were used during all laser scans.

Before delving into the scanning and registration processes of the sites being used for this project, it is first important to quickly look at some of the different terms used within the Scene software when processing point clouds.

Artificial References

These include spheres, and checkerboard targets. They are placed around an area of a scan and are of a very specific nature, which makes them easily identifiable to the Scene software.

Natural References

Natural references include planes, slabs, pipes, corner points and rectangles. They are specific features that may be visible from a number of scanner locations that can then be used in place of artificial references to assist in registering scans in Scene (Reinhard Becker 2014).

Tensions

The term tension within Scene refers to the divergence in overall coordinate system between positioning of two relating reference objects in corresponding scans (Reinhard Becker 2014). It is an important value to the registration process, and is a good indicator of how well scans are being stitched together.

4.2.1 SITE 1: MODERN OFFICE BUILDING

The office building to be scanned was located at 6 Graves St in the township of Kadina, and is the local office of Mosel Steed, a medium sized surveying firm in South Australia.

The scanning process was relatively straightforward. It provided some excellent insight into scanning buildings and registration techniques. It included a total of 14 scans and 27 artificial targets which were a combination of Faro checkerboard targets and ATS spherical targets.

In initial processing to start with I tried the auto registration available in Scene, allowing it to attempt to automatically recognize all the artificial targets that were placed in the office, and then place the scans automatically, by calculating between respective scans. The automatic target identification successfully identified all but one of the artificial targets in all 14 scans. It was a sphere located only a couple of metres from the TLS in scan number 4. This was quickly rectified by marking each of the missed targets within the software which then recognized the sphere.

Once all the targets were recognized, automatic placement of scans was attempted. This failed initially due to a lack of targets in a few key points. Scene managed to adequately tie together the first 10 scans and the final 3 scans as two individual clusters. However, there were insufficient artificial targets to adequately tie it all together. Further investigation revealed that scan number 10 (the one sitting out on its own) was an integral scan which should have tied both ends of the building together, with no overlap between the front and back parts of the office (being scans 12-14 and 1-11 respectively).

In order to try and tie all the scans together I then tried the automatic recognition of planes in the Scene software. It came up with quite a number of false planes, or ones that concerned me enough to not use this method initially.

An example of a plane that the software came up with that concerned me was the software using laser scan of the carpet as a plane, which was not perfect, and included a number of rocks, and mud clumps bought in by survey field crews. So I decided to pick a number of more precise areas, and use the software packages region grow tool to create a number of key planes in the areas that needed tying together.

Once this was done, an acceptable registration was achieved where all scans were successfully placed in reference to each other.

The entire registration process took approximately one hour and was relatively simple, whilst still allowing for some control and continuing quality control to be carried out during the process.

As a test to compare time of processing data for registration and placement of scans, the scans were reprocessed using the full automatic option, allowing Scene to automatically detect all spheres, checkerboard targets, planes, rectangles, edges, and corner points. It was then told to place all scans using fine registration in order to optimize tensions between all scans. This process was timed, to see how long it took the computer to process to use as a comparison for processing techniques in comparison to the semi-manual techniques described earlier. The automatic processing took approximately 22 minutes, and ultimately failed miserably. It initially split the scans into two separate scan clusters, but couldn't tie them together. After a lot of looking through the results, and the dozens of natural references that scene had identified during the automated process. Trying to make these scans register with all the automatically recognized references had to be abandoned as it had taken considerably longer than using the semi-manual process described earlier.

Whilst carrying out the scan was relatively straightforward, it highlighted the fact that it is very important to be careful with placement of targets, and that the fully automatic process within the software is not entirely up to the task for even simpler scans.

Reflective Surfaces

Considering the results that became evident in the surface reflectivity testing in section 4.1.4 and the issues that became evident with the scanning of the retro-reflective yellow tape causing gross errors within the scan, it was clear that any highly reflective surfaces within the point cloud needed to be inspected and dealt with if errors were found to evident. In this case, the only highly reflective surface that fit this description was a mirror in the bathroom, which had only been partially scanned. Upon inspection, it was found that the mirror which was mounted directly to the wall had its scan points approximately 1.26 metres further away from the scanner than the wall itself. To deal with the scan points over the relatively small mirror, they were deleted from the scan entirely. This reflectivity issue causing problems will be dealt with again in the scanning of the Strathneath household, along with some illustrations of the problem.

4.2.2 SITE 2 – INDUSTRIAL SHED

The industrial shed to be scanned was of a medium size, being approximately 20 metres long by 14 metres wide. It has 4.5 metre high walls with a gable roof. Its construction is with steel beams and columns, wooden purlins, and galvanized iron cladding, primarily, it is used as a small workshop and storage shed. As a result of its current usage it is very cluttered, and had quite a number of "in progress" projects, making it difficult for good coverage of all the areas inside with only a small number of scans.

The scanning of the shed involved 7 internal stations and a further 7 external stations to scan the both the inside and outside of the shed. The total number of scan points, once excess data away from the shed was cleaned from the scan, totaled approximately 368 million points. Of which 77 million were internal points and the remaining 291 million were external. Scanning took approximately 2 hours, and went relatively without a hitch.

Following the results from the attempted fully automatic registration from the office software, it was deemed that the similarly timed (although more labour intensive) semi-automatic registration process was to be adopted. As it provided a more hands on approach, and also means less time needs to be applied with respect to quality checking the registration and target recognition later, as this is carried out whilst marking the targets.

The scans were split into two separate clusters being inside and outside before being placed together for one homogenous point cloud. The inside point cloud was initially attempted to be registered with only the artificial targets that were placed around the shed which consisted of a total of 6 reference spheres and one checkerboard target. However, a problem presented when in a number of the scans some targets were either partially obscured from the scan, or were too far away from the scanner to give adequate points to be recognized at the resolution that had been scanned.

This failed attempt at registration meant that more thought had to be put into the scan registration. However, it was a relatively straight forward to identify a number of planes within the shed and mark them within the scans. Then the registration process supplemented the lack of artificial targets with these planes, and the internal cluster registration worked very well. All scans registered with a mean tension of less than 4mm except for scan number 4 which was the one that was causing problems, with the artificial target only registration, which still ended up with a mean tension of less than 7mm.

Following successful registration of the inside of the shed, attention was then turned to the scans that were carried out on the exterior. Initial attempts at registration involved only 10 spherical targets around the shed that were not a part of the inside scans, and also 4 of the spherical targets that were used for the inside scans so that the two clusters could eventually be tied together.

Initial thoughts were that the number of targets and their placement would have been adequate to carry out a successful registration. However it quickly became evident that this was not going to be the case. The reason for this is that a number of the smaller spherical targets were not close enough to some of the scanning stations, and hence were not able to be recognized by the software (due to the insufficient number of points scanned on their surface). This presented a challenge to try and get the scans to have an sufficient number of references to adequately tie the scans together. The solution was to look around the rest of the scans and locate enough planar surfaces within the scans to effectively tie them together.

Once the registration of both the inside and outside clusters were completed, the two clusters were placed together with Scene and resulted in mean tensions of less than 2mm.

Data import, initial perusal of the data, and full registration of all scans, took approximately two hours to carry out and the end result was a fully referenced point cloud. Lessons learnt with the processing of this set of scans, were that the type of target and the distances at which they are placed are a very critical factor to consider when carrying out field work. In this case there was an adequate number of planar surfaces that could be used as references, but it is a very real possibility that this may not have been the case and may have resulted in the scans having to be carried out again.

