University of Southern Queensland
Faculty of Engineering and Surveying

Accuracy Evaluation of 3-D Laser Imaging Scans

A dissertation submitted by

James Finlay Stephens

In the fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Surveying

Abstract

Technological advances in the area of spatial sciences over the past 10 – 20 years have brought about many new equipment types for the capture of 3-dimensional data. An emerging technology is the terrestrial laser scanner, which enables the collection of detailed 3-D data of an area.

The implementation of the terrestrial laser scanner in the surveying industry has been slowed by a lack of knowledge of its useful application in comparison with well-understood, and practiced, traditional methods. This leads to the question of whether the terrestrial laser scanners relative accuracies and its practical use in the field are of value to the surveying industry.

Scanners allow the collection of data without having to physically touch objects. Their use as surveying instruments is exceptional in situations of limited access to structures or target areas, such as moving conveyors or dangerous heights, and creates large amounts of usable information. Data capture times are short and the instrument may easily be used by a single person. The laser scanner would prove highly valuable as a new surveying tool.
University of Southern Queensland
Faculty of Engineering and Surveying

ENG 4111 and ENG 4112 Research Project

Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and staff of the University of Southern Queensland, do not accept any responsibility for the material associated with or contained in this dissertation.

Persons using all or any part of this dissertation do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Engineering and Surveying, and staff of the University of Southern Queensland. The sole purpose of the unit entitled “Project” is to contribute to the overall education process designed to assist the graduate enter the workforce at a level appropriate to the award.

The project dissertation is the report of an educational exercise and the document, associated hardware, drawings, and other appendices or parts of the project should not be used for any other purpose. If they are so used, it is entirely at the risk of the user.

Prof G Baker
Dean
Faculty of Engineering and Surveying
Certification

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.

James Finlay Stephens
Student Number: Q10212499
Acknowledgements

The author wishes to acknowledge the support and guidance received by his supervisor, Dr. Frank Young of the University of Southern Queensland, throughout the course of the research project.

Acknowledgement is also given to Mr. Toni Gangemi of the University of Southern Queensland, for his software support.

James F. Stephens

University of Southern Queensland
Contents

Abstract i
Acknowledgements iv
List of Figures x
List of Tables xi

Chapter 1 Introduction 1

1.1 Outline of the Study 1
1.2 Introduction 1
1.3 The Problem 4
1.4 Research Objectives 4
1.5 Risk Assessment 5
1.6 Schedule of events 5
1.7 Conclusions 6
Chapter 2 Literature Review

2.1 Introduction

2.2 Need for an accuracy evaluation

2.3 Comparison of Data Capture Methodology

2.3.1 Planning the survey for the best results.

2.3.2 Development of survey results

2.3.3 Limits and expected results from laser scanner

2.3.4 Qualities of targeted objects which may effect scan capture

2.3.5 Traditional Survey Methods

2.4 Manufacturers Specifications and Expected Result Values.

2.4.1 Riegl LMS-Z210 Laser measuring scanner Specifications

2.4.2 Sokkia Powerset specifications

2.5 Conclusions

Chapter 3 Methodology

3.1 Introduction

3.2 Research Method

3.2.1 Literature Contribution to Research Method
Chapter 4 Results and Discussion

4.1 Introduction

4.2 Analysis of Results

4.2.1 Laser Scanner Survey Results
a) Overview 36
b) Processing Techniques 36
c) Results 40

4.2.2 Traditional Survey Results 43
a) Overview 43
b) Processing Techniques 44
c) Results 44

4.2.3 Comparison of Survey Results 46
a) Relative Accuracy of Scan Survey 46
b) Practicality of Scan Survey 48

4.3 Conclusion 51

Chapter 5 Conclusions and Recommendations 52

5.1 Conclusions 52
5.2 Recommendations 54

References 55
## Appendices

<table>
<thead>
<tr>
<th>Appendix</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendix A</td>
<td>Project Specification</td>
<td>57</td>
</tr>
<tr>
<td>Appendix B</td>
<td>Work Permit &amp; Standard Work Procedure</td>
<td>59</td>
</tr>
<tr>
<td>Appendix C</td>
<td>Field Notes from Laser Scan Survey</td>
<td>64</td>
</tr>
<tr>
<td>Appendix D</td>
<td>Field Notes from Traditional Survey</td>
<td>66</td>
</tr>
<tr>
<td>Appendix E</td>
<td>Plans of Scan Survey Results</td>
<td>69</td>
</tr>
<tr>
<td>Appendix F</td>
<td>Plans of Traditional Survey Results</td>
<td>72</td>
</tr>
<tr>
<td>Appendix G</td>
<td>Comparison of Corner Point Coordinate Results</td>
<td>75</td>
</tr>
<tr>
<td>Appendix H</td>
<td>Edge Method Comparison</td>
<td>77</td>
</tr>
</tbody>
</table>
## List of Figures

2.1 Plan view of Opera House, from scans (I-SiTE Pty. Ltd., 2003).  
2.2 Laser scanner registration process (N. Pfeifer et al., 2001, p4).  
2.3 Point cloud of box showing phantom points (Cheok et al., 2002, p16).  
2.4 Photo of Riegl LMS-Z210 Laser Scanner.  
2.5 Photo of Sokkia Powerset 2010.  
2.6 Photo of Scanner and mobile workstation.  
2.7 Photo of Sokkia Powerset 2010.  
2.8 Photo of Surveying reflector.  
2.9 Photo of first scan station view.  
2.10 Filtered data.  
2.11 Edge point data.  
2.12 Four scans - filtered and registered.  
2.13 Edge dimensions.
# List of Tables

1.1 Project event schedule.  

2.1 Evaluation of edge quality (Boehler et al., 2003, p8).  

2.2 Major advantages of some laser scanners (Boehler et al., 2003, p9).  

2.3 Major disadvantages of some laser scanners (Boehler et al., 2003, p9).  

2.4 Distance correction due to different surface materials  

(Boehler et al., 2003, p9).  

4.1 Scanned corner point coordinates.  

4.2 Dimensions from corner points.  

4.3 Software determined edge dimensions.  

4.4 Surveyed dimension checks.  

4.5 Point coordinates from traditional survey.  

4.6 Edge dimensions from traditional survey.  

4.7 Coordinate differences.  

4.8 Edge length method comparison.
Chapter 1: Introduction

Chapter 1

Introduction

1.1 Outline of the Study
This study will evaluate the accuracy and benefits of using the RIEGL LMS-Z210 laser scanner and related software, through comparing traditional surveying measurements with laser scan modelling results. The same object will be measured for both methods and a comparative analysis of these two techniques will be evaluated.

1.2 Introduction
The surveying industry has always embraced new technology for its own current and evolving requirements. The terrestrial laser measuring scanner is a recent development in technology that will allow the surveyor another option by which to acquire three dimensional data quickly and easily.

Today’s surveyors are relied on more and more to attain answers and solutions in situations or environments previously not required or not necessary. Also, solutions that have previously been acquired by surveying techniques are now required to be gathered in shorter time or at less cost to the client.

Providing solutions or data for growing or emerging needs include the trend toward greater environmental conservation; the restoration and protection of cultural heritage; the requirement of most (if not all) industries to be ‘worksafe’; the need for most of modern construction to be highly accurate; and modern societies expectance that any problem or query should be able to be answered for a fee.
Chapter 1: Introduction

Environmental conservation creates a need for surveyors to monitor forest areas for depletion of size; monitor tides and their fluctuations; detect any movement or failure in areas of possible landslide (Bornaz et al., 2002); locate positions of particular species of trees so development may be designed around it; and many other tasks in the environmental areas. To capture this data surveyors have had to evolve their techniques and equipment to accommodate the needs.

Cultural heritage spans a vast array of situations, and surveyors are increasingly being employed to help in the restoration and conservation of objects of historic value or significance. Data of many varying objects may be required from surveyors and spatial analysts, such as the recording of dimensions and position of objects like the façade of an historic building or an ancient stone statue, or details of decaying or eroding constructs of early man (Wessex, 2003).

The introduction of government agencies, such as Workcover, and an increase in law suites for “at work” injuries as well as a general increase in the respect of employee well being, has created a new problem for surveyors (Stanfill, 2004). Surveyors now often need to be able to achieve results while not putting themselves in any danger from having to physically touch or go near objects being surveyed. This might be in situations of great height (or depth) or high temperatures or even hazardous materials (Stanfill, 2004). Surveyors may be liable for damages if equipment or workers come in contact with machinery or live electrical apparatus when working around them. One relatively new solution to these predicaments, the reflectorless total station, is able to measure distances and angles to objects without physical contact needing to be made. The next step in this equipment evolution is the laser scanner.

Many companies, these days, require a much higher accuracy of construction of equipment, such as large scale conveyors for example, because they now know that if trestle legs and roller idlers are positioned to low accuracies, then losses from downtimes of correcting
their positions can invariably be more expensive than the longer construction times for a high position accuracy. Modern construction techniques such as the use of prefabricated steel and concrete panelling, or positioning of high speed conveyor systems create a need for high accuracy and precision of initial fabrication and also footing positions on site (Monteath & Powys, 2004). These levels of accuracy have previously not been required due to cost reasons and also a lack of necessity.

In today’s’ society, people expect more of professionals than ever before. If someone, for whatever reason, would like to know dimensions or the volume of a particular object in a hard to reach position, then that client expects that the surveying professional should be able to come up with solutions for this. Hence, the need to understand and employ modern technology.

Many jobs that the professional surveyor has historically been contracted for are now required to be undertaken at a lower cost or in a shorter time span. This is brought about by competition between businesses and demands by society’s perceptions of new technology. New technology has been the medium of this cost cutting and time shortening. The introduction of electronic distance measuring instruments (EDM’s) combined with theodolites, known as total stations, has been a major step. The next step was electronic data storage, doing away with masses of time consuming field notes and gross recording errors. The introduction of robotic total stations allows the surveyor to work alone as the robotic total station tracks the surveyor’s movements in the field and the surveyor records positions using a remote recorder.

A recent advancement in spatial analysis equipment, after the total station, is the terrestrial laser scanner. The laser scanner can be used to monitor movement of various objects by comparison of 3D scans. Objects can be scanned and dimensions determined without contact, volumes can be calculated by a series of scans with the use of common points to create a complete single 3D image. Locations of objects relative to other object positions
can also be determined and thus the density of objects in an area may be established. The laser scanner can be used to record 3D images of building interiors and exteriors for future recollection.

