University of Southern Queensland

Faculty of Health, Engineering and Sciences

A Qualitative Assessment of Close Range Photogrammetry for use in measuring Stratas/Stratums

A dissertation submitted by

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i. Abstract

This project was conducted for the purpose of assessing the use of Close Range Photogrammetry, using a portable high resolution camera to determine whether it will produce the same accuracy as traditional survey methods in measuring Strata/Stratums. The test was based on completing a stratum survey of a commercial building basement using a DSLR camera and an electronic tape for control data. An analysis of accuracies and precision for both types of equipment would be determined to assess the practicality and reliability of the camera in completing traditional strata and stratum surveys.

This project was undertaken to increase the speed of measuring both strata and stratum plans to compensate for the increasing amount of high density residential and commercial building being constructed within Sydney. With a high consumer demand to live closer to Sydney's CBD, land has been reclassified and rezoned to allow for multi-storey developments, which in turn requires the need for stratum plans to be produced at a subsequent rate. Similarly, this project was conducted to reduce the cost of each survey, finding an affordable alternative to equipment including 3D scanners. Reducing the time on site will also minimise the wages required for each surveyor, overall reducing the expenses to complete the job.

The close range photogrammetry method within the project was completed using a Canon EOS 600D accompanied with a Canon Tripod and swivel bracket. The control data for the stratum was completed using a Leica Disto D510, marked according to a Draft Strata Plan. The project used AutoCAD and Civilcad for the processing software for the electronic tape measurements and Photomodeler for photogrammetry extraction later to be reduced through both AutoCAD and Civilcad.

The project was completed within a section of a commercial building carpark, a common site to be used with strata/stratums. The area has approximately 12 car spots with columns between each spot. There are 3 walls that are concrete block and one that is opened with meshing. The use of electronic measurements for control data was to provide the accuracies accepted by current methods and generate a coordinate system to be used in comparison to the close range photogrammetric method.

The coordinates and areas between the different methods were compared both analytically and statistically, determining whether the accuracies are suitable for practical application. When compared to the electronically computed coordinates, the photogrammetric coordinates had minimal differences and were within the acceptable limits of the 95% confidence interval. Also when comparing the areas between the various models, the differences were acceptable to the standards set by current Strata legislation.

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ii. Limitations of Use

iii. 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.

Martin Wahbe

Student Number: [redacted]

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vii. Glossary of Terms and Abbreviations

CP - Control Points (Used for reflectorless stickers placed to compare results between data sets)

AHD - Australian Height Datum

CRP – Close Range Photogrammetry

DSM – Dense Surface Mesh

MPV – Most Probable Value

ID – Identification (usually a point number or identifying the side shot)

HA – Horizontal Angle

VA – Vertical Angle

SD – Slope Distance

HT – Height of target

HI – Height of Instrument

CO - Code

EDM – Electronic distance meter

STD DEV – Standard Deviation

E – Easting (Coordinate system)

N – Northing (Coordinate system)

H – Height (Coordinate system)

PT – Point

STN – Station

INST – Instrument

TAR – Target

DLSR – Digital Single Lens Reflex (Camera)

1. INTRODUCTION

1.1 Introduction

The following study provides research conducted on a Qualitative Assessment of Close Range Photogrammetry for the use in measuring Stratas and/or Stratums. It analyses the relevant issues to the topic and completes a field assessment using researched methods to provide accurate data for examination.

Due to the continual advancement of technology, the methods used in surveying are developing on the application of photogrammetric procedures to generate a high quality three dimensional model. For example; Unmanned Aerial Vehicles have been utilised to collect data in areas inaccessible to surveyors, allowing high precision models to be produced. This technology can therefore be applied to produce high quality models using without the need for an aerial drone. DLSR cameras are readily available and preferred for when a higher pixel count is required, an effective feature that can be applied in close range photogrammetry.

This project is based on a qualitative assessment of photogrammetry for the use in measuring stratas and stratums. Strata and Stratum surveys are used to allocate titled lots to units, commercially owned and privately owned areas limited in height and depth within a building.

The current method of completion is by using an electronic tape to measure between solid structures, primarily walls and columns. A mark-up is produced to detail what was located during the data collection and is processed through both Civilcad and AutoCAD. If a Stratum is completed, measurements are taken to from the ceiling to roof at various zones within the area and a model is generated into AutoCAD.

Photogrammetry is the process of extracting data from digital photographs to enable the reconstruction of the shape, size and position of objects to generate a 3D model. It uses both natural and artificial control points to determine the orientation and position of the consecutive photos which are tied together within processing technology and exported as a three dimensional CAD space object. Close Range photogrammetry is the process which allows a model to be generated from photos taken from the ground position rather than aerially.

This study will test the accuracy and application Close Range Photogrammetric methods have when compared to traditional survey methods which will overall simplify surveying methods without compromising accuracy.

1.2 Statement of the Problem

Due to the continuous population growth within Australia, the need to meet residential supply and demand is growing exponentially. Despite this high demand of work, there is a slowly increasing shortage in the amount of surveying professionals within Australia. This shortage is placing greater pressure on the Surveyors trying to keep up with the demand, risking the ability to work efficiently and effectively while still completing a job within a suitable timeframe.

The amount of time it takes to measure stratas and stratums can be extensive, which if rushed can produce errors in the plan. Stratas and Stratum measurements in basements, require the location of columns, walls, any public access areas and personal storage areas if provided. These measurements must be taken individually and noted for future processing, extending the time taken for the completion of the task, which can also lead to writing and transcription errors.

Providing the methods are accurate, Close range photogrammetry can be used as an alternative, minimising the time taken for the completion of the job which will in turn reduce the expenses the company will incur.

1.3 Significance of the Study

With the development of close range photogrammetry (CRP) and other technological advancements in the surveying field, applications can be made to reduce the time spent completing a job without forgoing accuracy. This dissertation will assess the application of close range photogrammetric methods for the implementation in strata stratum surveys with the intention to replace the traditional method.

This testing of this project is vital since stratums and stratas are becoming more common within today's building industry, with unit construction booming in urban city centres due to the high demand of living within Sydney. This overpopulation combined with a desire to live closer to developed Central Business Districts have resulted in the rezoning of land to be used for multi-unit development which consequently results in large amount of strata/ stratums plans being created. These plans are becoming more complex with the need to show in some cases three dimensional location plans. These plans can be very confusing to users who are not accustomed to these plans sometimes causing problems when creating additional lots or building within these stratums/stratas.

The surveying industry in Australia is exponentially declining, placing additional pressure to complete a high demand of jobs for the current surveying professionals. The application of close range photogrammetry will allow for a more effective and efficient method to complete an otherwise time consuming task. The current advancement and availability of portable devices including smartphones and tablets can also be utilised, allowing digital copies of the plans and possibly interactive models of the area to be accessed without the need to carry hardcopies.

1.4 Aim and Objectives

Photogrammetric technology has progressed significantly over the past decade, producing an overall dependency for certain methods that are continually used in surveying. Due to the constant increase of demand for surveys, the development of faster production methods of the surveys is subsequently growing. Most commonly, aerial photogrammetry is used to save time on a project, especially if accessibility is an issue. This approach will be carried through within this project, using close range photogrammetry, with the aim to improve the efficiency of a surveyor's work within a compromising accuracy.

The aim of this project is to provide an alternate method for measuring stratas and stratum with the same or greater accuracy as traditional methods. Currently, the method for completing a strata or stratum is measured using an electronic tape and later reduced in a CAD system. 3D scanners have also been developed to aid with this aim; however it is generally an expensive process which will place stress on the financial operation within a company. The application of close range photogrammetry using an affordable, portable and high resolution camera will save surveyors the costs of purchasing equipment including 3D scanners, while also minimising time on site when using an electronic tape.

Apart from the socio-economic objectives, there are technical objectives that are to be met through this project. A technical objective of the project is to assess the practicality of the method to be used by surveyors in any required environment. Time efficiency is therefore a necessity to ensure the overall time, including the rendering process of the images is realistic and suited to a work environment.