4.2.3 SITE 3 – HOMESTEAD

The homestead to be scanned was a relatively large single story house, with full return verandah. Excluding verandahs, the building is approximately 21m long by 12m wide. It has a central corridor, with a number of rooms running off both sides. The total number of scans was 34. This included 26 inside and 8 outside. This number could have been reduced by removing two scans inside which were not necessary to adequately scan all the rooms, but were added to get extra coverage in two of the larger rooms.

Registration of the scans within Scene on this particular site presented the greatest number of challenges within this project. Once extraneous points around the outside of the building were deleted from the data set, the scan totaled in excess of 2 billion points, of which 351 million were measured from the external scans, and the remainder were on the internal scans..

Registration of the scans for this site were split up into two separate clusters. Similar to how it was carried out for the industrial shed, inside and outside. The inside scans presented a bit of a challenge. With the central corridor being scanned initially at every door way with a large number of checkerboard targets placed in order to tie each individual room to the passage scans. There were no issues in tying the scans within the passage together, as each scan station could see not only a number of checkerboard targets, but they could also see a number of spheres. This meant that mean tensions between passage scan stations was extremely low resulting in what should be a very accurate model in this area of the house. However, issues arose with the registering of the scans of the separate rooms that came off the passage.

The artificial references that were placed in order to tie each room scan to the passage were only one target on a passage wall and one target on an internal wall of the room. It would have been preferred to also have some spheres within the scans, this was not possible as all the spheres had already been used out in the passage. Whilst this situation was not ideal, it was initially thought that the two targets would provide adequate registration points when coupled with the compass and inclinometer sensor data from the TLS. This assumption however, turned out to be only partly correct. With a limited range within which the targets could be placed (so they could be seen through the doors) it turned out that some of the rooms had similar (although not identical) target relationships, resulting in the auto placement of scans routine within Scene not completing successfully as it tried to place scans on top of each other. In one instance it placed scans from three separate rooms on top of each other, which resulted in it reporting target tensions in excess of 5 centimeters. Which was strictly not correct, as the scans in some cases were being placed at completely wrong ends of the house. In an attempt to rectify the problem, a number of natural reference planes (namely walls within the rooms and passage) were added to the scans that were causing problems and their corresponding passage scans. This however did not manage to fix the problem. The reason behind this, it was found, was that all the rooms were of a very similar size so the same problem continued. The solution was finally found by using an option within the Scene software that allows you to name targets within scans, and force correspondences between them, this in essence forces scans to match up with certain targets. In this case, only two checkerboard targets needed to be forced to manually match, and then all internal scans managed to successfully register, with mean target tensions for all 26 scans at around 2mm or less.

Registration of the outside of the homestead was much simpler, with sight lines available down all four sides of the building, and the use of the reference spheres. It was a very simple process of marking the artificial targets within each of the scans and Scene then easily tied them all together with mean reference tensions below 1.5mm.

Once both the inside and outside clusters had been successfully registered, Scene was then used to tie both the clusters together. This went relatively smoothly with a total of 5 reference spheres tying the two clusters together, means tensions were 0.5mm for the two scans.

4.2.4 CONCLUSIONS

Whilst carrying out the scans a number of natural workflows and observations developed. Whilst analysing the work processes that were being carried out as each project scan developed, it became very evident how each problem that was faced and overcome could be applied to the final workflows in order to minimize problems in future large projects.

Artificial Reference Spheres

Artificial reference spheres offer the most accurate and easily recognizable targets for use within scan registration. They are easy to place, and they offer excellent versatility. Such as with the ATS kit used it enables reference points to be measured with total stations or GPS receivers, for orienting point clouds onto predefined coordinate systems or for quality assurance checks. For more information see Appendix 4.

Whilst the targets are extremely accurate, care must be taken to place them in suitable positions for use in the registration process. The biggest problem that came about during the process of this project was that at times spheres were placed too far away from the scanner, and therefore unable to be recognized due to insufficient number of scan points falling on the sphere. In order to avoid this problem within the workflows of a business, it would be highly recommended to carry out some simple tests on any new scanners or targets to ascertain and tabulate both ideal and maximum distances for artificial targets. This could then be taken in the field for an operator to quickly refer to when placing targets to ensure there are no errors. It would simply be a resolution vs distance table for each type of reference. Indicating maximum distances to targets before recognition within the processing software, is outside of optimum range or unrecognizable all together. In the case of the TX5 used in this experiment. It appears that whilst this testing has not been done specifically (as it will vary between instruments and targets) it would be highly recommended and could potentially save a lot of problems with registration of scans in the office after leaving the field.

Large Sites

Since the three sites chosen for this research were relatively small, and resulted in what could be considered small data sets. The problems and registration of scans were relatively simple. However, with the potential of using scanners to scan entire multi story buildings or multi-building sites, it is a very real possibility that the problems could be greatly multiplied on a larger job.

An excellent example that comes to mind, would be if one were to undertake a project such as providing a point cloud of an entire multi story hotel. It is very likely that there are quite a number of rooms with almost identical geometry, if not whole floors with potentially similar geometry. With narrow halls, doorways and corners in passages and rooms it would be highly likely that similar problems to those experienced when scanning the homestead would appear. In that references would appear to correspond with references that in reality they don't correspond too.

The solution to this, prior to carrying out any scanning project, is to consider how scans will be clustered for processing once they have all been completed. Then once the scan project is underway, it would be beneficial to keep field notes on targets, and scan stations. It would also be highly recommended for any project where the scans did not form a closed loop (but had more of an open traverse) to be coordinated by some other form survey method such as total station or RTK GPS for quality assurance purposes.

Computer Power

A full analysis of the workflows involved in registering and working with the point clouds cannot be complete without a look at the processing power and process times required. As the saying goes, "Time is Money" and as surveyors we find ourselves constantly pushed for time, and any time saved in computer processing is money saved in the long term.

As described earlier, the computer used for all processing of this project was quite a way above those recommended by Faro, and it completed all tasks to process the scans carried out. However, at times it was at its extreme limits. Close monitoring of the computer, found that during processor and memory intensive tasks, such as point cloud creation and point colourisation, all 8 logical cores within the CPU were operating at 100% for extended periods of time and memory usage was extremely high. In fact when creating the point cloud for the homestead, memory usage was up over 97% of the available 16 gigabytes. Such high usage of system resources renders the computer almost unusable for other tasks whilst these resource intensive processes run.

Recommendations from this information, would be for any person considering handling point clouds and TLS data to carefully consider the processing power they have available in the office and the size of the projects under consideration to be carried out. With the rapid increases in personal computing power and decrease in price, it is no longer necessary to spend the massive amounts of money that have historically been required to handle point clouds. However, when handling point clouds and the associated tasks, it is evident that memory, and processing power are still vastly important, and must be considered when setting up to handle such projects.

4.3 Building Information Modelling

Following the field work, testing, and registration of all the necessary laser scans. It was determined, with the testing and subsequent results that had been carried out to this point, that the laser scanners were still potentially suitable for building information modelling. As long as the data is treated with caution keeping consideration for the errors, and inherent attributes of the cloud produced from the laser scan as previously discussed.