In this project the laser scanner, Riegl LMS-Z210, is being used to scan a rectangular shaped building and then determine the relative accuracy of dimensions attained from the scans compared to dimensions from more standard surveying techniques, using a Sokkia Powerset total station and related surveying equipment. The time taken and the results of these surveys will also help to determine the practicability of the laser scanner as an efficient surveying tool.

1.3 The Problem
Of this project, the problem is to evaluate accuracy and practicality of laser scanner use against more commonly used methods in the surveying industry. Whether, or not, the use of the terrestrial laser scanner is practical, physically, accurately and financially, will be solved within this project also.

The method of solving this will be to measure a building, using a terrestrial laser scanner to scan the building and produce dimensions with the use of appropriate software. Then, use traditional survey techniques to produce the buildings dimensions to a useful accuracy. The two sets of results will be compared and used to solve the usable accuracy of the laser scanner.

1.4 Research Objectives
The aim of this research is:

a) To determine the accuracy of results from 3D laser scans, relative to results acquired by traditional survey methods.
b) To determine the benefits gained from using laser scanners for survey work compared to traditional methods of survey.

1.5 Risk Assessment

As the practical part of this project will be conducted on the open areas of the 6th and 7th floors of the building, a risk assessment of working at heights must be completed. A standard work procedure and Work Permit for this area have been attached in Appendix B.

Other hazards in the practical part of the project may be trip hazards from communication and electrical cables, and sunburn. The risk of these hazards shall be lowered by wearing sensible clothing and by a conscientious attitude to working safely and sensibly.

1.6 Schedule of events

The necessary events of this project are shown below, in table 1.1, with their desired maximum durations, starting and finishing times.
Table 1.1 Project event schedule.

<table>
<thead>
<tr>
<th>Event</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review literature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire work permit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan scanner survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carry out laser scan survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce scan data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plan traditional survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carry out traditional survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduce traditional survey data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compare the results</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Examine scanner benefits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.7 Conclusions

This dissertation aims to evaluate the accuracies of laser scanning surveys in verbatim to traditional surveys. The research will result in quantifiable results of the comparative accuracy, but also describe the advantages of the laser scanned survey over the more standard survey methods.

A review of literature is required to determine the manufacturer’s expectations of the equipment used and examples of engineering based projects using laser scanners. It will also provide examples of laser scanning for various other purposes.
Chapter 2: Literature Review

2.1 Introduction

This project will give results of the relative accuracies of the laser scan survey against a traditional survey, and describe the benefits of the laser scan survey.

This chapter will review literature to establish the need to describe the advantages of the laser scan operation and survey to compare against traditional survey methods of capturing data of 3-dimensional objects. It will also establish the need to compare the relative accuracies of both types of survey. To ascertain the expected results of surveys of this type, manufacturers technical notes on the instruments used will also be reviewed.

In addition to establishing the advantages and accuracies of both systems, this chapter will consider how they will be equated and review what results have been achieved in related tests in the past.

2.2 Need for an accuracy evaluation

Laser scanning is a new technology to the surveying industry, and as such, needs to be tested for validity of its use in this field.

Mitchell states that . . .

“commercially available scanners... obtain the shapes of objects by measuring vertical and horizontal angles and distances to many points at a very close spacing.”, and thus “Terrestrial laser scanners... could well be the cause of the next revolution in surveying.” (Mitchell, 2003, p1).
Because of the short times taken to collect large amounts of immediately usable point data, the 3-D laser scanner could become an integral part of a surveying firms’ equipment inventory.

In the surveying industry, it is of utmost importance to give correct results to clients. Simply assuming that results deduced from laser scans will be as accurate as those achieved from traditional survey methods is a risk that the professional surveyor is unable to take. Mitchell states . . . .

“In the case of surveying, having ‘something going wrong’ . . . might mean giving an incorrect survey result to a client, another surveyor, a supervisor, or a regulatory authority. Surveyors clearly need to be able to guarantee the measurements they generate” (Mitchell, 2003, p2).

If the terrestrial laser scanner is to be used for establishing the shapes and dimensions of objects, then its accuracies, over other forms of data capture, must be shown to be adequate for the purposes of the job at hand. Paton (2004) describes a terrestrial laser scanner being used to locate the position of particular beams in the existing roof of a large sports stadium so that the roof could be extended from these beams. Consultants considered that “It would have taken up to two weeks to get even the minimum amount of data using traditional survey techniques”. Also, “this new technology has delivered a result that previously would have been virtually impossible to achieve without the inherent risk of placing personnel up on the structure to take detailed measurements and place targets for traditional survey instruments” (Paton, 2004, p2).

In the article ‘Boeing Takes Stake in Local Laser Scanner Manufacturer’, Chris Genna explains about the Boeing company’s investment in laser scanner development, to help in
the time consuming task of checking measurements of its manufactured airplane parts. In the article, Chris has noted that “The scanner speeds the verification of complex-shaped parts such as airfoils, propeller blades and jet engine turbine blades. Parts that once took nine hours to check for accuracy can be verified in 20 minutes” (Chris Genna, 2003, p1).

These points, by Leigh Finlay and Chris Genna, highlight the inherent advantages of laser scanners, that they require very little time to capture the necessary data and that they take away some of the possible risks involved with physical contact of objects. Risks that most traditional surveys would need to surmount. This had demonstrated that the laser scan survey has obvious benefits over traditional survey methods, but has not addressed if the laser scanner is of real practical use in more usual survey jobs and if there are other possible benefits of its use. Can the terrestrial laser scanner produce results which are accurate enough for clients, relative to the high accuracies achieved by common practice survey methods? These questions will be the focus of this project.

2.3 Comparison of Data Capture Methodology
2.3.1 Planning the survey for the best results.
In the field of engineering, multiple scans are often required for a complete portrayal of the surveyed object (Bornaz et al., 2002).
Chapter 2: Literature Review

In testing by N. Pfeifer et al., the “Kleine Galerie” was scanned using the Riegl LMS-Z210 instrument, which is the instrument available for this project. The large room had many niches and a total of 15 positions were used for the set-up of the laser scanner to allow complete coverage. The survey included the attachment of 23 reflective targets to wall pillars, so as to aid in the modelling process in the office.

I-SiTE Pty. Ltd. Conducted a structural mapping survey of the Sydney Opera House. With this survey, four scan set-up locations deemed sufficient to acquire full coverage. These positions are indicated by white triangles in figure 2.1.

The setting up and scanning at each of these four positions took around 15 minutes, and so, the entire outer surface of the Opera House was scanned in one hour. Due to the chosen positions of the scan stations and the low number of them, disruption to pedestrian traffic was minimal (I-SiTE Pty. Ltd., 2003). The software used to model the scans were I-SiTE 3D and Vulcan software, which is the software available for scan manipulation for this project.
Chapter 2: Literature Review

In the journal article ‘Engineering and Environmental Applications of Laser Scanner Techniques’, Leandro Bornaz et al. have highlighted some conventions that should be considered for the undertaking of laser scan surveys . . . .

“In the field of engineering and environmental applications, some rules should be considered so that laser scanner instruments can be used correctly: the maximum measurement range of a laser range finder often limits the survey to a part of the object, if the surveyed object is large or its shape is complex, a series of scans is necessary, the angular constant resolution of laser scanner acquisition corresponds to a variable resolution of the surveyed point on the surface of the object. A good planning of measurement operations is necessary for survey design. The positions of single acquisitions must be chosen in order to:

• see the largest possible part of the object considering that the maximum measurement range should be limited to 70-80% of that declared by the manufacturer with the aim of preventing any possible holes;
• not lose any important details or hidden zones;
• establish large overlaps between the adjacent scans so as to preview any systematic errors during their joining.” (Bornaz et al., 2002, p2).

2.3.2 Development of survey results.

In the use of laser scanners, large numbers of 3-Dimensional coordinates on an objects’ surface are measured. Object features, such as corner points or edges, are not directly recorded (Boehler et al., 2003). They will have to be modelled from the acquired point clouds in a separate process. Boehler et al. noted that “While it is possible to record the same object several times from different observation points, it is impossible to record the very same points in these repeated surveys.” (Boehler et al., 2003, p2). Therefore, the laser scans will have to be used within the software to create the necessary corners and edges.
Chapter 2: Literature Review

The scanned data sets will have to be orientated relatively to each other, so that common features or points have the same coordinates. This is known as registration. Figure 2.2 shows where different positions of the laser scanner have to be oriented to each other. The laser scanner can be mounted on the tri-pod horizontally or vertically, or, theoretically, in any orientation.

I-SiTE Pty. Ltd. Suggests that after registration of data sets, the next step is to edit out and filter any data that is not required or is in overlapping adjacent scans. It is also suggested that within the I-SiTE software, the editing/filtering functions of point smoothing, data deletion, edge detection and masking as well as scan colouring options are employed for this task. The scan data can then be exported to the VULCAN software for further editing, modelling and result extraction (I-SiTE Pty. Ltd., 2003).
In ‘Calibration Experiments of a Laser Scanner’, by Cheok et al., simple testing scans were conducted on a box, which was similar in shape to the test subject of this project. It was found that ‘split signals occurred which resulted in the creation of phantom points, as illustrated in figure 2.3. These points do not actually exist, and will need to be edited out if any occur in the scan data of this project.

![Figure 2.3 Point cloud of box showing phantom points. (Cheok et al., 2002, p16)](image)

2.3.3 Limits and expected results from laser scanner.

The confidence in the final products of laser scanning (3d models, positioning, derived quantities, etc.) depends largely on the accuracy and precision of the laser scanner. Where accuracy is defined by how close a measurement is to the true value, or in the case of this project, how close it is to the previously measured value.

The laser to be used for this project is an imaging laser sensor which provides not only ranges but also the intensities of the return signals, known as active measurement. The tests using this type of scanner, the Riegl LMS-Z210, by N. Pifiefer et al., showed it was very applicable for the measurement of interiors. The accuracy reached, with this testing, was in the range of better than 20mm, and the process was considered fast and highly automated.
Chapter 2: Literature Review

Results of this level would be preferred as a maximum for the purposes of this project (N. Pfiefer et al., 2001).