The intention of the project is to analyse photogrammetric methods and programs to collate digital images in order to create a coordinated point cloud which is able to be post processed into an interactive, measurable 3D model. A Canon EOS 600D will be used for the image capture to later be exported and processed to generate a 3D model through Photomodeler. A Leica Disto D510 is to be used to manually measure the distance between structures to provide control data and coordinates for the 3D model which will be processed in Civilcad and later through AutoCAD. Both these methods will produce a coordinated system to allow for the comparison between models.

Throughout the testing of the project using the basement of a commercial building, images will be taken from a singular fixed position taking consecutive photographs over 360 degrees. It will then test the same method from 2 separate fixed positions. The timeframe to complete the task will be appropriate to reflect work conditions and will not be extended. The collection of data between methods will be completed in a minimum of a day and maximum of a week to ensure there are no differences in the area. Overall this project will benefit the surveying industry through:

Time

- The time to complete a stratum would be a fraction of the time as the need to measure between every structure is abolished.

Quality

- The quality of the strata or stratum survey should produce the same, if not greater accuracy when compared to traditional methods.
- The 3D model will display the true bearing and distance of each wall, structure and feature.

Equipment

- The cost of an electronic tape is valued between $230 and $1000 depending on the features desired. A DSLR camera can cost between $400 and $2000, however separate lenses can be purchased to enhance the quality of the photographs.
- Despite the possible higher initial expenses of the photogrammetry equipment, there is less need to employ 2 surveyors on site; therefore saving the employer financially.

Socially

- The surveyor will be able to work more effectively and efficiently, spending less time on site which will provide more time to complete the rest of the job given, therefore reducing overall stress.

1.5 Scope and Limitations of the Study

Due to time constraints and accessibility during the extent of the project, certain aspects of the project have been disregarded or adapted to allow for accurate testing and results to be achieved. The basement was chosen as a controlled environment to ensure the intended criteria was tested, however further research into the limitations may produce a different result than what is being assessed.

This research project will include:

- Quality of photogrammetry when applied to stratas and stratums
- Comparison of electronically measured data to photogrammetry data
- Errors and Accuracies for equipment used in both methods
- Quality of the images
- Locations of the photos taken and amount of photos needed
- Overlap of each consecutive photo and methods to achieve it
- 3D model of the basement manually produced using traditional measuring method
- 3D models of the basement, created using Photomodeler, using 2 different setups.

This research project will not include

- Effects of weather on the photographs
- Effects of lighting or shadows
- Different camera lens qualities
- Strata measurements in residential units

To ensure the intended criteria is being met while limitations are being controlled, a detailed analogy of specific methods and the selection of certain equipment will be discussed within the Literature Review.

1.6 The Organisation of the Dissertation

This project has been formulated to introduce the research idea, explaining the need of the study and the intended outcomes. After the concept of the research project is comprehended, the literature review is detailed to provide collective information and previously completed research as confirmation for the selected methods to follow. The research methods are then explained, detailing the methods to be used to complete the research project, using the research within the literature review as precedence. Following the methodology is the results gained from the field work of the project, detailing processed and unprocessed information from both methods to be used for comparison. Once the data is presented it will then be discussed, analysing usefulness of key findings and possible errors in the methodology. Following this, a conclusion will be written to summarise the appropriateness of the research project with reference to its application in the industry. Finally, recommendations will be given on the research gap within the research project, detailing any error encountered or suggesting more efficient methods of completing the project.

1.7 Summary

This chapter has provided an introduction into what this research project will be assessing, information on the significance of the study and expected outcomes from the project to assist the surveying industry. It details the application of close range photogrammetry and how it is to be used in surveying, with relevant limitations to the project.

2. LITERATURE REVIEW

2.1 Introduction

Close range photogrammetry is a method increasing in popularity with applications expanding within the surveying industry. The continual advancement in technology allows data to be captured and later processed to generate an accurately scaled 3D model.

These developments have been applied and are frequently used based on the:

- High accuracies for the data collected
- Ease of use for both the field and processing stages
- Portability and availability
- Non-contact and non-invasive

In order to validate the concept of the research project, the literature review is detailed to provide a technical understanding of the technology and methods from previously completed research which in turn will fulfil the needs of the aims and objectives for the project.

The Literature review provides a comprehensive report on the background research which has been completed that shapes the methods to be used to the project. The literature review ensures the methodology is supported by previously proven studies to validate the claims which undergo testing when to creating the 3D model using the detailed techniques, equipment and software.

This section will elaborate on the technical requirements needed when completing the photogrammetric model, including the most appropriate software, image files and calibration technique. It will also cover the specifications and resources required to justify the selection of the equipment used and the most appropriate procedures to ensure the most accurate results are achieved.

2.2 Data Required for Strata and Stratum Plans

Strata and stratum plans within NSW are under strict control with the requirements to be set by the Land and Property Information department (LPI). These plans have a set of legislation which must be followed for the strata/stratum plan to be accepted.

The legislation includes:

- Strata Schemes (Freehold Development) Act 1973 No. 68
- Strata Schemes (Leasehold Development) Act 1986 No. 219

- Strata Schemes (Freehold Development) Regulation 2012
- Strata Schemes (Leasehold Development) Regulation 2012
- Strata Schemes Management Act 1996
- Strata Schemes Management Regulation 2010

The registrar general checklist can also be used to help complete the final plan to a standard suitable for registration. A strata plan fast facts document has also been provided to help complete a final strata plan; this document is what will be assessed for what data is required as it has all the main sections that are required.

As this project is mainly concentrating in basements, the facts produced will be mainly related to defining basements when creating a strata/ stratum plan.

To define car spaces within a basement the need for the following is required which has been provided from the Strata plan fast facts (LPI, 2015)

1. All corners of each lot must be defined by reference to structural features or right-angled offsets from them.
2. All line boundaries are to be dimensioned by distance.
    a. One allowance is line between two structural features see front boundary of lot 1. A dimension is not required but may be shown at the surveyor's discretion.
    b. See front boundaries of lots 2 and 3; you must show length of both. You can not only show one and leave the other to be the residue of the total length of line between the two columns.
3. Identify lines as line of face of column or centreline of column.
4. If the boundary is not from centre of column show connections along column.
5. Connection from corner of wall to car space boundary.
6. There is no need to define the stratum of internal car spaces.

The following is not allowed to be used to define car spaces in a strata plan which has also been provided by the Strata plan fast facts (2015):

- At right angles to a curved structure such as a round column.
- Prolongation of the centre line of a single circular column.
- Use of intersecting method, where two boundaries of fixed lengths are each fixed at one end and the other end is fixed by their intersection. Although this is mathematically possible it is not acceptable for a strata plan.
- Prolongations of structures which are not visible (e.g. the prolongation of an internal wall to define an external boundary).