4.3.1 Converting and Importing the Cloud

The first step in working with the point cloud in BIM is to have it converted to a format that the BIM software being used can handle. In previous versions of Autodesk's Revit software it was necessary to use third party add-ons to handle point clouds. However in recent revisions Revit has added the ability to natively handle indexed point clouds within the Revit environment. The format required by Revit are either rcs or rcp files.

To enable the point cloud to be used within Revit each cloud was exported from Scene to the E57 file format. The E57 file format is a compact open source data exchange format that is vendor neutral and used for storing point clouds, images and metadata from 3D imaging systems such as the TLS used in this project (*libE57: Software Tools for Managing E57 files* 2010).

Once the point clouds were successfully converted to the E57 file format, it was simply a matter of using the conversion tools available within Revit to convert the E57 files to indexed RCP files for use in Revit. This process involved selecting the files to be converted and then waiting for the process to complete as it takes a while.

Once converted, the point cloud was inserted into Revit so that it may be used to create a building model.

4.3.2 Building the Model

As stated earlier, to create the BIM the Revit add-on from Imaginit Technologies known as Scan to BIM was to be used. Scan to BIM has a number of tools available for BIM creation. However the main one that was to be investigated for its suitability was the wall creation tool.

In order to create a wall using the tools available within Scan to BIM, a user simply selects three points on a plane that they would like to recreate, and the tool automatically searches for points found within a tolerance as set by the user to fall within that plane and it reports back on the points found. Once the plane has been found, the user then selects what type of wall to create, hence specifying its thickness and then it's done.

The above described process presents a number of problems inherent with this work process. The largest problem that arises is that the walls created are of an equal thickness throughout their entirety, and this thickness is required to be known prior to the wall creation. This problem can have varying levels of significance. For example, in the modern office scanned for this project, walls were of modern construction, flat with even and standard thicknesses throughout. So once the thickness of one internal wall onsite was known, it was possible to use this thickness throughout whilst building the model. However, this approach doesn't work on buildings such as the homestead used in this project. With walls of varying thickness's throughout the building and intricate mouldings around door frames and windows, it was difficult to measure accurate wall thicknesses manually. Through a process of trial and error, it was discovered that the most efficient and accurate way to determine wall thickness, was to measure from a cross section of the point cloud. This was then used to determine the wall thickness, and then the assumption was made that the wall had an even thickness throughout each plane.

The other major problem inherent in this work process is that it assumes walls are perfectly flat. Whilst this is generally true in modern buildings such as the office scanned, it is obviously not the case in buildings such as the homestead in this project. Therefore, walls created using this work process will have inherent inaccuracies in their model. Whilst, measurements could be made on the point cloud directly, this is not ideal due to the large size of point cloud datasets, and large computing power required for handling such datasets.

4.3.3 Accuracy of the Model

To compare accuracy of the building models, a number of rooms in sites 1 and 3 were measured using tape measures and laser distance meters. A number of both diagonal room measurements and cross-sectional measurements were taken for comparison. The dimensions chosen to be compared varied, between measurements that had walls that were measured from the same scan, to others where some walls had been created from scans on the far side of the wall.

Dimensions that were to be compared were also measured in the Scene software in order to compare results for the plane fit algorithms in both Scene and Scan to Bim. The results can be seen tabulated in (Figure 14)

Perusal of the results shown in this table show a number of interesting things. First and possibly most importantly, when comparing the Scene measured distance against the manually measured distance, the dimensions are extremely close. With all but one of the compared measurements falling under 10mm, and an average difference of 4mm, it is clear that the TLS accuracy and the subsequent registration are extremely accurate and producing the results that would be expected given the specs of the TLS. In fact the only result over 10mm, can be accounted for as the measurement that is being compared, is in a room where the distance comparison used in the laser scan data was measured at approximately 2m above the floor level. due to a door blocking part of the laser scan, whereas the tape measured distance was measured approximately 1m above the floor. With the varying wall thicknesses and walls not being square, this result can therefore be discounted. This brings the average difference in distance comparisons to only 3mm.

The other important observation to make in regards to these results is the unexpected inaccuracy of the BIM measured distances. Since the data sets being used in both Revit and Scene are identical, the only element that affects the plane that is created is the algorithm that is used within the respective software. It is important to note that all planes and walls within both software packages were created using manufacturer recommended settings and were not adjusted at all. With all this information in mind, it is clear that the default settings used in Scene are a more accurate method of creating planes automatically than those in the Scan to Bim add-on for Revit. To see if either can be made to more accurate and reliably calculate accurate locations for planes/walls further testing would be required.

CHAPTER 5 – CONCLUSION

The purpose of this project was to ascertain the suitability of TLS in BIM. Whilst this project's ultimate conclusion is that TLS are indeed suitable for BIM it should be made clear that they need to be treated with caution. It is very important to remember when producing point clouds and building models from TLS that they have inherent errors due to the way in which they work and are produced. All of these errors have been discussed in earlier sections.

The initial aims of this project were to investigate not only the suitability of TLS in BIM, but to also develop workflows for extracting geometric and structural information from laser scanning point cloud data. The workflows have come a long way, but as stated in many online blogs and websites, the reconstruction of structural and geometric information is an extremely complex and difficult group of tasks. Whilst it is relatively simple to recreate structural elements such as walls, floors and ceilings from point clouds. It is a much more difficult task to recreate more complex components of buildings such as columns, windows, doors, and fixtures.

The reason it is so difficult to reconstruct more complex components of buildings is due to a number of factors. These include smaller size and therefore fewer number of scan points on them, the increased complexity of such structural elements, and the high reflectivity of some elements such as galvanized structural steel and ducting.

5.1 Further Work

Further work to be carried out following this project would initially involve continued investigation into the accuracy of the Scan To BIM Revit add-on, to ascertain whether it could be made reliably accurate for modelling building elements. Furthermore, future work and investigations will include looking into some of the other commercial applications available that claim to assist in modelling more complex building elements. Software packages that may be looked at include Leica Cyclone, Edgewise 3D Modelling Software, or Kubit Software's multiple programs for laser scanning.

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APPENDIX 1

ENG 4111/ENG4112 Research Project
PROJECT SPECIFICATION

FOR: **BRENTON LIGHT**

TOPIC: Terrestrial laser scanning for building information model (BIM) development and application

SUPERVISOR: Dr Zhenyu Zhang

SPONSORSHIP: Ultimate Positioning, Mosel Steed

PROJECT AIM: To investigate the use of terrestrial laser scanning for building information modelling as an alternative to conventional survey techniques.

PROGRAMME: Issue A, 7th April 2014

1. Research background information relating to building information modelling
2. Research background information relating to Terrestrial laser scanners
3. Analyse suitability of laser scanners in building information modelling.
4. Design workflows to implement terrestrial laser scanning in as-constructed data capture by taking on a real world project.
5. Analyse workflows and ascertain whether they may be viable and necessary in today's market.