In the ‘Structural Mapping’ article, by I-SiTE Pty. Ltd., the scanner used (type not stated) produced an accuracy of +/- 25mm, and obtained an amount of data that would have been extremely difficult using other methods. This article states that “Mapping and measuring sites and structures with access difficulties becomes an easy, safe and quick task, often providing extra useful data.” (I-SiTE Pty. Ltd., 2003, p1). With most other forms of data capture of objects, such as the Opera House, the main safety issues would relate to accessibility. As most of the exterior is virtually inaccessible, it would have been an extremely risky job to measure it using any conventional method (I-SiTE Pty. Ltd., 2003).

Boeler et al. states that “Since short distances only are measured, the change of the propagation speed of light due to temperature and pressure variations will not seriously affect the results.” (Boehler et al., 2003, p3). This is notable for the purposes of this project as the measured distances should be no more than 15metres, and so atmospheric conditions should not play any part in errors of measurement unless under highly extreme conditions.

Table 1 to 3 are results produced by Boehler et al. They indicate some of the qualities of tested laser scanners. The Rieg1 LMS-Z210 was one of the test subjects and produced a ‘low’ edge quality. It also had a low accuracy, but high ranges are possible and it was able to use a large field of view.

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Type</th>
<th>Edge quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callidus Prec. Syst.</td>
<td>Callidus</td>
<td>low</td>
</tr>
<tr>
<td>Cyra Technologies</td>
<td>Cyrax2500</td>
<td>average</td>
</tr>
<tr>
<td>Mensi</td>
<td>S25</td>
<td>average</td>
</tr>
<tr>
<td>Mensi</td>
<td>GS 100</td>
<td>average</td>
</tr>
<tr>
<td>Rieg1</td>
<td>LMS-Z210</td>
<td>low</td>
</tr>
<tr>
<td>Rieg1</td>
<td>LMS-Z420i</td>
<td>average</td>
</tr>
<tr>
<td>Zoller+Fröhlich</td>
<td>Imager 5003</td>
<td>low</td>
</tr>
</tbody>
</table>

(Boehler et al., 2003, p8)
Table 2.2 Major advantages of some laser scanners

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callidus</td>
<td>Very large field of view.</td>
</tr>
<tr>
<td>Cyrax2500</td>
<td>Good accuracy.</td>
</tr>
<tr>
<td>S25</td>
<td>Very high accuracy for short ranges.</td>
</tr>
<tr>
<td>GS100</td>
<td>Large field of view.</td>
</tr>
<tr>
<td>Riegl Z210</td>
<td>High ranges possible. Large field of view</td>
</tr>
<tr>
<td>Riegl Z420i</td>
<td>Very high ranges possible. Large field of view</td>
</tr>
<tr>
<td>Z+F</td>
<td>Very high scanning speed. Large field of view</td>
</tr>
</tbody>
</table>

(Boehler et al., 2003, p9)

Table 2.3 Major disadvantages of some laser scanners

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Callidus</td>
<td>Very coarse vertical resolution (0.25°)</td>
</tr>
<tr>
<td>Cyrax2500</td>
<td>Small scanning window (40° x 40°)</td>
</tr>
<tr>
<td>S25</td>
<td>Does not work in sunlight. Not suited for long ranges.</td>
</tr>
<tr>
<td>GS 100</td>
<td>Large noise.</td>
</tr>
<tr>
<td>Riegl Z210</td>
<td>Low accuracy.</td>
</tr>
<tr>
<td>Riegl Z420i</td>
<td>Large noise</td>
</tr>
<tr>
<td>Z+F</td>
<td>Low edge quality. Limited angular resolution (0.018°)</td>
</tr>
</tbody>
</table>

(Boehler et al., 2003, p9)

This information suggests that the accuracies produced by this instrument could be low and that it may not prove to be the best type of scanner for the purposes of the surveying industry, but this is yet to be proven here.

2.3.4 Qualities of targeted objects which may effect scan capture.

Considering that laser scanners have to rely on a signal reflected back from an objects surface to the receiving unit, the qualities of possible surfaces must be investigated. The potency of the returning signal is subject to reflective abilities of the surface, among other factors such as distance and incident angle. From tests described in the journal article ‘Investigating Laser Scanner Accuracy’, by Boehler et al., it was found that white surfaces
Chapter 2: Literature Review

yielded strong reflections and black surfaces had weak reflections. Also, it was found that shiny surfaces are usually hard to record. Boehler et al. observed that surfaces with different levels of reflectivity resulted in systematic errors in range. Table 4 shows results of scans on different surfaces by different scanners. The Riegli LMS-Z210 shows poor results for grey (40% white) surfaces, metal painted surfaces, aluminium foil and an orange cone which was tested.

Table 2.4 Distance correction due to different surface materials (mm). Positive sign = Distance is measured too short as compared to white surface. a Scanner did not record any points on this surface.

<table>
<thead>
<tr>
<th>Type</th>
<th>white 90%</th>
<th>white 80%</th>
<th>gray 40%</th>
<th>black 8%</th>
<th>metal paint</th>
<th>alu foil</th>
<th>blue foil</th>
<th>orange cone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calidus(1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0-100</td>
<td>-7</td>
<td>-10</td>
</tr>
<tr>
<td>Calidus(2)</td>
<td>0</td>
<td>0</td>
<td>+4</td>
<td>-3</td>
<td>0-10</td>
<td>0-15</td>
<td>-5</td>
<td>-20</td>
</tr>
<tr>
<td>Cyrax (1)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0-10</td>
<td>+22</td>
<td>-40</td>
</tr>
<tr>
<td>Cyrax (2)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+17</td>
<td>-70</td>
</tr>
<tr>
<td>S25</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GS 100</td>
<td>0</td>
<td>0</td>
<td>+8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>n.a.</td>
<td>0</td>
</tr>
<tr>
<td>Riegli Z210</td>
<td>0</td>
<td>0</td>
<td>+13</td>
<td>-3</td>
<td>0-100</td>
<td>0-250</td>
<td>0</td>
<td>-100</td>
</tr>
<tr>
<td>Riegli Z420</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-20</td>
</tr>
<tr>
<td>Z+F</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0-50</td>
<td>-18m</td>
<td>-20</td>
</tr>
</tbody>
</table>

(Boehler et al., 2003, p9)

In the journal article ‘Calibration Experiments of a Laser Scanner’, by Cheok et al., it was indicated that highly reflective targets exhibit large errors in the shorter ranges of 0-60m. In the short range, the errors for white, black, green and yellow targets were seen to conform to ±20mm accuracy, but beyond 20m, the black target results begin to deviate. Pink and grey targets, however, exceed the ±20mm accuracy immediately, and throughout the tested range (Cheok et al., 2002). It was observed that the angle of incidence affects the range accuracy. Highly reflective targets were found to yield the largest measurement errors, and were the least precise, for angles of incidence of 50 degrees and larger.
Chapter 2: Literature Review

The targeted object for this project has a tile lined surface. These tiles are made up of, light grey to black, flecks which gives an overall grey colouring. The top and bottom edges of the building are capped with stainless steel. The results reviewed from literature indicate that this building may give low accuracy results due to the materials that it is lined with, but as this is a common type of structure it will be a good test subject for the purposes of this project.

2.3.5 Traditional Survey Methods

Accuracy specifications will have a large affect on determining the field methods to be adopted in order to achieve that accuracy (Faculty of Eng. and Surv., 2003). From the website news report, a reasonable accuracy for the survey to be undertaken in this project is assumed to be ±10 to ±15mm (Monteath & Powys, 2001). Minimum accuracy standards, taken from the Department of Works, Engineering branch, state that “reduced levels of features to be shown to 0.01m and shall be within 0.01m of the correct level” (Faculty of Eng. and Surv., 2003). This statement confirms the assumed accuracy for the traditional survey of ±10mm.

The method of survey to be undertaken for the project is that of a detail survey, where the test structure has its important features recorded from known survey stations. It is the position of the author that this form of survey is common in the surveying industry and has been decided upon from experience gained in the industry. The basic detail survey with control stations is a simple and cost effective approach to recording positions of structures and will be able to achieve the prescribed accuracy specifications for the survey.
Chapter 2: Literature Review

2.4 Manufacturers Specifications and Expected Result Values.

2.4.1 Riegl LMS-Z210 Laser measuring scanner Specifications.

The information taken from the ‘LMS-Z210 Technical Documentation’ manual that is most relevant for this project is:

- The vertical scan angle range: 80degrees (40 above and below horizontal).
- Scan speed: 5scans/sec. up to a max. 52scans/sec.
- Angle step width: 0.072degrees to 0.36degrees.
- Horizontal scan angle range: 0degrees up to a max. 333degrees.
- Scan speed: 1deg/sec. up to max. 15deg/sec.
Chapter 2: Literature Review

- Measurement range for retroreflecting targets: Up to 700m @ 50mm resolution.
- Measurement range: (For natural targets, 80%)
  - Up to 450m @ 50mm resolution.
  - Up to 350m @ 25mm resolution.
- Minimum range: 2m.
- Measurement accuracy: typically +/- 25mm @ 25mm resolution.
- Weight: 13.5kg (with heat shield).
- Operating temperature range: -10°C up to +50°C.
- Voltage supply range: 11 – 18V DC.

These values are taken as for average conditions. In bright sunlight, the operational range is considerably shorter than under an overcast sky. At dawn or night the range is even higher. (Riegl, 2001).
2.4.2 Sokkia Powerset specifications.

The information taken from the ‘Sokkia Powerset 2010 User Manual’ that is most relevant for this project is:

- **Angle Measurement Accuracy:** 2 seconds of arc.
- **Distance Measurement:** range to a single prism = 2,700m.  
- **Distance Measurement:** ± (2mm + 2ppm)  
- **Telescope Magnification:** 30x  
- **Minimum Focus:** 1.0m  
- **Measurement principle:** time-of-flight measurement.

![Photo of Sokkia Powerset 2010](image-url)
21

Chapter 2: Literature Review

These values are taken as in good conditions, being no haze, visibility 40km, overcast and no heat shimmer (Sokkia, 2004).

2.5 Conclusions

This chapter has established the need for a description of the advantages of the laser scan survey over traditional survey methods of 3D data capture, and the need for a comparison of relative accuracies of the two methods of survey. The descriptions of the advantages of the laser scan survey are needed because of a lack of knowledge amongst surveying professionals of the inherent benefits of using laser scanners. Other industries, such as manufacturing, are making good use of the laser scanner technology for checking products against design specifications. The laser can be seen to be a quick and effective method of gathering large amounts of data. As an effective surveying tool, the scanner needs to be proven to be able to do the job to a usable accuracy and that it is a practical tool for surveyors before it will be widely accepted.