The following image relates to the documentation above:

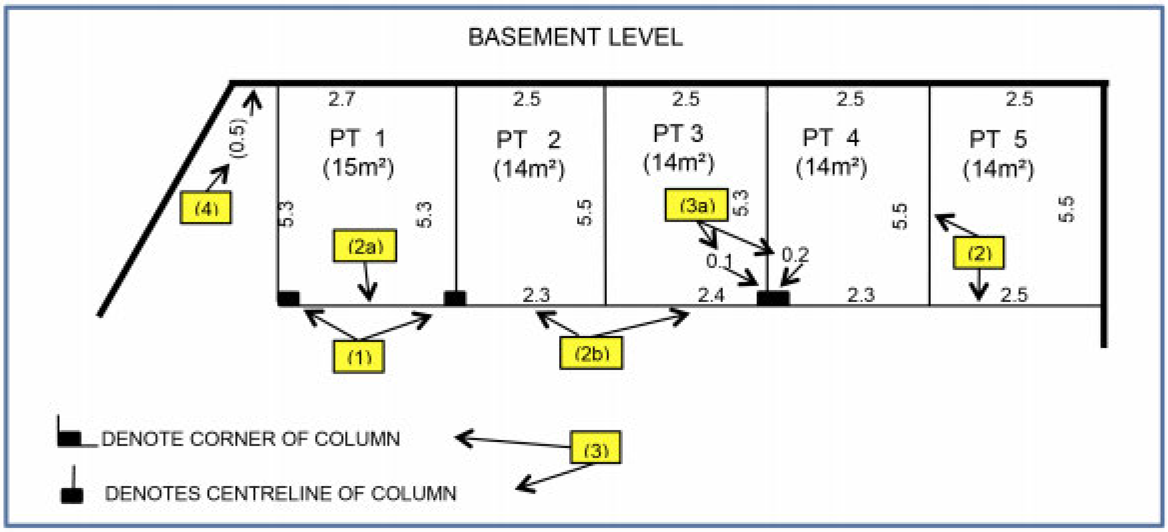

Figure 2.1.1 - Strata Plan Fast Facts.
(NSW LPI 2015) Example 9, page 13.

With this data we can create a strata plan that will be successfully accepted by the LPI.

2.3 Site Selection

(Luhmann 2011)
Luhmann, T. & ebrary, I. 2011, Close range photogrammetry: principles, techniques and applications, Whittles Publishing, Dunbeath, Scotland.
The site selection is critical for the dissertation to be assessed as the need for a controlled environment will allow for accurate and precise results. To ensure the site environment is suitable for the close-range photogrammetry, limiting these factors for the site will be needed:

- Lighting/Shadow
  - Previous projects have shown that shadowing from poor camera quality can cause shadows to cover the targets from being seen in the images. Lee F. DeChant (2011) details the need to control the lighting and shadow for a project in order to generate the most accurate 3D model. This is justified within Luhmann (2011), explaining that by using a better quality camera with a higher pixel resolution, a higher quality model is generated in the post processing photogrammetry software.

- Sun Reflection/Glare and weather attributes
  - Timothy. M (2016) has shown images that couldn't be used within the project due

to the glare in the images. This also affected how the final 3D model was produced causing many problem when assessing the final coordinates. Luhmann (2011) continues to explain the necessity image quality has when trying to locate accurate control points for photogrammetry. This factor will be completely removed as the site selection is going to be within an enclosed area removing any glare or natural sunlight whatsoever.

- Accessibility
    - The need to access the entire site to capture images correctly without any interruptions is critical. To ensure the site is free of obstructions the site chosen is a basement. Lee F. DeChant (2011) has shown the effectiveness when creating a 3D model using CRP techniques when the environment is controlled. This will allow an accurate image to be taken, removing blur from moving images. The basement has many key attributes that allow for a better overall 3D model to be created, which include many common features that will help when determining the 3D model.

    - Other key attributes of the basement is movement within the images which may cause issues when creating the 3D models. As stated throughout Luhmann (2011), obstructions should be minimised wherever possible to ensure the camera is focused on the intended object and a larger point cloud can be generated. Timothy M. (2016) had many problems with car movement between photos; to limit this factor in the basement the project will be conducted in a controlled section during times that the basement is free of vehicle use.

- Target Placement
    - Target placement is very important when trying to produce a 3D model using CRP. The extensive research within Luhmann (2011) emphasises the need to have a minimum of 3 common control points between a pair of consecutive photos. Timothy M. (2016) had many issues when trying to place targets on the site that was selected due to traffic obstructions and inaccessibility. The basement selected for this project will allow placement for targets within a 4 quadrant area which will increase final accuracies.

Overall the site selection should reduce the issues that had been found within both projects completed by Lee F. DeChant (2011) and Timothy M.(2016) accompanied by the research within Luhmann (2011) and the NSW LPI, helping to improve the methods used for CRP and overall producing a more accurate model for final analysis.

2.4 Electronic Measurement Assessment

2.4.1 Methods

In order to provide control data for the dissertation, electronic distance measurements will be taken. In accordance with the requirements of a strata and stratum, the distances between structures determine the allocations for lot area. Electronic Tapes are renowned for their accuracies, giving a deviation of 1mm when measuring up to 10m and increasing to 1.5mm over 30m (Refer to ***Appendix E*** for specifications sheet). This accuracy is deemed reliable for its use in stratas and stratums, eliminating errors in sag and incorrect positioning.

Surendra Pal Singh (2013) analysed the use of close range photogrammetry for the application of virtual 3d modelling of the exterior of a university campus. A tape was used for control data to compare the accuracies between models. The accuracy of the model was within the acceptable limit for the project since it wasn't used for lot defining areas. Based on this conclusion, the same method will be used however the electronic tape will be used for its higher accuracy.

This is confirmed within Lee F. DeChant (2011), researching the uses of close range photogrammetry in crime scene investigation and 3d model development. Initially, the site (chosen as a house) was measured using a Leica Disto and annotated on as a field sketch. The information was processed into Civilcad to provide a controlled, coordinated system for the model which was later compared to a model generated using photogrammetric methods with a DSLR camera.

2.4.2 Errors

Despite the constant development of technology, there are still several errors that could be encountered during the use of Electronic Measurement devices. There are two main types of errors that could occur during the use of a Leica Disto; Systematic errors and human errors. A list of errors that could potentially occur is detailed within Section 3 of the Report.

Refractive errors and atmospheric errors can be an issue when taking measurements using an electronic measuring tape. This occurs mainly from sun refraction or excess dust in an area. Since the environment for the project is controlled, there shouldn't be any refractive errors from the sun or atmospheric errors present; however multiple measurements should still be taken to confirm the data collected.

There are two key human errors that can occur when manually measuring distances using an electronic tape. Errors in distance can occur if the device is not held perpendicular with the structure when measuring to another structure. Since the bearing is not produced, the user must ensure the device is perpendicular to eliminate any errors horizontally and vertically. The most common error with using an electronic measuring tape to complete a stratum is the transcription errors when recording distances. The mark up of the plan must be completed neatly and accurately to ensure the spaces between the structures are accurately noted so lot areas can be allocated.

2.5 Photogrammetry Assessment

2.5.1 Methods

The overall methods for photogrammetry are simplistic; collating photographs to locate common points, tying them together to set the orientation of the eventual 3D model. Reflective targets will be placed to be used for 3D coordinated points with known distances between them for accuracy checks.

A key factor in photogrammetry that needs to be considered in order to achieve the highest accuracy of 3D model is the positioning of the camera stations. Multiple control points need to be located within each photograph to ensure there is sufficient overlap between control tie points for the overall model generation in Photomodeler. The more known common tie points that can be referenced within the image, the greater accuracies and precisions are achievable (Soni, Robson & Gleeson, 2014).

To effectively calculate the position and orientation of the 3D model, camera stations must be positioned to obtain a sufficient amount of coordinated points. The points are calculated through intersecting light rays reflecting a minimum of two camera stations. To ensure there is sufficient overlap between the photographs there should be a minimum intersection of 90 degrees).

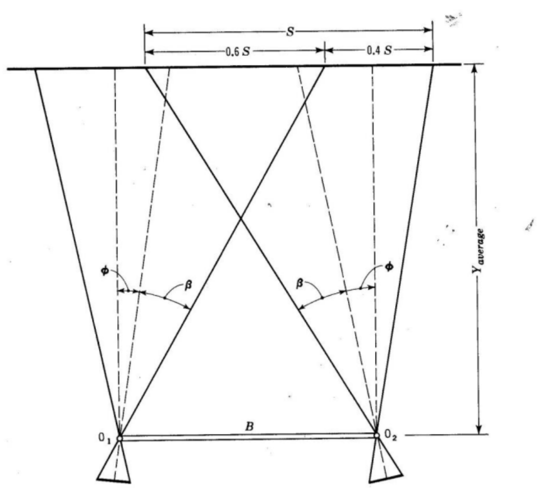

Figure 2.5.1 - Base distance between stations to determine overlap. (Luhmann 2011)

A commonly used method of terrestrial photogrammetry is the process known as Stereo convergence. The camera stations are setup to provide horizontal and vertical orientations to provide an overlap between 60% and 100%. Once the overlap is determined and the site is selected, the base distance can be calculated and targets placed in the area.