If time permits:

6. Compare terrestrial laser scanning with other forms of as-constructed data such as terrestrial photogrammetry.

APPENDIX 2

ISO Rounds Report

Project	BAL ANGLE TEST	**Date**	19.06.2006

Instrument	Trimble S6 3 DR 300+	**Distance unit**	Metres
Serial Number	13367	**Angle unit**	DMS Degrees
Firmware Version	R12.5.37	**Temperature unit**	Celsius
		Pressure unit	hPa
Trimble Survey Controller	v12.49		

Project Properties

Coordinate System

System Name	
Zone	
Datum	

Projection

Projection	ScaleOnly
Latitude Origin	?
Longitude Origin	?
False Easting	?
False Northing	?
Scale	1.000000

Datum Transformation

Type	No Datum
Earth radius	?
Flattening	?
Scale	? ppm

Corrections

Distances as	Ground
South azimuth	No
Grid Orientation	Increasing NE
Magnetic Declination	0°00'00"
Neighborhood Adjustment	Off

Instrument Station

Stationing Type	Station Setup

		Atmospheric Settings	
Station	BASE	**Temperature**	18.0°C
Code		**Pressure**	1011.4hPa
Instrument Height	0.000	**Refraction Const.**	0.142

Horizontal Circle Mode	Set To Azimuth
Standard Deviations	
Hz	0°00'03"dms
V	0°00'03"dms
EDM constant	3mm
EDM ppm	2ppm
Centering Error	0mm

Backsight Points

Point Name	Easting	Northing	Elevation
1	5003.1965	9991.2177	98.4817

Measurements

Point Name	Code	SD [m]	HA [dms]	VA [dms]	th [m]	PC [mm]
1	SPHERE	9.4689	160°00'00"	99°13'32"	0.0000	-34
1	SPHERE	9.4690	339°57'36"	260°46'10"	0.0000	-34
1	SPHERE	9.4684	160°00'00"	99°13'25"	0.0000	-34
1	SPHERE	9.4674	339°59'55"	260°46'15"	0.0000	-34

Result

	Coordinates	Std.Dev.					Std.Dev.
Easting	5000.0000	?m			**Orientation**	0°01'12"	?
Northing	10000.0000	?m			**Scale**	1.000000	?
Elevation	100.0000	?m					

Multiple Rounds

1. Horizontal Angles

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean L1+L2	Mean Reduced	Mean out of all sets	Diff. (D)	Res. (R)	R^2
		dms	dms	dms	dms	dms	sec	sec	sec^2
BASE	1	160°00'00"	339°57'36"	159°58'48"	0°00'00"	0°00'00"	00.0	-29.7	879.382
	2	213°30'41"	33°32'00"	213°31'20"	53°32'32"	53°33'17"	44.8	15.1	228.027
	3	270°59'26"	91°00'02"	270°59'44"	111°00'56"	111°01'40"	44.2	14.6	211.813
							29.7		
	1	160°00'00"	339°59'55"	159°59'57"	0°00'00"		00.0	29.7	879.382
	2	213°33'27"	33°34'31"	213°33'59"	53°34'02"		-44.8	-15.1	228.027
	3	271°02'04"	91°02'40"	271°02'22"	111°02'24"		-44.2	-14.6	211.813
							-29.7		
Sum								00.0	2638.444

Number of sets	2
Number of targets	3
Number of degrees of freedom	2

Std.Dev. of a direction measured in both faces	36.3 sec
Std.Dev. of a direction averaged over 2 sets	25.7 sec

2. Vertical Angles

1	2	3	4	5	6	7	8	9
Station	Target	Face 1	Face 2	V-Index	Mean L1+L2	Mean out of all sets	Res. (R)	R²
		dms	dms	sec	dms	dms	sec	sec²
BASE	1	99°13'32"	260°46'10"	-09.1	99°13'41"	99°13'38"	-03.1	09.735
	2	92°48'39"	267°10'55"	-13.2	92°48'52"	92°48'47"	-05.1	25.621
	3	91°24'26"	268°34'59"	-17.3	91°24'43"	91°24'41"	-02.7	07.102
				-39.6				
	1	99°13'25"	260°46'15"	-09.6	99°13'35"		03.1	09.735
	2	92°48'22"	267°10'58"	-20.1	92°48'42"		05.1	25.621
	3	91°24'19"	268°35'03"	-19.0	91°24'38"		02.7	07.102
				-48.7				
Sum							00.0	84.915

Mean Index Correction	-14.7 sec
Number of sets	2
Number of targets	3
Number of degrees of freedom	3
Std.Dev. of a vertical angle measured in both faces	05.3 sec
Std.Dev. of a vertical angle averaged over 2 sets	03.8 sec

3. Distances

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean out of all sets	Res. (R1)	Res. (R2)	Sum (R²)	Std.Dev	Std.Dev. Mean
		m	m	m	mm	mm	mm²	mm	mm
BASE	1	9.4689	9.4690	9.4684	-0.5	-0.6	0.59	0.8	0.5
	2	11.5190	11.5196	11.5195	0.4	-0.1	0.20	0.3	0.2
	3	4.9158	4.9159	4.9157	-0.2	-0.2	0.09	0.3	0.2
	1	9.4684	9.4674		0.0	1.1	1.13		
	2	11.5194	11.5198		0.1	-0.4	0.15		
	3	4.9152	4.9157		0.4	0.0	0.20		
Sum					0.31	-0.31	2.36		

Number of sets	2
Number of targets	3
Number of degrees of freedom	3

Std. Dev. of a distance measured in 1 face - see column 9 above	
Std. Dev. of the mean of all sets - see column 10 above	
Std. Dev. for all distances (1 obs only)	0.5 mm
Std. Dev. for all distances (mean)	0.4 mm

4. Averaged Data Sets

Point Name	Code	HA	VA	SD	ih/th	PC	Temp [°C]	Press [hPa]
BASE					0.000			
1	SPHERE	0°00'00"	99°13'38"	9.4684	0.000	-34.0	18.0	1011.4
2	SPHERE	53°33'17"	92°48'47"	11.5195	0.000	-34.0	18.0	1011.4
3	SMAL SPHERE	111°01'40"	91°24'41"	4.9157	0.000	-34.0	18.0	1011.4

Point Name	Code	Az	VA	SD	ih/th
BASE					0.000
1	SPHERE	160°00'00"	99°13'38"	9.4684	0.000
2	SPHERE	213°33'17"	92°48'47"	11.5195	0.000
3	SMAL SPHERE	271°01'40"	91°24'41"	4.9157	0.000

Point Name	Code	Az	HD	VD
BASE				
1	SPHERE	160°00'00"	9.346	-1.518
2	SPHERE	213°33'17"	11.506	-0.565
3	SMAL SPHERE	271°01'40"	4.914	-0.121

Point Name	Code	Easting	Northing	Elevation
BASE		5000.0000	10000.0000	100.0000
1	SPHERE	5003.1954	9991.2167	98.4816
2	SPHERE	4993.6404	9990.4123	99.4334
3	SMAL SPHERE	4995.0830	10000.0907	99.8770

Instrument Station

Stationing Type	Standard Resection

		Atmospheric Settings	
Station	BASE2	**Temperature**	18.0°C
Code		**Pressure**	1011.4hPa
Instrument Height	0.000	**Refraction Const.**	0.142

Horizontal Circle	

Mode	Set To Azimuth
Standard Deviations	
Hz	0°00'03"dms
V	0°00'03"dms
EDM constant	3mm
EDM ppm	2ppm
Centering Error	0mm

Backsight Points

Point Name	Easting	Northing	Elevation
1	5003.1965	9991.2177	98.4817
2	4993.6405	9990.4117	99.4347