The laser scanner has a maximum range of around 450m. It is limited in the vertical by a 40 degree range above and below horizontal. These factors set the scene for the test site. The test site structures’ qualities also play a part in the results from scanning and may need to be considered. The laser scanner manufacturers’ specifications indicate an accuracy of ±25mm at best and the total stations accuracy is ±(2mm + 2ppm) for distance and 2” for angles.

The methodology for testing and comparing, chapter 3, is based on the information and knowledge gained here in the literature review.
Chapter 3: Methodology

Chapter 3

Methodology

3.1 Introduction

The methodology of the project has been established by the findings of the literature review, chapter 2. The laser scanner’s limitations and other appropriate considerations have been used to come up with the best method of survey. The functions of filtering and registering data are used in the reduction processes via the I-SiTE software. An established form of traditional survey, the detail survey, is utilised with commonly used surveying equipment.

From previous, the objectives of this project are:

a) To determine the accuracy of results from 3D laser scans, relative to results acquired by traditional survey methods.

b) To determine the benefits gained from using laser scanners for survey work compared to traditional methods of survey.

Chapter 2 indicates that the surveying industry is relatively unaware of the possible results of these objectives and that revealing them will help surveyors to embrace this new technology.

To achieve these objectives, a laser scan survey of a chosen object, needs to be completed and analysed. A traditional survey of the same object needs to be carried out and also analysed. The two survey types then need to be compared for accuracy and also for advantages and disadvantages of use.

The methodology chosen to be undertaken for this project, to give simple and concise results to the aims of the project, is in the form of:
Chapter 3: Methodology

a) Research:  - literature review on laser scanning previous testing and appropriate teachings for survey comparison.

b) Strategy:  - Plan laser scan survey outline to capture complete 3D model of selected structure.
               - Plan traditional survey outline to capture necessary dimensional data of object.

c) Data Collection:  - Carry out laser scan survey of chosen object.
               - Carry out traditional survey from outline.

d) Analysis:  - The laser scan survey data is filtered and manipulated with software to produce a 3D model, which will allow dimensional and positional results for comparison.
               - The traditional survey data is reduced to give dimensional positional results.

e) Comparisons of surveys and results:
               - The laser scan survey results are reviewed to achieve a relative accuracy to traditional surveys.
               - The two methods of survey are compared for field-time, ease of use, cost, software needs, time of reduction of data, transportability and manpower needed.

f) Conclusion:  - Reflect on results attained and benefits of laser scanning.

3.2 Research Method

3.2.1 Literature Contribution to Research Method

The review of literature has given a basis with which to structure a laser scan survey so as to achieve the best possible results. (Bornaz et al, 2002, p.1) The important aspects to be considered in developing a methodology from the literature review are:

- Maximum and minimum range of the laser scanner should be considered (Bornaz et al, 2002, p.1).
Chapter 3: Methodology

- Vertical and horizontal angle ranges must be considered for placement of the instrument.
- A series of scans may be necessary due to these previous limitations and complexity of the subject structure (I-SITE Pty. Ltd., 2003, p.1)
- Acquisition location is chosen to see the largest possible part of the object. (Bornaz et al, 2002, p.2)
- Important details or hidden zones must be acquired. (Bornaz et al, 2002, p.2)
- Large overlaps between adjacent scans are necessary to help prevent systematic errors. (Bornaz et al, 2002, p.2)
- Potency of return signals are subject to the reflective qualities of the target surface and should be taken into account before deciding the preferred data capture method. (Boehler et al, 2003, p.5)

3.2.2 Data Collecting and Testing

a) Equipment Utilized

For the laser scan survey part of this project, the laser scanner made available for use was the Riegl LMS-Z210 instrument (Figure 3.1).
Chapter 3: Methodology

The scanner was originally supplied for the project with a laptop computer loaded with I-SITE studio software for data capture. During preliminary testing of the scanner to become accustomed with its use, the laptop hardware failed, and the laptop was replaced with an office workstation computer on a trolley, for mobility, (Figure 3.2). The new computer was also loaded with the I-SiTE Studio software.

Figure 3.1 Photo of Riegl LMS-Z210 Laser Scanner.
Chapter 3: Methodology

The traditional survey part to this project required the use of regularly used survey equipment. The Sokkia Powerset 2010 total station was used here (Figure 3.3), and was accompanied by custom built survey reflectors with –30mm constants (Figure 3.4).
The instruments used in the survey were placed on either survey pillars or survey tripods, accurately situated over the stations used in the scan survey.

b) Software
The I-SITE Studio software captures and stores the laser scanner data, and is also used for the data editing process. VULCAN v4.5 software was also available for the 3D modelling purposes and CAD manipulation to enable the determination of dimensions. For reduction of the traditional survey data, Liscad software was used. Autocad 2002 was used to produce plans of the structure from each surveys’ results.

c) Basic Operation
The terrestrial laser scanner is positioned on either a survey tripod or pillar, and connected to the computer and a power source (12V rechargeable battery). The software on the computer directs the scanner to a specified start point of scanning. Vertical and horizontal angle ranges are specified, as well as resolution, from coarse to ultra fine, range gating and
some other more advanced specifications. The scan is then acquired as the face of the scanner turns passed the target object. After the necessary locations of the scan are acquired, the data maybe edited and registered to a coordinate system using the software, in the field or back in the office.

The total station used in the traditional survey, was set up over a tripod or pillar and had a bearing and distance set to a known station or reference object. A mini-reflective prism was then placed on the target object in locations of importance and the total station was turned to view the prism directly. At the press of a button, the bearing and distance and also vertical angle and distance was acquired from the station to the point. This data can be stored for download to a computer, but was recorded to field notes for the purposes of this survey.

d) Test Structure
For the purposes of this project, the building to be surveyed is the top section of the elevator shaft of the engineering and surveying building on the campus of the University of Southern Queensland, in Toowoomba. The building is near cubic in shape, with dimensions of around 4-5 metres, with a few attachments, which support aerials and dishes for different uses. On the top of the building is a GPS survey base station and a safety fence. For the purposes of the survey these attachments will be ignored in determining major dimensions. The building is covered in tiles and has stainless steel edging around the base and the upper edges. The dimensions to be acquired are the eight main corners of the building, four at the bottom corners and four at the top. The elevator shaft building is on level 6 of the engineering and surveying building and its' roof is level 7. The area of level 6 is not spacious and this may result in 3 or 4 scanning stations being set up to allow a full 3D image of the building to be acquired, excluding the roof.

The acquisition of a work permit was necessary before any work could commence (refer to 1.5 and Appendix B).
3.2.3 Field Testing

a) Laser Scan Survey

The possible amount of scanning stations is due to the scanner's vertical angle limit of 40° from horizontal. This means that when a station is near to the building the top corners may not be in the scanner's range, thus requiring another scanning station to capture all of the corners at least twice. The need for the extra scan station may serve to help simulate a real surveying job in which unforeseen circumstances may hinder the job's progression.

For the first scan, the scanner was set-up on a survey pillar that would give the largest amount of view of the structure (see figure 3.5). The scanner was set to face a reference object in the distance through the use of a removable targeting telescope, and this direction was given an adopted bearing. The software was given a height of instrument and a false coordinate of its position. The horizontal range was set to be able to encompass the full view of the structure. The vertical angle was set to its maximum to ensure that the top and bottom of the structure were captured. The resolution was originally set to ultra-fine mode, but due to software problems had to be lowered to coarse mode. This will be examined in the results chapter. The range gating was set to 2m as minimum and 30m as a maximum. This first scan was then acquired with six corners and two sides of the structure in the viewing range. Using the I-SITE software, a quick check of the scan was made to see that all necessary data was acquired.
The instrument was then taken down and set up in a new position near the south western corner of the structure. The limited roof area here required that the set up location be as close to the edge of the limited area as possible to minimise any possible missed data in the scanners viewing range. For this location, the scanner was placed on a survey tripod. The steps involved in the first scan position were then repeated for this second location, except that a specific back bearing was not set. Upon checking the resultant scan it was found that
Chapter 3: Methodology

the top corner of the structure nearest the scanner had been missed due to the vertical angle limits of the scanner. This finding required that there would definitely need to be four scans of the structure to acquire data of all eight corners.

Two more scans were made in the same manner: one at the south eastern corner and one more at the north eastern corner of the structure. The total time of field work and filenames were recorded on field-notes (see Appendix C). The location of the scan positions were marked for use as set up (or sighting) points in the traditional survey.

b) Traditional Survey Method

The Sokkia Powerset total station was placed on the survey pillar used for the first laser scan position. Reflective prisms were placed on the two scan positions, visible from station one, being station two and station four. Height of instrument and height of targeted reflector were recorded. The total station (T.S.) was targeted to a communications tower in the distance as a reference point and a bearing of 90 degrees was set. A round of bearings and distances were taken to all visible corners of the structure and to both visible stations, in face left and face right of the T.S. The corners of the structure were first targeted directly with cross hairs of the T.S.’s telescope and angles were recorded in the field notes, then the mini-reflective prism was held in place by the assistant and distances were then recorded. After a quick reduction of bearings to check for gross errors, the T.S. was taken down and placed on the survey tripod located at station 4, and the reflective prisms were placed at stations one and three. Again, a round of bearings and distances were taken to all visible corners and to both stations, in face left and face right and recorded in the field notes (See Appendix D). For this second T.S. position, four corner points of the structure overlap from the first station position. Reflective prism station heights and instrument heights were recorded.
It was decided that more stations were not needed, as all corner points of the structure had been recorded, and the next step of measuring up the structure would tie in any of the points that had only been recorded once. The next part of the process involved the use of a 10m offset tape to measure between each of the corner points to check for any errors and these were also recorded. The equipment was then packed up and a field time was recorded for the survey.

3.2.4 Data Analysis
a) Laser Scan Data
I-SITE Studio was used to analyse the scan data. Training for use of the VULCAN software was not able to be acquired and as such this software was not used to manipulate the scan data. Within I-SITE, the particular scan is viewed and a masking field is decided upon to remove any superfluous points outside of a specified field of range from the original scanner position. A point smoothing option may be used at this point to smooth out differences between consecutive points, but after comparison of this function’s results, it was decided not to use this function. The next function option to use is ‘edge detection’. This removes all points that are not within a specified distance of what the software decides is an edge of the scanned subject. This function removes a lot of unnecessary data and leaves an outline of the structure.