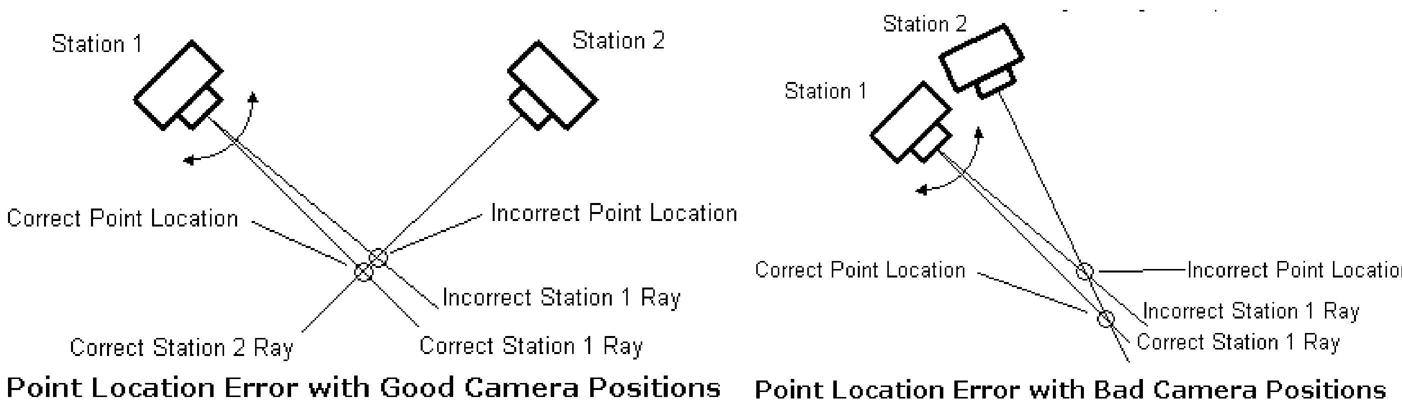

Figure 2.5.2 - Difference between accuracies for camera setup. (Luhmann 2011)

Overlap between photographs is necessary to increase the accuracy of the digitalised points, enhancing the correlation between photographs. Correctly placed camera positions are therefore needed to produce the best results.

2.5.2 Calibration

Camera calibration is an essential process to ensure the accuracy of the project is maintained. It is necessary to correct the internal parameters for the camera used in the process to resolve large errors during the post processing stages of photogrammetry

Photogrammetry Software such as Photomodeler supplies its own camera calibrator program designed for pre-planning processes to determine errors relating to the camera used (Hassan, Ma'Arof & Samad 2014).

As stated within the project studied by J. Valença, E.N.B.S. Júlio & H.J. Araújo (2011) “camera calibration consists, essentially, in correcting the lens distortion and in estimating the camera internal parameters”. This notion is also supported by Santiago et al. (2013) and T. Michael (2016).

The internal parameters that are in need of calibration include the focal length, format size, principal point, and lens distortion. These specifications for the camera are generally provided, however they must be measured to improve the pixel resolution to achieve the highest accuracy

This is the process that will be used for the project to eliminate any internal errors in the camera during the photogrammetry process. This process is further explained within Section 3 of the report.

2.6 Photomodeler

Photomodeler is a crucial program to be used in this project, providing the software needed to complete the production and rendering of photos to produce a final 3D model. Developed by EOS Systems Inc. Photomodeler is renowned for being a low cost photogrammetry software program which offers highly accurate results for a range of applications.

Photomodeler uses a series of photographs of an object or structure to produce a 3D model by connecting relative points, edges and defining corners. The program uses “lines, surfaces and edges to be used to specify Cartesian coordinated XYZ points on the image” as stated by PennWell Publishing Corp (2001). The data is combined from each photograph where common points are located and adjusted if needed. The marked features are coordinated and the result is a 3D model that can be exported to any digital rendering or CAD software.

In order to achieve an accurate 3D model with errors kept minimal, EOS systems Inc. 2015 states that several significant factors are required to be included within the photogrammetric process:

- The camera must be calibrated to ensure the processing of the camera’s focal length, format size, principal point, and lens distortion is adjusted for the Photomodeler.
- The camera quality and photo resolution should be as high as possible to ensure the results are of higher accuracy.
- There should be multiple photos taken of the structure from different angles to ensure there is sufficient overlap.
- There should be at least one known physical measurement between points that appear on a photo. This is to test the accuracy of the scale calculations.
- There should be a network of referenced, coordinated control points to ensure the accuracy of the process remains high.

Below is a table formulated from Heidi Jane Belbin (2015), a project analysing the use of low cost close range photogrammetry techniques. Within the study the accuracy obtained by other previously researched papers provides an overview of the range of accuracies that have been achieved using Photomodeler.

Author of Paper	PM Product	Application	Accuracy
(Al-Baghdadi et al. 2012)	PM Scanner	3D modelling of a human foot	0.250mm – model surface 0.015mm between targets
(Galantucci et al. 2014)	PM Scanner 6.0	Mannequin faces	0.126mm
(Green, Matthews & Turanli 2002)	PM Pro	Underwater site mapping	2.3mm – 2.9mm
(Hernán-Pérez et al. 2013)	PM	Sculpture	10mm
(Oniga & Chirilă 2013)	PM Scanner	Sphere	0.007mm – 0.38mm
(Percoco, Galantucci & Lavecchia 2011)	PM	Mannequin torso	1.5mm – 4.5mm
(Rahman & Alam 2013)	PM Pro 4.0	Human faces	1mm
(Randles et al. 2010)	PM	Damaged cars (accidents)	2mm ±1.4%
(Lynnerup, Andersen & Lauritsen 2003)	PM	Mannequin	<10mm

Table 2.6.1 - Table of previous Photomodeler projects

There are other photogrammetry software packages that can be used to achieve similar results to Photomodeler such as I-Witness and Dimension, however based on how commonly used it is and the accessibility it presents to the thesis, it will be the software used to complete the project.

2.7 Image File Formats

The viability of the project is based on the quality of images produced from the DSLR Camera. The images will need to be of the highest quality and best resolution possible with no compression to ensure a sufficient number of pixels are included and an accurate model is produced.

The file formats that are able to be exported and used within the photogrammetry section of the report include:

- Joint Picture Expert Group (JPEG), and
- Tag Image File Format (TIFF)

The most common format for storage of images from digital cameras is exported using the JPEG format, where the compression ratio consists of finding similar pixels with respect to their colour and determining that each is identical to the other. TIFF images are based on standard bitmap images and use larger compression ratios to reduce file sizes and provide a more accessible image at a reduced quality.

As suggested within the previous study submitted by Bryde (2006), which drew comparison to both DeChant and Gwartney (1999) and Pappa (2002), the use of JPEG files when analysing photographs for photogrammetric modelling is recommended, providing the highest quality in pixel count.

Therefore JPEG will be the image format that will be used throughout the project, as it is the most common format for digital cameras and provides the highest quality of image without distorting the pixels or compression ratio to a stage where it is unusable.

2.8 Summary

This section has provided a summary on all the required information from previous research that was needed to ensure the processes within the methodology are effectively going to achieve the aims and objectives of this project. It provides information regarding the requirements needed to produce both strata and stratum plans and the justifications for the selections of site. It examined the methods and techniques used when completing surveys using electronic measurement equipment and also analysed the methods and errors involved with using Photogrammetry. Finally it assessed Photomodeler and the image file formats the software will process based on prior research.