Measurements

Point Name	Code	SD [m]	HA [dms]	VA [dms]	th [m]	PC [mm]
1	SPHERE	7.2073	122°00'48"	98°59'55"	0.0000	-34
2	SPHERE	5.7783	217°32'28"	91°44'50"	0.0000	-34

Residuals

Point Name	Code	Station [m]	Offset [m]	delta Hz [dms]	delta E [m]	delta N [m]	delta El [m]
1	SPHERE	0.0006	0.0000	-0°00'00"	0.0005	-0.0003	-0.0009
2	SPHERE	0.0005	0.0000	0°00'00"	-0.0003	-0.0004	0.0009

Result

	Coordinates	Std.Dev.					Std.Dev.
Easting	4997.1600	0.001m			**Orientation**	0°00'00"	0°00'15"
Northing	9994.9917	0.000m			**Scale**	1.000000	?
Elevation	99.6099	0.001m					

Multiple Rounds

1. Horizontal Angles

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean L1+L2	Mean Reduced	Mean out of all sets	Diff. (D)	Res. (R)	R²
		dms	dms	dms	dms	dms	sec	sec	sec²
BASE2	2	217°32'13"	37°33'43"	217°32'58"	0°00'00"	0°00'00"	00.0	24.0	573.749
	3	337°51'26"	157°51'58"	337°51'42"	120°18'44"	120°18'09"	-35.8	-11.9	141.128
	1	122°01'51"	302°02'07"	122°01'59"	264°29'01"	264°28'25"	-36.0	-12.1	145.765
							-24.0		
	2	217°33'11"	37°33'42"	217°33'27"	0°00'00"		00.0	-24.0	573.749
	3	337°49'00"	157°52'59"	337°50'59"	120°17'33"		35.8	11.9	141.128
	1	122°01'08"	302°01'23"	122°01'16"	264°27'49"		36.0	12.1	145.765
							24.0		

Sum								00.0	1721.283

Number of sets	2
Number of targets	3
Number of degrees of freedom	2
Std.Dev. of a direction measured in both faces	29.3 sec
Std.Dev. of a direction averaged over 2 sets	20.7 sec

2. Vertical Angles

1	2	3	4	5	6	7	8	9
Station	Target	Face 1	Face 2	V-Index	Mean L1+L2	Mean out of all sets	Res. (R)	R²
		dms	dms	sec	dms	dms	sec	sec²
BASE2	2	91°44'50"	268°14'33"	-18.7	91°45'08"	91°45'02"	-06.2	38.477
	3	87°13'09"	272°46'17"	-17.1	87°13'26"	87°13'24"	-02.1	04.263
	1	99°00'18"	260°59'24"	-08.9	99°00'27"	99°00'24"	-02.6	06.922
				-44.7				
	2	91°44'54"	268°15'02"	-01.8	91°44'56"		06.2	38.477
	3	87°13'28"	272°46'45"	06.4	87°13'22"		02.1	04.263
	1	99°00'09"	260°59'25"	-13.3	99°00'22"		02.6	06.922
				-08.7				
Sum							00.0	99.323

Mean Index Correction	-08.9 sec
Number of sets	2
Number of targets	3
Number of degrees of freedom	3
Std.Dev. of a vertical angle measured in both faces	05.8 sec
Std.Dev. of a vertical angle averaged over 2 sets	04.1 sec

3. Distances

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean out of all sets	Res. (R1)	Res. (R2)	Sum (R²)	Std.Dev	Std.Dev. Mean
		m	m	m	mm	mm	mm²	mm	mm
BASE2	2	5.7780	5.7788	5.7784	0.4	-0.4	0.30	0.4	0.3
	3	5.5128	5.5122	5.5123	-0.5	0.1	0.25	0.5	0.3
	1	7.2078	7.2079	7.2076	-0.2	-0.3	0.10	0.3	0.2
	2	5.7781	5.7786		0.3	-0.2	0.14		
	3	5.5125	5.5117		-0.2	0.6	0.39		

	1	7.2073	7.2075		0.3	0.1	0.11		
Sum					0.10	-0.10	1.29		

Number of sets	2
Number of targets	3
Number of degrees of freedom	3
Std. Dev. of a distance measured in 1 face - see column 9 above	
Std. Dev. of the mean of all sets - see column 10 above	
Std. Dev. for all distances (1 obs only)	0.4 mm
Std. Dev. for all distances (mean)	0.3 mm

4. Averaged Data Sets

Point Name	Code	HA	VA	SD	ih/th	PC	Temp [°C]	Press [hPa]
BASE2					0.000			
2	SPHERE	0°00'00"	91°45'02"	5.7784	0.000	-34.0	18.0	1011.4
3	SMAL SPHERE	120°18'09"	87°13'24"	5.5123	0.000	-34.0	18.0	1011.4
1	SPHERE	264°28'25"	99°00'24"	7.2076	0.000	-34.0	18.0	1011.4

Point Name	Code	Az	VA	SD	ih/th
BASE2					0.000
2	SPHERE	217°32'28"	91°45'02"	5.7784	0.000
3	SMAL SPHERE	337°50'37"	87°13'24"	5.5123	0.000
1	SPHERE	122°00'53"	99°00'24"	7.2076	0.000

Point Name	Code	Az	HD	VD
BASE2				
2	SPHERE	217°32'28"	5.776	-0.177
3	SMAL SPHERE	337°50'37"	5.506	0.267
1	SPHERE	122°00'53"	7.119	-1.128

Point Name	Code	Easting	Northing	Elevation
BASE2		4997.1600	9994.9917	99.6099
2	SPHERE	4993.6404	9990.4123	99.4334
3	SMAL SPHERE	4995.0830	10000.0907	99.8770
1	SPHERE	5003.1954	9991.2167	98.4816

APPENDIX 3

LISCAD Report: Least Squares Adjustment Report - Angle Testing
Tuesday, 28 October 2014   10:09

File: Angle Testing
Projection: Plane grid
File Date: Friday, 12 September 2014

Units
=====

Angle: Degrees Minutes Seconds
Distance: Metres

Earth constants
===============

Refraction constant: 0.070
Earth's radius: 6378000.00000

Combined scale factor: 1.000000

Fixed Co-ordinates

Point ID	East	North
BASE1	5000.00000	10000.00000

Adjusted Co-ordinates

Point ID	East	North
1	5003.19687	9991.21668
2	4993.64039	9990.41158
3	4995.08571	10000.08816
BASE2	4997.16057	9994.99149

Constraints

Bearing

At	To	Bearing
BASE1	1	160°00'00"

Observations

Directions

At	To	Direction	+/-SD	Residual	Orientation	Plane Bear.
BASE1	1	0°00'00"	0°00'02"	0°00'00"	160°00'00"	160°00'00"
BASE1	2	53°33'17"	0°00'02"	-0°00'00"		213°33'17"
BASE1	3	111°01'40"	0°00'02"	0°00'00"		271°01'40"
BASE2	2	0°00'00"	0°00'02"	0°00'00"	217°32'47"	217°32'47"
BASE2	3	120°18'09"	0°00'02"	-0°00'00"		337°50'56"
BASE2	1	264°28'25"	0°00'02"	-0°00'00"		122°01'12"