At this point, corner positions can be depicted and individual points can be saved to a survey point file. The above process is repeated for scans with multiple overlapping corner points. The process of registering ‘matching point pairs’ is used to place each scan into the coordinate system of the previous scan. In the end, each scan has the same northerly direction as the others. A query function then allows edge lengths and point coordinates to be shown.
Chapter 3: Methodology

**b) Traditional Survey Data**

The Liscad SEE software was used to produce results from the traditional survey data. The hand written field note data was used to create 3D points within the Liscad program. These points were then used to calculate and examine the dimensions of the structure. As a check, these dimensions were compared to the measurements, recorded in the field notes, from using the 10m tape.

### 3.2.5 Practicality Review

The characteristics reviewed to indicate the practical use of the laser scanner were:

- a) The field time necessary to complete the survey.
- b) The ease of use of the instrument.
- c) The office time necessary to produce the requested results.
- d) The ease of use of the software.
- e) The manpower required to complete the field work.
- f) The costs of purchase of the equipment.
- g) The weight and mobility of the equipment.
- h) The range limits of the instrument.
- i) Ability to work at night or in areas of low light levels.
- j) Reliability of the instrument throughout the survey.

These characteristics were compared with those of the traditional survey equipment to indicate whether the laser scanner is practical for use in the surveying industry.

### 3.3 Conclusions

The laser scan survey and traditional survey were carried out and the acquired data was then reduced with the appropriate software for both surveys. As no training was gained in
the use of the VULCAN software, and it being a more complicated program to learn, the I-SiTE Studio software was utilised for all of the scan data processing and extraction of results. The surveying software, Liscad, was used for the reduction of the traditional survey data.

The two types of survey were noted for their advantages and disadvantages to indicate what the benefits are of the laser scan survey.
Chapter 4: Results and Discussion

Chapter 4

Results and Discussion

4.1 Introduction

In the methodology of this project, chapter 3, the two methods of survey, a terrestrial laser scan survey and a traditional survey, were conducted on a building structure as examples of a possible structural survey.

This chapter’s purpose is to:

a) Produce dimensional and positional results from the laser scan survey.

b) Produce dimensional and positional results from the traditional survey.

c) Compare the results from the two methods of survey and produce a relative accuracy of the laser scan survey against the traditional survey.

d) Analyse and indicate the benefits of the laser scan survey.

The laser scan data was processed within the I-SiTE Studio software. The amount of point data is reduced, leaving only the necessary point data of the building. This is then registered into a local coordinate system. This filtered and registered data would then have been transferred to VULCAN software for 3D modeling processes, but as suitable training for this software was not attainable within the project period, the I-SiTE software was further used for achieving dimensions and point data, as will be seen in section 4.2.1.

The traditional survey data was entered into the Liscad software, a common surveying tool, and point coordinates and building dimensions were able to be extracted. The results from both surveys were then represented in plan form and also tabulated to achieve a relative accuracy against the traditional survey.

4.2 Analysis of Results
Chapter 4: Results and Discussion

4.2.1 Laser Scanner Survey Results

a) Overview

The I-SiTE Studio software was used to manipulate all of the laser scan data. Due to a lack of training, the VULCAN software was not able to be used in the processing of the data. The I-SiTE software allowed the production of corner point coordinates and edge dimensions of the test structure used in this project.

b) Processing Techniques

Within the I-SiTE Studio environment the first scan was viewed as a point cloud. Firstly, the data was filtered using the ‘range’ function. This disregards points that are not within a specified minimum and maximum range of the scanners position. The next filter used was the ‘plane’ function. This disregards points on one side of a plane, specified by three points from the user. The resulting point cloud is shown in figure 4.1.
The ‘edge detection’ function was then used to remove all points that the software determined were not at the edges of the structure, by a distance threshold algorithm, thus leaving only points at edges, as shown in figure 4.2. This process was carried out on all four scans from the survey.
The first scan was the only scan that was acquired with the backsight bearing set correctly, and thus the other scans required registration to the first scans coordinate system. Also, the coordinates of all the scan stations were entered as zero for their easting, northing and reduced level. This then required that the scan station for the first scan be given coordinates that were chosen by the author, for a local coordinate system, of:

- E 10,000.000
- N 200,000.000
- RL 700.000, for the first scan station.

From the minimal point data left over after filtering, and considering the coarse mode of the scanner throughout the scanning process, the six visible corner points of the structure were located and placed into a survey point file, within the software. This process was carried out for the rest of the scans and, keeping the first scan’s corner points as ‘fixed points’, the
Chapter 4: Results and Discussion

scans were then registered to the local coordinate system by a ‘matching point pairs’ function. A visual check then confirmed that the scans had been registered correctly, as can be seen in figure 4.3.

Figure 4. 3 Four scans - filtered and registered.

At this stage of the process, the scan files would normally be transferred to the VULCAN software to extract corner positions and structural dimensions, as it is understood from reviewed literature that VULCAN is recommended for that part of the process. Using the I-SiTE software for this process was rather tedious, but results were attained.
Corner points of the 3D scans were able to be decided upon, and a query function of the software produced Eastings, Northings, RL’s and ranges from the original scan position. Distances between these corner positions could also be queried, as in figure 4.4.

![Edge dimensions (m).](image)

A ‘fitted line’ function was also used to acquire these edge dimensions. This function required that all points along an edge be highlighted, and the software would then produce a line of best fit with an extrapolated length. This data was also used in the survey method comparison.

c) Results
The information produced from I-SiTE Studio was used in Autocad 2002 software to produce two plans of the necessary information. One plan of edge dimensions and one of
Chapter 4: Results and Discussion

3D point coordinates. These plans are examples of that which might be produced, for clients, in a surveying job (see appendix E for these plans).

The point coordinate data produced in I-SiTE Studio is shown in table 4.1.

Table 4.1 Scanned corner point coordinates.

<table>
<thead>
<tr>
<th>Corner Point Description</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
<th>Reduced Level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. Top Cnr.</td>
<td>10,009.518</td>
<td>199,997.477</td>
<td>704.136</td>
</tr>
<tr>
<td>N.W. Top Cnr.</td>
<td>10,004.034</td>
<td>199,997.390</td>
<td>704.084</td>
</tr>
<tr>
<td>S.W. Top Cnr.</td>
<td>10,004.068</td>
<td>199,992.698</td>
<td>704.135</td>
</tr>
<tr>
<td>S.E. Top Cnr.</td>
<td>10,009.628</td>
<td>199,992.705</td>
<td>704.109</td>
</tr>
<tr>
<td>N.E. Base Cnr.</td>
<td>10,009.498</td>
<td>199,997.452</td>
<td>698.514</td>
</tr>
<tr>
<td>N.W. Base Cnr.</td>
<td>10,004.024</td>
<td>199,997.385</td>
<td>698.477</td>
</tr>
<tr>
<td>S.W. Base Cnr.</td>
<td>10,004.071</td>
<td>199,992.760</td>
<td>698.506</td>
</tr>
<tr>
<td>S.E. Base Cnr.</td>
<td>10,009.633</td>
<td>199,992.773</td>
<td>698.557</td>
</tr>
</tbody>
</table>

The test structure’s edge dimensions produced from the corner point coordinates are in table 4.2.
Chapter 4: Results and Discussion

Table 4.2 Dimensions from corner points.

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Scan Survey (from selected cnr. pts.) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>5.623</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>5.607</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>5.630</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>5.556</td>
</tr>
<tr>
<td>North top edge</td>
<td>5.485</td>
</tr>
<tr>
<td>West top edge</td>
<td>4.693</td>
</tr>
<tr>
<td>South top edge</td>
<td>5.560</td>
</tr>
<tr>
<td>East top edge</td>
<td>4.773</td>
</tr>
<tr>
<td>North base edge</td>
<td>5.475</td>
</tr>
<tr>
<td>West base edge</td>
<td>4.625</td>
</tr>
<tr>
<td>South base edge</td>
<td>5.563</td>
</tr>
<tr>
<td>East base edge</td>
<td>4.681</td>
</tr>
</tbody>
</table>

The ‘fitted line’ function results are displayed in table 4.3.
Table 4.3 Software determined edge dimensions

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Scan Survey (software determined edge lengths) (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>5.652</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>5.704</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>5.629</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>5.635</td>
</tr>
<tr>
<td>North top edge</td>
<td>5.586</td>
</tr>
<tr>
<td>West top edge</td>
<td>4.787</td>
</tr>
<tr>
<td>South top edge</td>
<td>5.560</td>
</tr>
<tr>
<td>East top edge</td>
<td>4.789</td>
</tr>
<tr>
<td>North base edge</td>
<td>5.565</td>
</tr>
<tr>
<td>West base edge</td>
<td>4.662</td>
</tr>
<tr>
<td>South base edge</td>
<td>5.570</td>
</tr>
<tr>
<td>East base edge</td>
<td>4.787</td>
</tr>
</tbody>
</table>

4.2.2 Traditional Survey Results

a) Overview

The data produced in the field by the traditional survey was entered into the Liscad program with the first station being given the assumed coordinate of:

E 10,000.000
N 200,000.000
RL 700.000

The dimensional results obtained were then compared to those measured in the field with the 10m offset tape.
Chapter 4: Results and Discussion

b) Processing Techniques
The field data was simply and quickly entered into the Liscad software using its ‘create point’ functions via coordinates and radiations. The test structure’s characteristics were then able to be tabulated for comparison to the previous laser scan survey and also for the creation of plans indicating corner point coordinates and edge lengths, as in Appendix F.

c) Results
Taped edge measurements are compared to results obtained from data entered into Liscad as a survey check (shown in Table 4.4).