3. RESEARCH METHODS

3.1 Introduction

This section of the report will cover the methods used to complete the project based on the research within the Literature review. It will analyse the site selected for the project and detail the equipment to be used and resources required to complete the collection, processing and rendering of data.

The analysis of a project's methodology is critical in determining the specific criteria needed to address the aims and objectives for the project. It allows a detailed analogy to be made between the project aim and the literature review to ensure the methods adopted are not arbitrary but instead supported by previous studies.

The site selection and description will be analysed to assess the reasons for choice as mentioned within the literature review. It will detail the requirements needed from the site prior to any field work completed, explaining the significance of size, orientation and any obstructions.

The equipment and resources required are determined based on the project aims but are supported within the literature review. This section will detail the necessary steps needed to calibrate and configure the essential equipment prior to the commencement of the field work.

Overall, this chapter will elaborate on the selections that have been made to complete the research project, allowing the necessary steps to be taken to ensure the correct equipment, site and methodology is comprehensive and followed to substantiate the viability of the assessment. This will provide an accurate approach on how the required data is to be gathered and how results are assessed for comparison.

3.2 Site selection

The selection of the commercial building basement level carpark was considered for accessibility and practicality when assessing strata and stratum surveys. The initial site was selected using the project aims and objectives as a basis and later supporting the selection with supporting evidence within the literature review. The selection criterion for the basement is detailed below:

Ability to control the environment

- There are no shadows drawn from sunlight which can affect the quality of the image
- There is also no glare from the sun, a common problem associated with cameras in close range photogrammetry.
- There will be no movement from cars which can affect the quality of the images taken.
- The lights are able to be controlled to ensure there is sufficient lighting.

Accessibility

- The ability to access the area whenever desired relieved pressure and ensured the fieldwork could be done as efficiently as possible.
- Also allowed for the control of the environmental and physical features, using the area when there are no obstructions other than the structural features themselves.

Realistic

- The site selection of a basement carpark is commonly found within strata and stratum plans
- Due to the size, orientation and access to the site, the field work can be completed with the same characteristics as a normal site visit, allowing a realistic timeframe to be assessed.

Site properties

- The ability to place Control points on the structures of the basement was granted which will ensure the project is being completed using the most efficient method and the errors within photogrammetry software are reduced.
- The control points are able to be located and measured using the Disto which will allow for a comparison between the models.
- There are also enough arbitrary points to be used once the consecutive photos have been collated and a 3d Model is generated. This will show the accuracies in areas that were inaccessible or not visible.

Minimal pedestrian traffic

- The area is able to be sectioned off to deter access by pedestrians. To minimise parking issues, the project will be completed during off peak times, generally during the weekends or outside of working hours.
- This will also allow for easier location of control points by reducing the risk of obstruction by non-strata relevant objects.

Figure 3.2.1 – North view of the Basement

Figure 3.2.2 – Northwest view of the Basement

Figure 3.2.3 – South East view of the Basement

Figure 3.2.4 – West view of the Basement

Considering limitations with time and without compromising the aims and objectives of the study, the area in focus will only be a section of the overall basement carpark. The site selected resembles an area that would frequently be measured within a Strata and Stratum plan. The area has 12 designated car spots with columns placed along the sides and face of the spots. The northern wall is concrete with a public access stairwell and doorway leading into another section of the basement. The Eastern wall is constructed using concrete block for its structural capabilities. The western wall is also constructed using concrete block; however the South West corner of the area wall is constructed using steel mesh. Since the site in focus is sectioned, there is no southern wall; however there are still columns that need to be accurately located to determine the correct allocations of area for each lot.

3.3 Resource Requirements

This section provides details on the equipment used for the entirety of the project and necessary resources to be used to complete the methodology for the report.

A large portion of the resources required has been supplied through employment with a surveying company, lending the components needed for the traditional electronic measurement requirements of the report. Already in possession of a rarely used DSLR camera, all that was required was the purchase of the tripod and swivel bracket to satisfy the photogrammetric methods of the report.

A list of the equipment used for the project includes:

1. Canon EOS 600D
2. Canon Tripod with swivel bracket
3. Camera Battery Charger
4. Memory Stick
5. Leica Disto D510
6. 5m Measuring Tape
7. Reflectorless Stickers (Targets)
8. Pen
9. Paper
10. AAA Batteries (For Disto)
11. Laptop
12. AutoCAD (Displaying of data and 3D model)
13. Civilcad (Processing of the measured strata plan)
14. Photomodeler (Photo data analysis)
15. Microsoft Office Excel
16. Draft Strata plan of Basement

All necessary equipment must be completely functional and serviced if needed. The camera should be calibrated to complete the photogrammetric methods, reducing errors in overlap and ensuring the essential information is collected and data stored. Where possible full versions of software are recommended to ensure the function of the processing of data is not limited.

The DSLR must be calibrated for the image files to be recognised and later processed within Photomodeler. Calibration sheets are provided through the Photomodeler software which must be completed prior to any field work being conducted.

Control points are to be positioned and measured to on site, allowing common coordinated points to be located in both the photogrammetry methods and the electronic tape measurements. These tie points will have both vertical and horizontal control which, when all models are generated, will allow for accuracies to be measured. Arbitrary points will also be used to determine the effectiveness of the alternative methods; however this will be determined during the processing stages.

The differing software used to complete the various methods within the project have been manipulated to process raw data in order to produce models that are under the same coordinate system for comparison.

Software Description:

Photomodeler

Photogrammetry software that collates consecutive photos locates common points and ties the images together to generate a 3D model.

Civilcad

Data extraction software, used to compute the measurements taken during the traditional electronic tape section of the report. Any errors in distance can be determined, bearing of structures or walls can be detailed. Has the ability to produce 3D models.

AutoCAD

Data display software, used in a more interactive system, allows the user to project 2D coordinated points into 3D. Used as a drafting tool from surveying data, compatible with Civilcad.

Microsoft Office Excel

Statistical analysis, computations of differences in XYZ coordinates from both models. Compatible with all software stated above.

3.3.1 Calibration

Calibration is necessary for each piece of equipment used to ensure it measures and records accurate and dependable data. Calibration and servicing the instruments and pieces of equipment will eliminate any inaccuracies and errors that may alter the manufacturer's determined errors. The instruments that are in focus for calibration is the Camera (Canon EOS 600D) and Disto (Leica D510) to guarantee the data recorded is accurate for the project.

The Disto will be sent to CR Kennedy (Manufacturer) prior to any measurements to eliminate any risk of errors. These errors can include: errors in receiver signals, calculation errors, tilt direction error and/or transverse tilt. The calibration is to be completed on a levelled surface to eliminate any tilt errors which will accurately measure the distances.

Calibration is important for achieving accurate results in Photomodeler, using calibration sheets to correct camera values including the focal length and lens distortion. Due to the large scale of the model area, a multi sheet calibration is used, supplied by Photomodeler. The functions of the camera that is used for the calibration must be kept consistent with no changes in zoom or focus. Errors in calibration will arise if any changes are made in either the camera or the positioning of the sheets. Photomodeler's camera calibration will overall ensure there is sufficient coverage between the photos in order to measure accurate results to generate a superior 3D model.

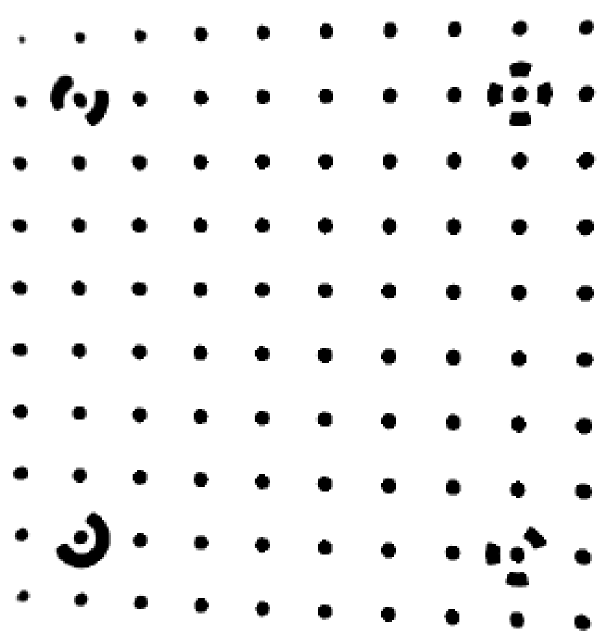

Figure 3.3.1 - Photomodeler's Multi sheet calibration (EOS Systems 2017)

3.4 Data Capture and Acquisition

This subsection provides details on the methodology that will be used for the capturing, editing and processing of the data. The section also elaborates on the features of the camera used in the photogrammetry data acquisition has and details on the electronic tape (Disto) that will be used for control data.