Distances

At	To	Distance	+/-SD	Residual	Grid	L.S.F.
BASE1	1	9.346	0.002	0.001	9.347	1.00000000
BASE1	2	11.506	0.002	-0.000	11.506	1.00000000
BASE1	3	4.914	0.002	0.001	4.915	1.00000000
BASE2	2	5.776	0.002	0.000	5.776	1.00000000
BASE2	3	5.506	0.002	-0.003	5.503	1.00000000
BASE2	1	7.119	0.002	0.000	7.119	1.00000000

Statistics

Degrees of Freedom: 3
Fixed Co-ordinates: 1
Floating Co-ordinates: 4

Constraints: 1
Bearings: 1
Observations: 12
Directions: 6
Orientation: 2
Distances: 6
Number of Iterations: 1

Error Analysis

Variance Factor: 1.05

Point ID	Adjusted Co-ordinates East	North	+/- 95% Confidence Limits East	North	Error Ellipse Semi Major	Semi Minor	Orientation
1	5003.19687	9991.21668	0.002	0.005			
2	4993.64039	9990.41158	0.003	0.004	0.005	0.000	33°30'20"
3	4995.08571	10000.08816	0.006	0.000	0.006	0.000	91°01'32"
BASE2	4997.16057	9994.99149	0.003	0.002	0.003	0.002	76°32'40"

APPENDIX 4

RRT System

KEY FEATURES

- Special kit for tunnel scanning
- Adapter for tribrach mount
- Standard signal height
- Two versions: with or without prism
- Large diameter spheres
- Lightweight case

Kit Overview

In Application

Pat. pending
+46-(0)31-209616 Phone
WWW.ATS. SE Web
laser@ats.se E-mail

RRT System

RRT System Version 1:
Included components in one case:
- 2 Large sphere references
- 1 Prism
- 1 Prism adapter
- 3 Tribrach adapters

RRT System Version 2:
Included components in one case:
- 2 Large sphere references
- 2 Tribrach adapters

Large sphere reference

Prism

Prism adapter

Tribrach adapter

Technical Data

Prism constant	-34 [mm]
Nominal sphere diameter	198,8 [mm]
Nominal offset height (from tribrach)	196 [mm]
Absolute accuracy for large sphere ref.: Δx, Δy, Δz	±1 [mm]
Mounts to	Tribrach
Outer dimensions for case	500x420x225 [mm]

ATS

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APPENDIX 5

ISO Rounds Report

Project	BAL HOUSE	**Date**	19.06.2006

Instrument	Trimble S6 3 DR 300+	**Distance unit**	Metres
Serial Number	13367	**Angle unit**	DMS Degrees
Firmware Version	R12.5.37	**Temperature unit**	Celsius
		Pressure unit	hPa
Trimble Survey Controller	v12.49		

Project Properties

Coordinate System

System Name	
Zone	
Datum	

Projection

Projection	ScaleOnly
Latitude Origin	?
Longitude Origin	?
False Easting	?
False Northing	?
Scale	1.000000

Datum Transformation

Type	No Datum
Earth radius	?
Flattening	?
Scale	? ppm

Corrections

Distances as	Ground
South azimuth	No
Grid Orientation	Increasing NE
Magnetic Declination	0°00'00"
Neighborhood Adjustment	Off

Instrument Station

Stationing Type	Station Setup

		Atmospheric Settings	
Station	BASE	**Temperature**	18.0°C
Code		**Pressure**	1014.5hPa
Instrument Height	0.000	**Refraction Const.**	0.142

Horizontal Circle Mode	Set To Azimuth
Standard Deviations	

Hz	0°00'03"dms
V	0°00'03"dms
EDM constant	3mm
EDM ppm	2ppm
Centering Error	0mm

Backsight Points

Point Name	Easting	Northing	Elevation
1	4985.2761	10000.0000	100.3495

Measurements

Point Name	Code	SD [m]	HA [dms]	VA [dms]	th [m]	PC [mm]
1	SPHERE	14.7330	270°00'00"	88°38'16"	0.0000	-30
1	SPHERE	14.7323	90°00'02"	271°21'31"	0.0000	-30
1	SPHERE	14.7324	270°00'00"	88°37'57"	0.0000	-30
1	SPHERE	14.7323	89°59'49"	271°21'30"	0.0000	-30
1	SPHERE	14.7285	270°00'00"	88°38'00"	0.0000	-34
1	SPHERE	14.7280	89°59'15"	271°21'16"	0.0000	-34
1	SPHERE	14.7278	270°00'00"	88°38'17"	0.0000	-34
1	SPHERE	14.7280	89°59'34"	271°21'19"	0.0000	-34

Result

	Coordinates	Std.Dev.				Std.Dev.
Easting	5000.0000	?m		**Orientation**	-0°00'01"	?
Northing	10000.0000	?m		**Scale**	1.000000	?
Elevation	100.0000	?m				

Multiple Rounds

1. Horizontal Angles

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean L1+L2	Mean Reduced	Mean out of all sets	Diff. (D)	Res. (R)	R^2
		dms	dms	dms	dms	dms	sec	sec	sec²
BASE	1	270°00'00"	90°00'02"	270°00'01"	0°00'00"	0°00'00"	00.0	-418.2	174929.116
	2	88°00'58"	268°01'06"	88°01'02"	178°01'01"	178°14'57"	836.5	418.2	174929.116
							418.2		
	1	270°00'00"	89°59'49"	269°59'54"	0°00'00"		00.0	418.2	174929.116
	2	88°57'05"	268°00'32"	88°28'48"	178°28'54"		-836.5	-418.2	174929.116
							-418.2		
Sum								00.0	699716.464

Number of sets	2
Number of targets	2
Number of degrees of freedom	1
Std.Dev. of a direction measured in both faces	836.5 sec
Std.Dev. of a direction averaged over 2	591.5 sec

sets

2. Vertical Angles

1	2	3	4	5	6	7	8	9
Station	Target	Face 1	Face 2	V-Index	Mean L1+L2	Mean out of all sets	Res.(R)	R²
		dms	dms	sec	dms	dms	sec	sec²
BASE	1	88°38'16"	271°21'31"	-06.7	88°38'23"	88°38'18"	-04.7	22.430
	2	91°00'52"	268°58'53"	-07.4	91°00'59"	90°50'34"	-625.0	390620.000
				-14.1				
	1	88°37'57"	271°21'30"	-16.4	88°38'13"		04.7	22.430
	2	90°18'51"	268°58'33"	-1277.8	90°40'09"		625.0	390620.000
				-1294.2				
Sum							00.0	781284.861

Mean Index Correction	-327.1 sec
Number of sets	2
Number of targets	2
Number of degrees of freedom	2
Std.Dev. of a vertical angle measured in both faces	625.0 sec
Std.Dev. of a vertical angle averaged over 2 sets	442.0 sec

3. Distances

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean out of all sets	Res. (R1)	Res.(R2)	Sum (R²)	Std.Dev	Std.Dev. Mean
		m	m	m	mm	mm	mm²	mm	mm
BASE	1	14.7330	14.7323	14.7325	-0.5	0.2	0.33	0.4	0.3
	2	18.3846	18.3841	15.8875	-2497.1	-2496.6	12468404.61	4993.8	3531.2
	1	14.7324	14.7323		0.1	0.2	0.05		
	2	8.3967	18.3846		7490.8	-2497.1	62346876.33		
Sum					4993.21	-4993.21	74815281.32		