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Taped lengths (m)</th>
<th>Liscad Results (m)</th>
<th>Difference (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>5.681</td>
<td>5.679</td>
<td>-2</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>5.684</td>
<td>5.681</td>
<td>-3</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>5.654</td>
<td>5.658</td>
<td>4</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>5.645</td>
<td>5.646</td>
<td>1</td>
</tr>
<tr>
<td>North top edge</td>
<td>5.627</td>
<td>5.624</td>
<td>-3</td>
</tr>
<tr>
<td>West top edge</td>
<td>4.771</td>
<td>4.769</td>
<td>-2</td>
</tr>
<tr>
<td>South top edge</td>
<td>5.63</td>
<td>5.626</td>
<td>-4</td>
</tr>
<tr>
<td>East top edge</td>
<td>4.778</td>
<td>4.771</td>
<td>-7</td>
</tr>
<tr>
<td>North base edge</td>
<td>5.609</td>
<td>5.610</td>
<td>1</td>
</tr>
<tr>
<td>West base edge</td>
<td>4.767</td>
<td>4.765</td>
<td>-2</td>
</tr>
<tr>
<td>South base edge</td>
<td>5.629</td>
<td>5.630</td>
<td>1</td>
</tr>
<tr>
<td>East base edge</td>
<td>4.758</td>
<td>4.754</td>
<td>-4</td>
</tr>
</tbody>
</table>

These check measurements showed no results greater than 7mm from the taped measurements. As this level of survey was required to have an accuracy of ±10 to ±15mm, these differences are within tolerance and the survey did not need adjustment. The corner
Chapter 4: Results and Discussion

Point coordinates and edge dimensions produced of the structure are listed in Tables 4.5 and 4.6.

Table 4.5 Point coordinates from traditional survey.

<table>
<thead>
<tr>
<th>Corner Point Description</th>
<th>Easting (m)</th>
<th>Northing (m)</th>
<th>Reduced Level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. Top Cnr.</td>
<td>10,009.638</td>
<td>199,997.470</td>
<td>704.196</td>
</tr>
<tr>
<td>N.W. Top Cnr.</td>
<td>10,004.014</td>
<td>199,997.421</td>
<td>704.202</td>
</tr>
<tr>
<td>S.W. Top Cnr.</td>
<td>10,004.098</td>
<td>199,992.652</td>
<td>704.204</td>
</tr>
<tr>
<td>S.E. Top Cnr.</td>
<td>10,009.724</td>
<td>199,992.699</td>
<td>704.183</td>
</tr>
<tr>
<td>N.E. Base Cnr.</td>
<td>10,009.627</td>
<td>199,997.476</td>
<td>698.517</td>
</tr>
<tr>
<td>N.W. Base Cnr.</td>
<td>10,004.017</td>
<td>199,997.419</td>
<td>698.517</td>
</tr>
<tr>
<td>S.W. Base Cnr.</td>
<td>10,004.092</td>
<td>199,992.653</td>
<td>698.546</td>
</tr>
<tr>
<td>S.E. Base Cnr.</td>
<td>10,009.722</td>
<td>199,992.722</td>
<td>698.537</td>
</tr>
</tbody>
</table>

Table 4.6 Edge dimensions from traditional survey.

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Traditional Survey (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>5.679</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>5.681</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>5.658</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>5.646</td>
</tr>
<tr>
<td>North top edge</td>
<td>5.624</td>
</tr>
<tr>
<td>West top edge</td>
<td>4.769</td>
</tr>
<tr>
<td>South top edge</td>
<td>5.626</td>
</tr>
<tr>
<td>East top edge</td>
<td>4.771</td>
</tr>
<tr>
<td>North base edge</td>
<td>5.610</td>
</tr>
<tr>
<td>West base edge</td>
<td>4.765</td>
</tr>
<tr>
<td>South base edge</td>
<td>5.630</td>
</tr>
<tr>
<td>East base edge</td>
<td>4.754</td>
</tr>
</tbody>
</table>
4.2.3 Comparison of Survey Results

a) Relative Accuracy of Scan Survey

In creating a relative accuracy of the laser scan survey, it must be understood that the scanner in this project was only able to be used in ‘coarse’ mode. Thus it was expected that the results from this survey would be inaccurate and greater than those specified by the manufacturer (Refer to section 2.3.1). Also it should be considered that only one set of scans were acquired and that multiple sets may give a more definite accuracy.

The traditional survey results, which are taken as true for the purpose of a relative accuracy, were individually compared with the point coordinate results of the laser scan survey, in appendix G. In table 4.7, it is shown that the differences in Easting range from +20mm to -129mm, with a mean of -57.3mm. The Northings differ by a range of +107mm to -34mm, with a mean of +16mm. The reduced levels range from +20mm to -118mm and have a mean variance of -48mm. Overall a standard deviation of accuracy of +/-6mm is created in any 3D direction from the surveyed point.
### Table 4.7 Coordinate differences.

<table>
<thead>
<tr>
<th>Corner Point Description</th>
<th>Differences in Easting (mm)</th>
<th>Differences in Northing (mm)</th>
<th>Differences in Reduced Level (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. Top Cnr</td>
<td>-120</td>
<td>7</td>
<td>-60</td>
</tr>
<tr>
<td>N.W. Top Cnr</td>
<td>20</td>
<td>-31</td>
<td>-118</td>
</tr>
<tr>
<td>S.W. Top Cnr</td>
<td>-30</td>
<td>46</td>
<td>-69</td>
</tr>
<tr>
<td>S.E. Top Cnr</td>
<td>-96</td>
<td>6</td>
<td>-74</td>
</tr>
<tr>
<td>N.E. Base Cnr</td>
<td>-129</td>
<td>-24</td>
<td>-3</td>
</tr>
<tr>
<td>N.W. Base Cnr</td>
<td>7</td>
<td>-34</td>
<td>-40</td>
</tr>
<tr>
<td>S.W. Base Cnr</td>
<td>-21</td>
<td>107</td>
<td>-40</td>
</tr>
<tr>
<td>S.E. Base Cnr</td>
<td>-89</td>
<td>51</td>
<td>20</td>
</tr>
</tbody>
</table>

Range from: 20 107 20
To: -129 -34 -118
Variance   = -57.3 16.0 -48.0
Std. Dev.  = ±7.6 ±4.0 ±6.9
Average accuracy: ± 6mm

When it comes to comparing dimensions, there were two procedures used to create edge dimensions from the laser scan survey. The first was by querying a distance between two chosen corner points. The second was to highlight the points along an edge and have the software establish a line of best fit with a length. Results from both of these procedures were compared to the traditional survey results in appendix H. Table 4.8 shows the differences in these sets of results.
Table 4.8 Edge length method comparison.

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Traditional - Scan Survey (from selected cnr pts) (mm)</th>
<th>Traditional - Scan Survey (software determined edge lengths) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>-56</td>
<td>-27</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>-74</td>
<td>23</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>-28</td>
<td>-29</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>-90</td>
<td>-11</td>
</tr>
<tr>
<td>North top edge</td>
<td>-139</td>
<td>-38</td>
</tr>
<tr>
<td>West top edge</td>
<td>-76</td>
<td>18</td>
</tr>
<tr>
<td>South top edge</td>
<td>-66</td>
<td>-66</td>
</tr>
<tr>
<td>East top edge</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>North base edge</td>
<td>-135</td>
<td>-45</td>
</tr>
<tr>
<td>West base edge</td>
<td>-140</td>
<td>-103</td>
</tr>
<tr>
<td>South base edge</td>
<td>-67</td>
<td>-60</td>
</tr>
<tr>
<td>East base edge</td>
<td>-73</td>
<td>33</td>
</tr>
<tr>
<td>Range from:</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td>To:</td>
<td>-140</td>
<td>-103</td>
</tr>
<tr>
<td>Variance =</td>
<td>-79</td>
<td>-24</td>
</tr>
<tr>
<td>Std. Dev. =</td>
<td>± 8.9</td>
<td>± 4.9</td>
</tr>
</tbody>
</table>

The differences from the assumed true, traditional survey edge lengths, to the corner point selected edges ranged from +2mm to -140mm. Whereas, the differences of true lengths to software determined edge lengths ranged from +33mm to -103mm. The standard deviations were ±9mm and ±5mm respectively. This indicates that the method if determining edges by a line of best fit may be more accurate, but more testing would need to be done to prove this.

b) Practicality of Scan Survey

To appreciate whether the laser scanner is a practical surveying tool, it is first compared to the traditional surveying instrument, the total station. This comparison includes the ease of
Chapter 4: Results and Discussion

use of the instrument, the manpower necessary to use it, the initial costs of the instrument and its mobility in the field.

Both instruments were found to be easy to set up, but the laser scanner used for this project required, at minimum, connection to a laptop computer to allow it to acquire data. Apart from this, both instruments required minimal understanding of their internal workings to be able to acquire the necessary data. The total station used for this project required that a field hand was used to hold the mini-reflective prism in place on the test structure. The laser scanner on the other hand did not require that any of the field crew come in contact with the structure. The cost of a new Sokkia Powerset 2010 as used in the traditional survey is $20,000, including 3 reflector stations. The Riegl LMS-Z210 is worth around $180,000.

The Sokkia instrument itself weighs 5kg and its case weighs 4kg. The Riegl laser scanner weighs 13kg and its case weighs 10kg. The laser scanner also requires a laptop computer of approximately 2kg. Both of these instruments require the use of a survey tripod to be set upon.

Secondly, the field time and office time required for the two methods of survey are compared to aid in the understanding of the practical use of the laser scan survey. Also, the ease of use of the necessary software has been noted.

The total time in the field for the traditional survey was 2 hrs 40mins (refer to Appendix D), which included 15 minutes of initial set-up time, 1 hour 40 minutes for the acquiring of data from two stations and station set-up times, 20 minutes of check measurements, 10 minutes of gross error checks in field notes, and 15 minutes for packing up the equipment. The laser scan survey required 1 hour 35 minutes to complete, which included 10 minutes initial set-up time, 1 hour to set up at 4 stations and acquire data, and 25 minutes to check the scans for any missed data and then pack up the equipment. The office time taken to enter the traditional survey data into the Liscad program, extrapolate results and create the
plans of the test structure was approximately 1 ½ hours. Due to a lack of experience with the I-SiTE Studio software, the office time for the scan survey was approximately 4 hours. More experience with the software could easily halve the time taken to reduce the scanned data.

Other characteristics of the Riegl laser scanner that might indicate its practicality as a surveying tool are the range limits of the instrument, whether it is able to be used at night and its reliability.

The Riegl LMS-Z210 instrument has a maximum range, as stated in section 2.3.1, of 700m. The Sokkia instrument has a maximum distance measuring range of 2,700m. The laser scanner used is an active sensor, which means it emits a laser light beam which it then senses upon reflection back to the instrument, and is quite suitable for use at night on unlit targets. The Sokkia Powerset is also an active sensing instrument and can be used at night, but does require that the target point be lit initially so that the user can aim the instrument at the target. During the process of the survey conducted, no reliability problems were found with the Sokkia Powerset 2010 instrument. One battery was used for the entire traditional survey. Due to software server problems with the workstation adopted for the laser scan survey, there was the stated problem of only being able to scan in ‘coarse’ mode. This is however a problem which could easily be corrected by using the correct laptop properties for the scanning operation. The reliability of the scanner itself seemed very good and the instrument required the use of one rechargeable twelve volt battery for the four scans acquired.