3.4.1 Data Capture Equipment

The electronic tape to be used for the project is a Leica Disto D510. Leica Geosystems have been developing revolutionary surveying technology for the past 200 years, engineering state of the art Swiss technology to produce precise and accurate instruments, advanced software, and trusted services.

The instrument will be used for the initial measurements of all the structural features within the site area, the location of control targets and the floor to ceiling and concrete beam heights. A model will be generated based on these measurements for which the coordinated data will be used in comparison with the data measured within the photogrammetric model.

As provided by Leica Geosystem, the features include:

- Accuracy: ± 1 mm
- Range: 0.05 – 200 m
- Measuring units: m, ft, in, yd.
- Tilt sensor: 360°
- Colour display with Pointfinder: 4x zoom
- Bluetooth
- Height tracking

Figure 3.4.1 - Disto D510 (Leica Geosystems 2017)

Figure 3.4.2 - Canon EOS 600D (Canon 2017)

The DSLR camera to be used is a Canon EOS 600D, equipped with an EF-S 18-55mm lens which allows for high quality images with minimal blur. Canon has been a leading innovator for high resolution camera products on a global scale. Originally developed in Japan, the company has successfully expanded throughout all regions of the world to provide a highly dependable product.

The instrument will be used for the photogrammetry process within the study, locating the position of structural features while also detecting control points to be tied within Photomodeler. This will be used to develop a 3D model for comparison to the traditionally created model using a Disto.

As provided by Canon Pty Ltd, the features of both the lens and camera include:

- Focal Length: 18-55mm
- Minimum Aperture: 22-38 (36)
- Maximum Aperture: f/3.5
- Minimum Focusing Distance (m): 0.25
- Image Sensor: CMOS sensor 22.3 x 14.9mm
- Digital, single lens reflex, AF/AE with built in flash
- Image type: JPEG, RAW
- Recorded pixels: Large (17.90 megapixels), Medium (8.00 megapixels), S1 (4.50 megapixels), S2 (2.50 megapixels), S3 (350,000 pixels), RAW (17.90 megapixels)
- Built in flash
- Auto-exposure lock
- Autofocus

3.4.2 Methodology for Collection of field data

This section explains the processes used to complete both the field work and reductions for the project, analysing the requirements for each method and any specifications used for each different process.

3.4.2.1 Placement of Control points

The Control Points (CPs) are fixed reflectorless stickers placed throughout the site on the faces of columns and walls. Marks including nails, door corners and other distinct features within the site will also be used as a precaution if there is a problem with the reflectorless targets. The control points will be accurately located with the electronic tape and recorded in relation to the walls and columns in the basement. These control points will also be used to tie consecutive photos when processing the images in Photomodeler for the photogrammetric methods.

Certain areas within the basement have less lighting, making it harder to detect the control points within the photograph. To ensure the centre point of the target is accurately located, black texta markings are drawn in as a cross, extending past the limits of the target onto the surface. This will guarantee the vertical and horizontal positioning for the control point can be located even if the centre of the target is difficult to see.

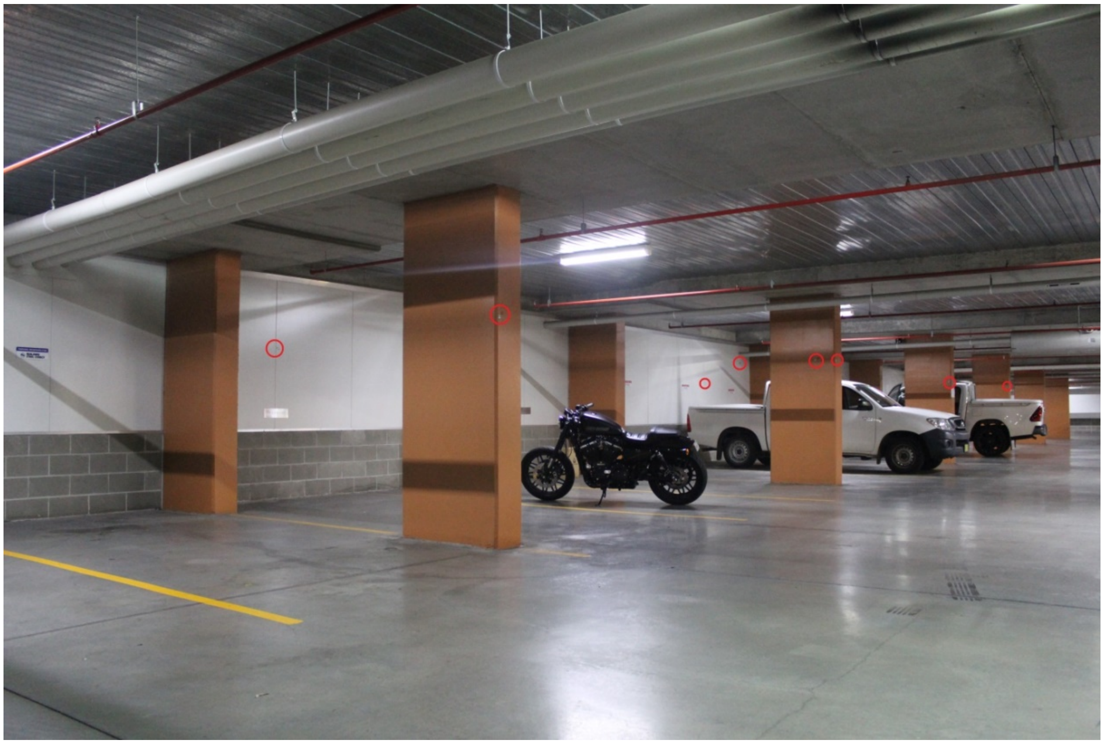

Figure 3.4.3 - Control Points on Eastern Side of basement

Figure 3.4.4 - Control Points and shadowing effect on Western Side of basement

Control points are to be placed on the faces of the walls and columns within all quadrants of the area in a manner that will allow common points to be located in overlapping photos to generate a dense point cloud. Although the area in focus is only one side of the basement (creating a three sided model) targets have been placed beyond the boundary of the model. This is to ensure there are a sufficient amount of marks in all photographs, allowing coordination in all sections.