Number of sets	2
Number of targets	2
Number of degrees of freedom	3
Std. Dev. of a distance measured in 1 face - see column 9 above	
Std. Dev. of the mean of all sets - see column 10 above	
Std. Dev. for all distances (1 obs only)	3531.2 mm
Std. Dev. for all distances (mean)	2496.9 mm

4. Averaged Data Sets

Point Name	Code	HA	VA	SD	ih/th	PC	Temp [°C]	Press [hPa]
BASE					0.000			
1	SPHERE	0°00'00"	88°38'18"	14.7325	0.000	-30.0	18.0	1014.5
2	SPHERE	178°14'57"	90°50'34"	15.8875	0.000	-30.0	18.0	1014.5

Point Name	Code	Az	VA	SD	ih/th
BASE					0.000
1	SPHERE	270°00'00"	88°38'18"	14.7325	0.000
2	SPHERE	88°14'57"	90°50'34"	15.8875	0.000

Point Name	Code	Az	HD	VD
BASE				
1	SPHERE	270°00'00"	14.728	0.350
2	SPHERE	88°14'57"	15.886	-0.234

Point Name	Code	Easting	Northing	Elevation
BASE		5000.0000	10000.0000	100.0000
1	SPHERE	5030.6390	10000.0000	100.3478
2	SPHERE	5063.7299	10000.3593	99.6697

Multiple Rounds

1. Horizontal Angles

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean L1+L2	Mean Reduced	Mean out of all sets	Diff. (D)	Res. (R)	R²
		dms	dms	dms	dms	dms	sec	sec	sec²
BASE	1	270°00'00"	89°59'15"	269°59'38"	0°00'00"	0°00'00"	00.0	-11.9	140.900
	2	87°59'25"	267°59'25"	87°59'25"	177°59'48"	178°00'11"	23.7	11.9	140.900
							11.9		
	1	270°00'00"	89°59'34"	269°59'47"	0°00'00"		00.0	11.9	140.900
	2	88°00'28"	268°00'17"	88°00'22"	178°00'35"		-23.7	-11.9	140.900
							-11.9		
Sum								00.0	563.601

Number of sets	2
Number of targets	2
Number of degrees of freedom	1
Std.Dev. of a direction measured in both faces	23.7 sec
Std.Dev. of a direction averaged over 2 sets	16.8 sec

2. Vertical Angles

1	2	3	4	5	6	7	8	9
Station	Target	Face 1	Face 2	V-Index	Mean L1+L2	Mean out of all sets	Res.(R)	R²

		dms	dms	sec	dms	dms	sec	sec²
BASE	1	88°38'00"	271°21'16"	-22.3	88°38'22"	88°38'26"	03.6	13.180
	2	91°01'31"	268°58'09"	-10.0	91°01'41"	91°01'34"	-06.6	43.966
				-32.3				
	1	88°38'17"	271°21'19"	-11.9	88°38'29"		-03.6	13.180
	2	91°01'17"	268°58'23"	-10.0	91°01'27"		06.6	43.966
				-21.9				
Sum							00.0	114.291

Mean Index Correction	-13.6 sec
Number of sets	2
Number of targets	2
Number of degrees of freedom	2
Std.Dev. of a vertical angle measured in both faces	07.6 sec
Std.Dev. of a vertical angle averaged over 2 sets	05.3 sec

3. Distances

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean out of all sets	Res.(R1)	Res.(R2)	Sum (R²)	Std.Dev	Std.Dev. Mean
		m	m	m	mm	mm	mm²	mm	mm
BASE	1	14.7285	14.7280	14.7281	-0.4	0.1	0.20	0.3	0.2
	2	18.3769	18.3769	18.3771	0.2	0.2	0.08	0.2	0.2
	1	14.7278	14.7280		0.3	0.1	0.08		
	2	18.3773	18.3773		-0.2	-0.2	0.08		
Sum					-0.19	0.19	0.45		

Number of sets	2
Number of targets	2
Number of degrees of freedom	3
Std. Dev. of a distance measured in 1 face - see column 9 above	
Std. Dev. of the mean of all sets - see column 10 above	
Std. Dev. for all distances (1 obs only)	0.3 mm
Std. Dev. for all distances (mean)	0.2 mm

4. Averaged Data Sets

Point Name	**Code**	**HA**	**VA**	**SD**	**ih/th**	**PC**	**Temp [°C]**	**Press [hPa]**
BASE					0.000			
1	SPHERE	0°00'00"	88°38'26"	14.7281	0.000	-34.0	18.0	1014.5
2	SPHERE	178°00'11"	91°01'34"	18.3771	0.000	-34.0	18.0	1014.5

Point Name	Code	Az	VA	SD	ih/th
BASE					0.000
1	SPHERE	270°00'00"	88°38'26"	14.7281	0.000
2	SPHERE	88°00'11"	91°01'34"	18.3771	0.000

Point Name	Code	Az	HD	VD
BASE				
1	SPHERE	270°00'00"	14.724	0.349
2	SPHERE	88°00'11"	18.374	-0.329

Point Name	Code	Easting	Northing	Elevation
BASE		5000.0000	10000.0000	100.0000
1	SPHERE	5030.6390	10000.0000	100.3478
2	SPHERE	5063.7299	10000.3593	99.6697

Instrument Station

Stationing Type	Station Setup		
		Atmospheric Settings	
Station	BASE2	**Temperature**	18.0°C
Code		**Pressure**	1014.4hPa
Instrument Height	0.000	**Refraction Const.**	0.142
Horizontal Circle Mode	Set To Azimuth		
Standard Deviations			
Hz	0°00'03"dms		
V	0°00'03"dms		
EDM constant	3mm		
EDM ppm	2ppm		
Centering Error	0mm		

Backsight Points

Point Name	Easting	Northing	Elevation
1	4985.2761	10000.0000	100.3495

Measurements

Point Name	Code	SD [m]	HA [dms]	VA [dms]	th [m]	PC [mm]
1	SPHERE	19.3642	270°00'00"	88°58'06"	0.0000	-34
1	SPHERE	19.3639	89°59'43"	271°01'33"	0.0000	-34
1	SPHERE	19.3641	270°00'00"	88°58'08"	0.0000	-34
1	SPHERE	19.3641	89°59'35"	271°01'39"	0.0000	-34

Result

	Coordinates	Std.Dev.				Std.Dev.
Easting	5050.0000	?m		**Orientation**	0°00'08"	?
Northing	10000.0000	?m		**Scale**	1.000000	?
Elevation	100.0000	?m				

Multiple Rounds

1. Horizontal Angles

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean L1+L2	Mean Reduced	Mean out of all sets	Diff. (D)	Res. (R)	R^2
		dms	dms	dms	dms	dms	sec	sec	sec²
BASE2	1	270°00'00"	89°59'43"	269°59'52"	0°00'00"	0°00'00"	00.0	-04.7	21.832
	2	88°29'53"	268°29'37"	88°29'45"	178°29'53"	178°30'03"	09.3	04.7	21.832
							04.7		
	1	270°00'00"	89°59'35"	269°59'48"	0°00'00"		00.0	04.7	21.832
	2	88°30'06"	268°29'54"	88°30'00"	178°30'12"		-09.3	-04.7	21.832
							-04.7		
Sum								00.0	87.328

Number of sets	2
Number of targets	2
Number of degrees of freedom	1
Std.Dev. of a direction measured in both faces	09.3 sec
Std.Dev. of a direction averaged over 2 sets	06.6 sec