All in all, other than the initial costs and the heavier weight of the laser scanner, it does seem that the laser scanner would be an efficient and practical tool in the surveying industry.
4.3 Conclusion

The aim of this project is to determine a relative accuracy of the laser scan survey to a traditional survey and to highlight the benefits of using laser scanners. Since this project has only covered a single survey on a test structure, it is hard to draw a definite relative accuracy and list of benefits of the laser scanner.

However, based on the testing carried out, it can be concluded that edge lengths determined by a line of best fit along edge points may be more accurate than the method of distances between user-defined corner points as edge length. However, more testing needs to be carried out to prove these findings. From the edge length comparisons a relative accuracy of ±5mm was acquired. Given that the traditional survey was conducted to an accuracy level of less than ±15mm, this relative accuracy would indicate a true accuracy of the laser scan survey close to the manufacturer’s specifications for the instrument’s use in ultra-fine mode. This may be a fluke of testing, or due to the number of scans acquired and combined for the 3D model. Again more testing is required to confirm this.

From the comparison of corner point coordinates a relative accuracy of ±6mm was achieved. Again, this seems to be a higher accuracy than that expected from the manufacturers specifications, and may be due the combined data used to create the 3D model of the test structure giving a better mean corner position than that of a single scan.
Chapter 5

Conclusions and Recommendations

5.1 Conclusions

The terrestrial laser scanner has been applied in fields of bulk volume calculations, monitoring of slopes and high-walls in the mining industry, modelling of structures and artefacts for various purposes and also in the manufacturing industry for checking products against design specifications.

The laser scanner is a new technology to the surveying industry, and as such its uses and limits are relatively unknown to most professional surveyors. For the laser scanner to be accepted more widely as a practical surveying tool, its relative accuracies against the more common methods of need to be examined. The benefits of the scan survey also need to be made known to the professional, and thus give the surveyor another tool with which to achieve results, that have been otherwise unattainable or time consuming. Examining these characteristics of the laser scanner have been the objectives of this project.

The results produced by the comparison of the two forms of survey gave relative accuracies of the laser scans against traditional surveys. The scanned point coordinates differed from the traditional survey results by a standard deviation of ±6mm. The standard deviation of the edge lengths produced was ±5mm. These results seem to be better than expected, as the scanner was used in a ‘coarse’ mode, which produces less accurate results than the finer modes. Manufacturer’s specifications indicate true accuracies of ±50mm for ‘coarse’ mode. Given that the accuracies produced are relative to the accuracy of the traditional survey, which was ±10mm, the results for the laser scan survey still seem better than would be expected. A reason for this may be that the combination of multiple scans to create the 3D
model may have helped to increase the accuracy of mean corner positions. The differences of results from the traditional survey to the scan survey had a range of around 150mm.

From the testing of the laser scanner, as well as reviewed literature, the benefits noted of the scanning system are broad. A laptop computer is necessary in the acquisition of data. Rather than being an extra burden for the surveyor, the laptop allows the reduction of the scanned data immediately. This would be of benefit when the client requests immediate results from the surveyor. The scanner software, in this case I-SiTE Studio, was simple to use and required no training for a proficient surveyor to understand. The scanner did not require that any physical contact needed to be made on the target structure. This would be of huge benefit in situations where a structure to be surveyed is dangerous to be near, or is hard to reach.

Initial purchase costs of the laser scanner are quite high, but the extra jobs it would allow a surveying firm put a tender in for would in a short period pay for the outlay. Though the scanner is heavier and bulkier than traditional surveying instruments, it is still easily carted around by a single person. Additionally, as it does not require an assistant to hold targets in place, the scanner can quite reasonably be considered for a one-person field crew.

Office time for an experienced user of the scan data software would require roughly the same time as that for the reduction of traditional survey data. Data acquisition times for a single station are very short at a maximum of around 15 minutes, including data extents checking. The laser scanner is an active sensing instrument, and thus, is quite suitable for scanning dark areas or at night and also for underground and mine surveys. This ability was not tested in this project but was mentioned in the manufacturer’s technical documentation. An added benefit, inherent of laser scanners, is the large amounts of data captured. An example of this benefit is the ability to produce results for any extra requests from clients that are post-survey. The data has already been captured and another survey may not be necessary.
Chapter 5: Conclusion and Recommendations

In conclusion, assuming that the laser scanners’ finer scanning modes are implemented and produce high accuracy results, the scanner would prove to be a useful tool for the surveying industry. Under the circumstances of the testing carried out in this report, the scans have produced reasonable results, relative to the traditional survey. The benefits of the laser scanners’ use are numerous and warrant that more testing be carried out to bring to light the instruments true usefulness.

5.2 Recommendations

As mentioned previously, the laser scanner was only able to acquire scans in ‘coarse’ mode. This meant that true indications of the scanners relative accuracies could not be determined. The author recommends that further study on accuracies of the scanner be conducted under the maximum data capture mode of ‘ultra-fine’. This would allow the scanner to work at maximum resolution.

Within the processing of the scan data, two methods of producing edge lengths were dealt with. As the scans conducted were limited to a single survey, a true indication of which method is more accurate was not properly determined. It is recommended that some efforts be taken to identify the more accurate method or a method of survey that would lead to similar results from both forms of edge production.

It has not been determined whether the results produced from multiple scans, combined to create a full 3D model, give better results than having fewer or single scans. The author recommends here that the effect of single scans for production of dimensions be compared to the results from multiple and combined scans.
References


Wessex Archaeology / Archæoptics Ltd. (2003), Stonehenge Laser Scans – An application of laser scanners in archaeology, Accessed:  
H:\Project\Literature\stonehenge\Laser Scanning Stonehenge.htm [2004, March 2004].

Stanfill, C (2004), Proper Planning Helps Minimize Workzone and Worksite Hazards, NCDOT Safety & Loss Control, Available:  


Mitchell, H (2003), Laser Scanning, University of Newcastle Accessed:  


References


Faculty of Engineering and Surveying (2003), Automated Surveying Systems – Study Book, DEC, University of Southern Queensland, Toowoomba, Australia.


Appendix A

Project Specification
ENG4111/2 RESEARCH PROJECT
PROJECT SPECIFICATION

FOR: 
James Finlay STEPHENS

TOPIC: 
Accuracy Evaluation of 3-D Laser Imaging Scans

SUPERVISOR: 
Dr. Frank Young

PROJECT AIM:
This project seeks to investigate the accuracy of the dimensions achieved from a scanned 3-D image, relative to dimensions produced with traditional survey methods.

PROGRAMME: Issue A, 22 March 2003
1. Review literature on 3-D Laser Scanning and appropriate software.
2. Choose a suitable object, and design measurement operations.
3. Scan the object with the Riegl Laser Mirror Scanner.
4. Using traditional survey techniques, determine the dimensions of chosen object.
5. Analyse and evaluate the results collected from the 3-D scanner using I-SiTE and Vulcan 3D CAD software.
6. Compare the two sets of results to help determine the accuracies and benefits achieved via the 3-D laser scanner.

AGREED: _________________ (student) _________________ (Supervisor)

(dated) ___ / ___ / ___
Appendix B

Part A - Work Permit

Part B – Standard Work Procedure
Part A – Work Permit

APPLICATION
Name of Applicant: JAMES STEPHENS

I wish to apply for approval to use the Faculty of Engineering and Surveying equipment and facilities:
Appendix B

Part B – Standard Work Procedure

TASK:
Student Use of Survey Pillars on the Fifth floor and Roof of Z Block

Department/Faculty: Engineering and Surveying

Operator Title: Lecturer E4019 Geodetic Surveying A

Hazard:
High [ ] Medium [ ] Low [X]

PPE Required:
1. Sunburn cream;
2. Protective hat able to remain on head during windy conditions;
3. Sunglasses;
4. Fully enclosed footwear with reliable sole to reduce slipping.

Tools/Equipment: Surveyor’s Equipment

<table>
<thead>
<tr>
<th>TASK STEPS</th>
<th>KEY POINTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Obtain Work Permit and access card from nominated lecturer. This card will enable access to the fifth floor from 6am to 6pm. Use of the card is logged and unnecessary use will result in those offending students being refused access for the remainder of the semester.</td>
<td>1. The roof of Z Block is a restricted area. Access to restricted areas is controlled by the a Work Permit. Failure to adhere to this Work Permit will result in access to the roof being revoked.</td>
</tr>
<tr>
<td>2. Students must obtain the required survey equipment from the survey store the day before planned observations. There is a locker located immediately outside the door to the fifth floor that may be used to store equipment overnight.</td>
<td>2. The operator as described above must always record and know who will be occupying the fifth floor and when it will be occupied. No persons other than those enrolled in the specified unit are given permission to be on the fifth floor.</td>
</tr>
<tr>
<td>3. Cards are loaned on the understanding that students will require access for one morning and one evening observation. So the card must be returned two days after being borrowed. If the required observations are not completed on the nominated day students may keep the access card but must notify the nominated lecturer before doing so.</td>
<td>3. An emergency phone is located on the common room side of the foyer on the fourth floor of Z Block. The Toowoomba Police, Crime Stoppers, USQ Security mobile (Speed Dial) 7120, Toowoomba Ambulance and 0-000 are all accessible from this phone.</td>
</tr>
<tr>
<td>4. Survey equipment likely to be required for general use through the normal university day</td>
<td>4. A minimum of two students must be together on the fifth floor at any one time. If one student is injured the other can provide assistance or go for assistance.</td>
</tr>
<tr>
<td>5. Use of the fifth floor facilities are not allowed during rain or thunderstorms</td>
<td>5. Use of the fifth floor facilities are not allowed during rain or thunderstorms</td>
</tr>
</tbody>
</table>
| must be made available.  
5. Students are not to take any unauthorised personnel onto the roof at any time. |
| 6. Use the lift when carrying heavy equipment to and from the fifth floor. |
| 7. Stairs must be climbed from the fifth level of Z Block to get to the next level on which the survey pillars are located. All floors including the fifth floor and above are only enclosed by railings. No part of any person’s body must ever protrude out over the protective railings. |
| 8. No item must ever be thrown or dropped over the side of the building. |
| 9. No action that could conceivably endanger the health or safety of any individual should ever occur. |
| 10. The door enabling access onto Level 5 is not to be left open (ie door stop) at any time. |

Issued by Operations Manager: Michael McLachlan  
Date: 15 March 2000  
Review Date: No later than 15 March 2005

Disclaimer

These procedures are for use within the Faculty of Sciences, University of Southern Queensland. This information is believed to be reliable and current. The University makes no guarantee and assumes no responsibility as to the absolute correctness of these procedures in all circumstances or for their suitability outside USQ.
INSTRUCTIONS TO ALL STUDENTS USING ROOF TOP AREAS IN Z-BLOCK

1. All students must be in possession of a current work permit issued by their supervisor before accessing the roof area.