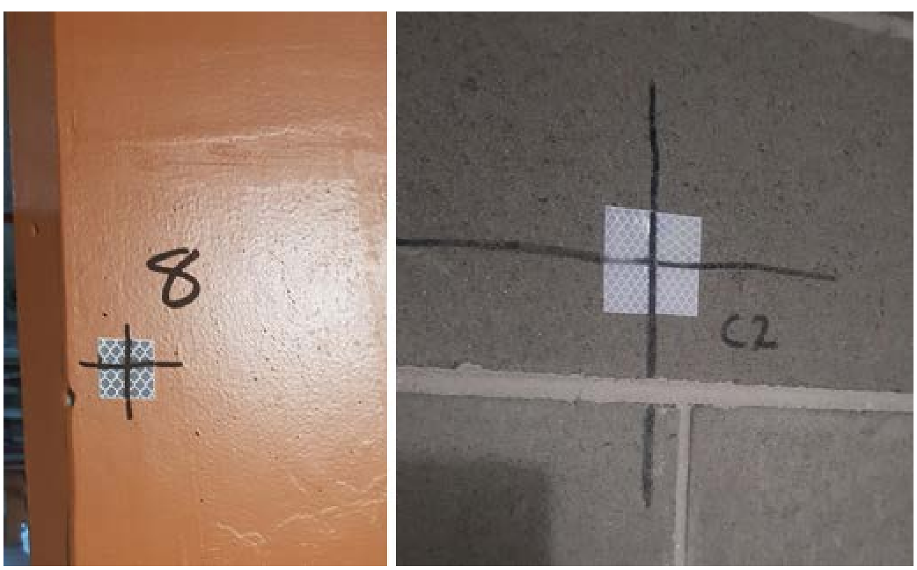

Figure 3.4.5 – Comparison of Normal sized and large control target

The targets are a reflective material that has been used as it contrasts well against the orange columns and dark grey bricks. This will make most control points easier to identify within a photograph to ensure the coordinate system is accurately generated. This can be seen within Figure 3.4.5 showing the base target to be four times larger than the other targets used.

3.4.2.2 Electronic Tape setup and Measurement

Initially, a control point will be placed by measuring the length of the northern wall to determine the centre, where a reflectorless sticker will be marked. This will become the north point for the photogrammetry stations to be facing. Targets will also be placed with approximately 5m distance between them to ensure there are a significant amount of control points when collating the images within Photomodeler. The base control point is shown as the larger target within Figure 3.4.6.

Figure 3.4.6 - Base control point in relation to other control points

Using the Disto, the draft strata plan and a pen, measurements will be taken of and between the structures and noted onto the plan. These measurements will eventually determine the allocated areas for private parking spaces in accordance with the LPI. Consistently check the measurements from the Disto by taking multiple shots along greater distances, verifying the equipment's accuracy. The measurements should also be clearly written on the draft strata plan with a red pen to avoid any transcription errors.

The dimensions of each column as well as its relative position to main walls and surrounding columns are to be measured and noted as well. In each corner take vertical measurements to determine the overall floor-ceiling height. Repeat this process with the 2 concrete beams that run

East-West along the ceiling, noting the width and height difference.

Once the measurements between structures for the site have been completed to the same standard as a strata plan, locate each control point using the Disto. From the centre of the target, take measurements to both the floor and either edge of column or wall. Ensure the device is held perpendicular to the ground for vertical measurements and with no horizontal tilt for horizontal measurements. The control points should be accurately located as they will be the basis for the comparison between control point coordinates for both the electronically measured data and photogrammetric data.

Manually input the distances of the area taken from the Disto into Civilcad to create a 2D wireframe of the area. Coordinate the base control point and adjust the other points to be relative in height based off the vertical measurements from the floor to ceiling and the horizontal and vertical position of the targets. Once the overall shape is generated with heights, export the data as a ‘Drawing Exchange Format’ (DXF), suitable for AutoCAD in order to generate 3D model. The coordinates of the control points are to be exported as an American Standard Code for Information (ASCII) format, providing the Easting, Northing and Elevation data of each point, suitable to be imported into excel to analyse the position of the control targets with the photogrammetric coordinates.

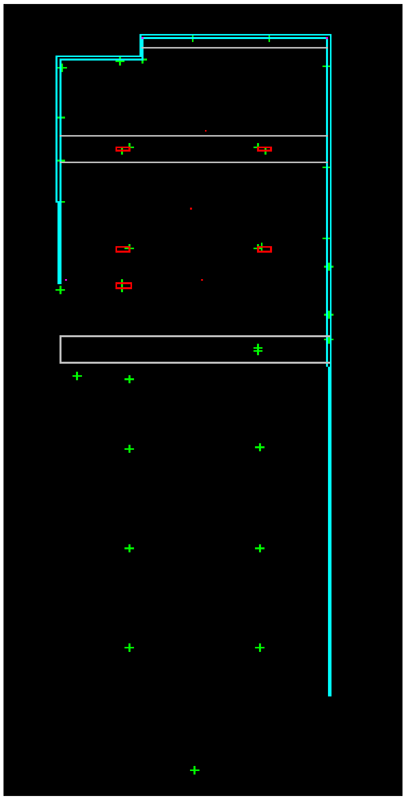

Figure 3.4.7 – Manually computed measurements of basement

Figure 3.4.7 is an aerial display of the measurements recorded with the Leica Disto. The raw data was manually calculated into Civilcad, where it was able to be manipulated and later coordinated. The blue line indicates the wall of the basement, showing differing thicknesses dependant on the material. Red indicates a column wall, running parallel and perpendicular with each other. The white line represents the concrete beams on the ceiling of the basement; it should be noted that only the beam towards the northern wall of the area is to be used in the model comparisons. Green marks indicate the position of the control points throughout the site. This figure is used as a representation to show the 2D positions of each feature.

Figure 3.4.8 is used for a visual representation of the control points that will be used for the comparison between data models. Shown on the Northern and Southern sides of the basement, control points C1 and C2 will be used as a basepoint for the coorindates. C2 has the coordinates 1000, 1000, 100 (XYZ cartesian coordinates) with the positioning and elevation of each target relative to the point. C1 was the furthest target from any setup station and will be a good measure of quality for the image within the photogrammetry methods.

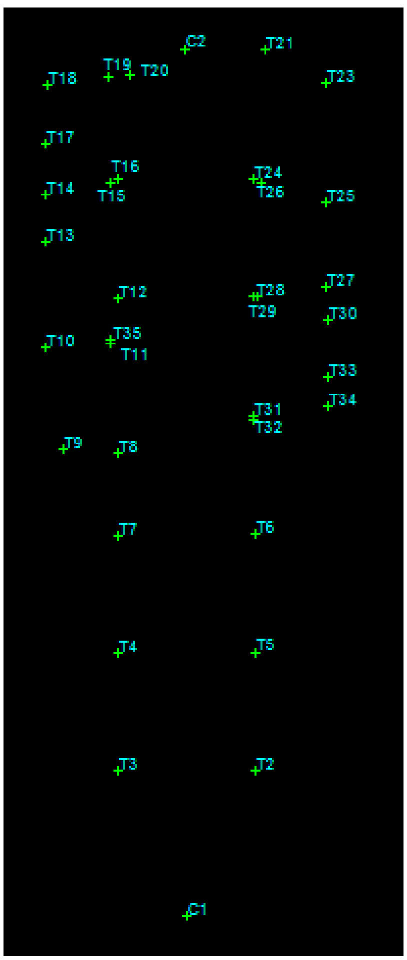

Figure 3.4.8 – Location of Control points

3.4.2.3 Photogrammetric Processes and Measurement

Control points will be placed throughout the site, placed on the faces of columns and walls, providing a coordinated link between both the photogrammetric and electronically computed models.

Primarily, the control point was placed by measuring the length of the northern wall to determine the centre, where the large reflectorless sticker was be marked. This base control point will become the initial point for the photogrammetry stations to begin taking each series of photos. Targets will also be placed with approximately 5m distance between them to ensure there are a significant amount of control points when collating the images within Photomodeler.

Using the Disto to accurately locate the centre line along the length and width of the selected area, differing intervals between 3m and 5m will be marked along the North-South intersection line for the setup of the camera stations. The differing intervals have been chosen to ensure there is sufficient overlap between each set of photos to locate all required features for the strata/stratum.

The camera will be set upon the 1.3m high tripod, at the centre of the first interval. Using the eyepiece viewfinder, the centre of the base control point at the Northern end of the basement will be focused to the middle of the camera. Without adjusting the focus lens or angle of the camera on the swivel bracket, a photo will be taken, in line with the control point. Using the angular compass on the bracket, the camera will turn 15 degrees to ensure there is 80% overlap between each photo.