2. Vertical Angles

1	2	3	4	5	6	7	8	9
Station	Target	Face 1	Face 2	V-Index	Mean L1+L2	Mean out of all sets	Res.(R)	R^2
		dms	dms	sec	dms	dms	sec	sec²
BASE2	1	88°58'06"	271°01'33"	-10.5	88°58'16"	88°58'15"	-00.9	00.757
	2	91°22'24"	268°37'11"	-12.6	91°22'37"	91°22'39"	02.7	07.271
				-23.1				
	1	88°58'08"	271°01'39"	-06.6	88°58'14"		00.9	00.757
	2	91°22'31"	268°37'07"	-10.9	91°22'42"		-02.7	07.271
				-17.5				
Sum							00.0	16.055

Mean Index Correction	-10.2 sec
Number of sets	2
Number of targets	2
Number of degrees of freedom	2
Std.Dev. of a vertical angle measured in both faces	02.8 sec
Std.Dev. of a vertical angle averaged over 2 sets	02.0 sec

3. Distances

1	2	3	4	5	6	7	8	9	10
Station	Target	Face 1	Face 2	Mean out of all sets	Res.(R1)	Res.(R2)	Sum (R^2)	Std.Dev	Std.Dev. Mean
		m	m	m	mm	mm	mm²	mm	mm
BASE2	1	19.3642	19.3639	19.3641	-0.1	0.2	0.05	0.1	0.1
	2	13.7388	13.7385	13.7386	-0.2	0.1	0.04	0.2	0.2
	1	19.3641	19.3641		0.0	0.0	0.00		
	2	13.7388	13.7383		-0.2	0.3	0.11		
Sum					-0.54	0.54	0.21		

Number of sets	2
Number of targets	2
Number of degrees of freedom	3
Std. Dev. of a distance measured in 1 face - see column 9 above	
Std. Dev. of the mean of all sets - see column 10 above	
Std. Dev. for all distances (1 obs only)	0.2 mm
Std. Dev. for all distances (mean)	0.1 mm

4. Averaged Data Sets

Point Name	Code	HA	VA	SD	ih/th	PC	Temp [°C]	Press [hPa]
BASE2					0.000			
1	SPHERE	0°00'00"	88°58'15"	19.3641	0.000	-34.0	18.0	1014.4
2	SPHERE	178°30'03"	91°22'39"	13.7386	0.000	-34.0	18.0	1014.4

Point Name	Code	Az	VA	SD	ih/th
BASE2					0.000
1	SPHERE	270°00'00"	88°58'15"	19.3641	0.000
2	SPHERE	88°30'03"	91°22'39"	13.7386	0.000

Point Name	Code	Az	HD	VD
BASE2				
1	SPHERE	270°00'00"	19.361	0.348
2	SPHERE	88°30'03"	13.735	-0.330

Point Name	Code	Easting	Northing	Elevation
BASE2		5050.0000	10000.0000	100.0000
1	SPHERE	5030.6390	10000.0000	100.3478
2	SPHERE	5063.7299	10000.3593	99.6697

APPENDIX 6

LISCAD Report: Least Squares Adjustment Report -
Tuesday, 28 October 2014   10:06

File: Traverse Test Through House
Projection: Plane grid
File Date: Saturday, 13 September 2014

Units

Angle: Degrees Minutes Seconds
Distance: Metres

Earth constants

Refraction constant: 0.070
Earth's radius: 6378000.000

Combined scale factor: 1.000000

Fixed Co-ordinates

Point ID	East	North
BASE1	5000.000	10000.000
1	4985.276	10000.000

Adjusted Co-ordinates

Point ID	East	North
2	5018.363	10000.640
BASE2	5004.636	10000.164

Observations

Directions

At	To	Direction	+/-SD	Residual	Orientation	Plane Bear.
BASE1	1	0°00'00"	0°00'03"	-0°00'00"	270°00'00"	270°00'00"
BASE1	2	178°00'11"	0°00'03"	0°00'00"		88°00'11"
BASE2	1	0°00'00"	0°00'03"	0°00'00"	269°30'49"	269°30'49"
BASE2	2	178°30'03"	0°00'03"	-0°00'00"		88°00'52"

Distances

At	To	Distance	+/-SD	Residual	Grid	L.S.F.
BASE1	1	14.724	0.002	0.000	14.724	1.00000000
BASE1	2	18.374	0.002	0.000	18.374	1.00000000
BASE2	1	19.361	0.002	-0.000	19.361	1.00000000
BASE2	2	13.735	0.002	-0.000	13.735	1.00000000

Statistics

Degrees of Freedom: 1
Fixed Co-ordinates: 2
Floating Co-ordinates: 2
Observations: 7
Directions: 4
Orientation: 2
Distances: 3
Number of Iterations: 1

Error Analysis

Variance Factor: 0.00

Adjusted Co-ordinates   +/- 95% Confidence Limits   Error Ellipse

Point ID	East	North	East	North	Semi Major	Semi Minor	Orientation
2	5018.363	10000.640	0.001	0.000	0.001	0.000	87°59'13"
BASE2	5004.636	10000.164	0.001	0.000	0.001	0.000	88°37'21"

APPENDIX 7

OHS HAZARD IDENTIFICATION AND RISK ASSESSMENT FORM

Institution: University of Southern Queensland	**Project Name:** Terrestrial Laser Scanning in Building Information Modelling
Work activity/task: Surveying	**Supervisor:** Zhenyu Zhang
Date: 31st May 2014	Risk Rating: 1. High Risk (Life Threatening) 2. Medium Risk (Personal Injury) 3. Low Risk (Minor Injury; No Potential Injury)
Prepared by: Brenton Light	
Signature:	

ITEMS	**JOB STEP** Break the job down into steps.	**POTENTIAL HAZARD** What can harm you?	**RISK RATING** 1. High Risk 2. Medium Risk 3. Low Risk	**CONTROLS** What you are going to do to make the job as safe as possible.	**PERSON WHO WILL ENSURE THIS HAPPENS**
1	Conventional Survey using tape and laser rangefinder	1. Tripping over tape whilst unwound	3	Keep tape wound up when not in use.	Brenton
		2. Eye damage of bystanders from rangefinder	3	Keep bystanders away, have minimal people in area when measuring	Brenton
		3. Manual handling injuries	2	Observe proper manual handling techniques	Brenton

OHS HAZARD IDENTIFICATION AND RISK ASSESSMENT FORM

2	Scanning Building	1. Eye damage from laser scanner	1	Ensure anyone nearby wears appropriate eye protection	Brenton
		2. Tripod sitting in rooms presenting tripping hazard	3	Delineate areas of trip hazards with witches hats	Brenton
		3. Targets set up in rooms presenting tripping hazards	3	Delineate areas of trip hazards with witches hats or similar or similar	Brenton
		4. Traffic whilst scanning outside of buildings	2	High visibility PPE Anywhere traffic could be a concern, signage indicating workers in area.	Brenton and Individual
		5. Dropping equipment including tripods and tools	3	Wear PPE including safety boots	Individual
3	Data Reductions	1. Standard OHS issues when sitting at workstation for long periods	3	Take regular breaks Set-up workstation to be ergonomic Ensure proper	Brenton

Reviewed by: ____________________ **Date:** ____________________