2. The work permit must be carried at all times whilst on the roof areas. Security will remove students unable to produce a current work permit.

3. All persons must be suitably attired: e.g. a hat, sunscreen and sun protecting clothing during the daylight hours, fully enclosed footwear.

4. Students with permission to access the roof area must not allow another person onto the roof area unless they are also the holder of a current work permit.

5. No access to the roof area is permitted during a storm or rain.

6. All persons must vacate the roof area if a storm is approaching.

7. Anyone indulging in horseplay whilst on the roof area will have their permissions revoked immediately.

8. All students must obey any instruction issued by Faculty or Security staff whilst working on the roof area.

I have read and understand the above instructions: Signature: ........................................

Student No: Q10212499

63
Appendix C

Field Notes from Laser Scan Survey
Appendix C

Date: 14/5/04

Weather: fine/breezy
Temp: 20°C pressure: 941mb

Laser Scan Survey

STN 3
SCANSTAR 1-129

STN 2
SCANSTAR 1-128

Level 7

N

Level 6

STN 7
SCANSTAR 1-629

PILLAR 4
SCANSTAR 1-0157

Field times: 3:00pm - 4:35pm

Data Files:

Pillar 4, mmf: scan course_1

scan_course_2

scan_course_3

scan_course_4

scan_course_5

scan_course_6

STN 2, mmf: scan course_1

scan_course_2

scan_course_3

scan_course_4

scan_course_5

STN 4, mmf: scan course_1

scan_course_2

scan_course_3

scan_course_4
Appendix D

Field Notes from Traditional Survey
Appendix D
<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Bearing</th>
<th>Mean</th>
<th>Adj. B</th>
<th>H dist</th>
<th>Vert. Acc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>STN 3</td>
<td>P4</td>
<td>89° 30' 55&quot;</td>
<td>55&quot;</td>
<td>267° 30' 57&quot;</td>
<td>14.405</td>
<td>10° 00' 56&quot;</td>
</tr>
<tr>
<td>36</td>
<td>3t</td>
<td>30° 39' 03&quot;</td>
<td>56&quot;</td>
<td>210° 33' 58&quot;</td>
<td>9.178</td>
<td>90° 00' 03&quot;</td>
</tr>
<tr>
<td>3t</td>
<td>4b</td>
<td>30° 29' 11&quot;</td>
<td>06&quot;</td>
<td>210° 29' 08&quot;</td>
<td>9.197</td>
<td>90° 00' 03&quot;</td>
</tr>
<tr>
<td>4b</td>
<td>4t</td>
<td>58° 32' 02&quot;</td>
<td>55&quot;</td>
<td>236° 31' 57&quot;</td>
<td>5.709</td>
<td>90° 00' 03&quot;</td>
</tr>
<tr>
<td>4t</td>
<td>1b</td>
<td>58° 25' 19&quot;</td>
<td>12&quot;</td>
<td>236° 25' 14&quot;</td>
<td>5.703</td>
<td>90° 00' 03&quot;</td>
</tr>
<tr>
<td>1b</td>
<td>1t</td>
<td>72° 49' 23&quot;</td>
<td>20&quot;</td>
<td>252° 49' 22&quot;</td>
<td>10.857</td>
<td>90° 00' 03&quot;</td>
</tr>
<tr>
<td>1t</td>
<td></td>
<td>72° 51' 09&quot;</td>
<td>08&quot;</td>
<td>252° 51' 10&quot;</td>
<td>10.860</td>
<td>90° 00' 03&quot;</td>
</tr>
</tbody>
</table>

**SURVEY TIMES:** 11:15 - 12:45

**TOTAL FIELD SURVEY TIME:** 2 hrs 40 min.
Appendix E

Part A – Point Coordinate Plan from Scan Survey

Part B – Edge Dimension Plan from Scan Survey
Appendix E

Part A - Point Coordinate Plan from Scan Survey
Appendix E

Part B – Edge Dimension Plan from Scan Survey
Appendix F

Part A – Point Coordinate Plan from Traditional Survey

Part B – Edge Dimension Plan from Traditional Survey
Appendix F

Part A – Point Coordinate Plan from Traditional Survey
Appendix F

Part B – Edge Dimension Plan from Traditional Survey
Appendix G

Comparison of Corner Point Coordinate Results
<table>
<thead>
<tr>
<th>Corner Point</th>
<th>Traditional Survey (m)</th>
<th>Scan Survey (m)</th>
<th>Differences in Easting (mm)</th>
<th>Differences in Northing (mm)</th>
<th>Differences in Reduced Level (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. Top Cnr.</td>
<td>E</td>
<td>10,009.638</td>
<td>10,009.518</td>
<td>-120</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,997.470</td>
<td>199,997.477</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>704.196</td>
<td>704.136</td>
<td>-60</td>
<td></td>
</tr>
<tr>
<td>N.W. Top Cnr.</td>
<td>E</td>
<td>10,004.014</td>
<td>10,004.034</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,997.421</td>
<td>199,997.390</td>
<td>-31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>704.202</td>
<td>704.084</td>
<td>-118</td>
<td></td>
</tr>
<tr>
<td>S.W. Top Cnr.</td>
<td>E</td>
<td>10,004.098</td>
<td>10,004.068</td>
<td>-30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,992.652</td>
<td>199,992.698</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>704.204</td>
<td>704.135</td>
<td>-69</td>
<td></td>
</tr>
<tr>
<td>S.E. Top Cnr.</td>
<td>E</td>
<td>10,009.724</td>
<td>10,009.628</td>
<td>-96</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,992.699</td>
<td>199,992.705</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>704.183</td>
<td>704.109</td>
<td>-74</td>
<td></td>
</tr>
<tr>
<td>N.E. Base Cnr</td>
<td>E</td>
<td>10,009.627</td>
<td>10,009.498</td>
<td>-129</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,997.476</td>
<td>199,997.452</td>
<td>-24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>698.517</td>
<td>698.514</td>
<td>-3</td>
<td></td>
</tr>
<tr>
<td>N.W. Base Cnr</td>
<td>E</td>
<td>10,004.017</td>
<td>10,004.024</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,997.419</td>
<td>199,997.385</td>
<td>-34</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>698.517</td>
<td>698.477</td>
<td>-40</td>
<td></td>
</tr>
<tr>
<td>S.W. Base Cnr</td>
<td>E</td>
<td>10,004.092</td>
<td>10,004.071</td>
<td>-21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,992.653</td>
<td>199,992.760</td>
<td>107</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>698.546</td>
<td>698.506</td>
<td>-40</td>
<td></td>
</tr>
<tr>
<td>S.E. Base Cnr</td>
<td>E</td>
<td>10,009.722</td>
<td>10,009.633</td>
<td>-89</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>199,992.722</td>
<td>199,992.773</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>698.537</td>
<td>698.557</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Range from -129 to 20

Variance = -57.3

Std. Dev. = ±7.6

±4.0

±6.9
Appendix H

Edge Method Comparison
## Appendix H

<table>
<thead>
<tr>
<th>Edge Description</th>
<th>Traditional Survey (m)</th>
<th>Scan Survey (from selected cnr. pts) (m)</th>
<th>Traditional - Scans (mm)</th>
<th>Scan Survey (software determined edge lengths) (m)</th>
<th>Traditional - Scans (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N.E. vertical edge</td>
<td>5.679</td>
<td>5.623</td>
<td>-56</td>
<td>5.652</td>
<td>-27</td>
</tr>
<tr>
<td>N.W. vertical edge</td>
<td>5.681</td>
<td>5.607</td>
<td>-74</td>
<td>5.704</td>
<td>23</td>
</tr>
<tr>
<td>S.W. vertical edge</td>
<td>5.658</td>
<td>5.630</td>
<td>-28</td>
<td>5.629</td>
<td>-29</td>
</tr>
<tr>
<td>S.E. vertical edge</td>
<td>5.646</td>
<td>5.556</td>
<td>-90</td>
<td>5.635</td>
<td>-11</td>
</tr>
<tr>
<td>North top edge</td>
<td>5.624</td>
<td>5.485</td>
<td>-139</td>
<td>5.586</td>
<td>-38</td>
</tr>
<tr>
<td>West top edge</td>
<td>4.769</td>
<td>4.693</td>
<td>-76</td>
<td>4.787</td>
<td>18</td>
</tr>
<tr>
<td>South top edge</td>
<td>5.626</td>
<td>5.560</td>
<td>-66</td>
<td>5.560</td>
<td>-66</td>
</tr>
<tr>
<td>East top edge</td>
<td>4.771</td>
<td>4.773</td>
<td>2</td>
<td>4.789</td>
<td>18</td>
</tr>
<tr>
<td>North base edge</td>
<td>5.610</td>
<td>5.475</td>
<td>-135</td>
<td>5.565</td>
<td>-45</td>
</tr>
<tr>
<td>West base edge</td>
<td>4.765</td>
<td>4.625</td>
<td>-140</td>
<td>4.662</td>
<td>-103</td>
</tr>
<tr>
<td>South base edge</td>
<td>5.630</td>
<td>5.563</td>
<td>-67</td>
<td>5.570</td>
<td>-60</td>
</tr>
<tr>
<td>East base edge</td>
<td>4.754</td>
<td>4.681</td>
<td>-73</td>
<td>4.787</td>
<td>33</td>
</tr>
</tbody>
</table>

| Range from             | 2                      | Range from                             | 33                       |
| to                     | -140                   | to                                     | -103                     |
| Variance =             | -79                    | Variance =                             | -24                      |
| Std. Dev. =            | ±8.9                   | Std. Dev. =                            | ±4.9                     |