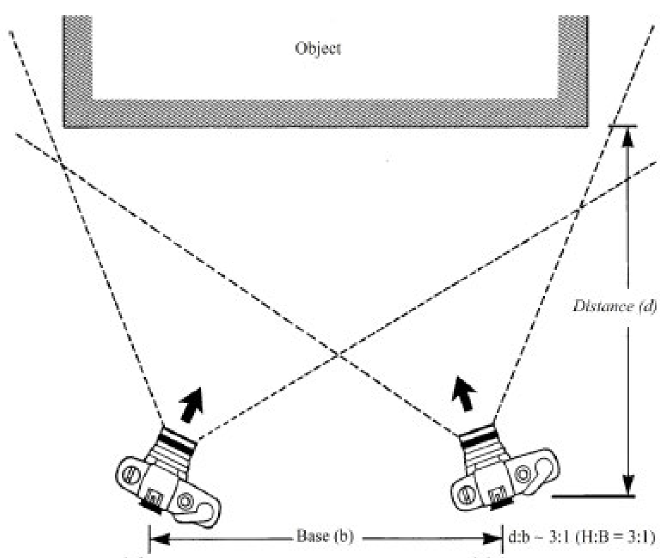

Figure 3.4.9 – Positioning of Camera stations to overlap images of same surface (Bryde 2006)

This process will be completed until a 360 revolution is completed such that the camera returns to the original position. Ensure no movement in the vertical angle for the camera so there is sufficient cover within each photograph.

Setting up the tripod onto the next interval station; complete the process above, using the same lens focus and consistent angle. The objects in focus should be measured from a minimum of 2 stations to achieve accurate results when tying points together in the processing stage. The greater the number of photogrammetric stations that measures to the same point, a higher degree of accuracy is achieved.

This process will be completed for the remaining stations to ensure multiple measurements are taken to the intended objects and control targets at different angles and distances to generate an accurate model. The setup of the camera stations can be seen within figure 3.4.10 once it had been orientated within Photomodeler.

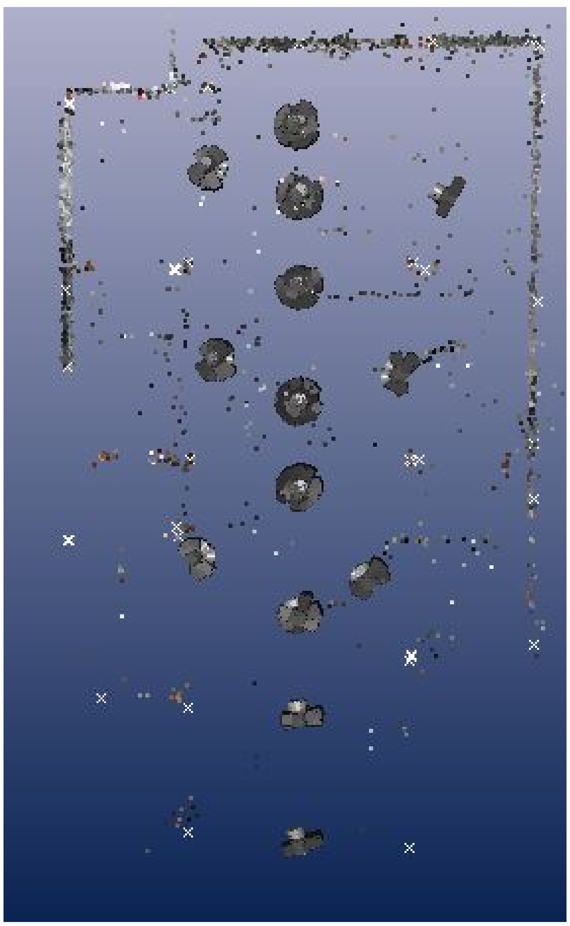

Figure 3.4.10 - Position of camera with smart match point cloud and target locations.

Export the data by copying the photos onto a computer (HP Pavilion was used with Windows 9). Keep a backup of the photos saved into a separate folder on the computer and also onto an external hard drive to avoid the risk of file corruption.

Ensuring the already calibrated camera is selected, begin processing the photogrammetric data, allowing Photomodeler to recognise common points and adjusting the accuracies when needed. The software should automatically join each set of photographs from each station together to provide an interactive, coordinated model. Once the model is generated and coordinated based on a control point, export the coordinated points into excel format. The Cartesian coordinates of the control targets will be analysed in excel, compared to the Cartesian coordinates of the electronically measured targets.

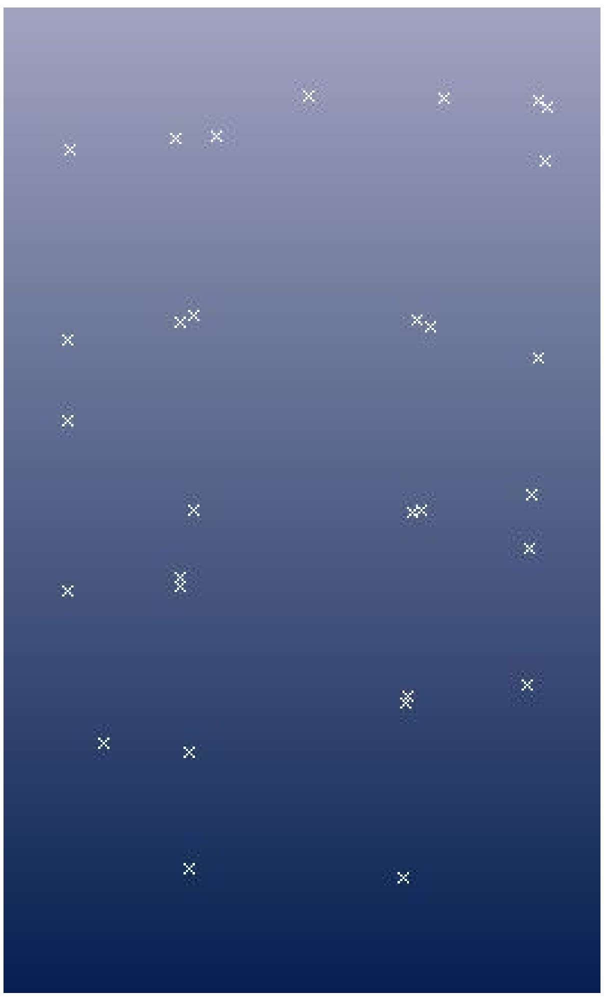

Figure 3.4.11 – Location of Control points

Analyse both sets of coordinates in excel, in order to compare the accuracies of both methods. Due to the currently used accuracy, use the electronic measurement model as a control file and compare how the coordinates of the photogrammetric model compare to these. This will provide the necessary statistics to determine the reliability on the project which will be computed using excel.

3.5 Data Pre-processing and Analysis

3.5.1 Electronic measurement data

The electronically measured data is transcribed onto a draft strata plan of the area which is later manually calculated into Civilcad. A specified control target is coordinated with arbitrary Cartesian coordinates 1000.00, 1000.00, 100.00 (XYZ) which has relative height and position to other objects and targets within the project. There are no internal checks to be completed to assess the reliability of the measured data, therefore multiple shots are needed in the field to avoid any measurement errors and clear and concise written notes are taken to avoid transcription error.

Once manipulated and edited in Civilcad, the data will be exported into an American Standard Code for Information Interchange (ASCII) format to display the coordinates for comparison. The ASCII data will display the Point Code, Easting, Northing and Height of each coordinated point to be imported into Excel for comparison.

The Civilcad data is the exported as a Drawing Interchange Format (DXF) file to be processed through AutoCAD. AutoCAD will be used to load the data and convert the 2D wireframe as a 3D rendered model for the visual display of the area for comparison. Both the area and volume of the model will be measured to be used in contrast with the 3D model from Photomodeler.

Figure 3.5.1 shows the 3D projection of the 2D wireframe of the measurements, using the vertical dimensions to determine the ceiling height and both the horizontal and vertical measurements of the control points in proximity to the nearest feature.

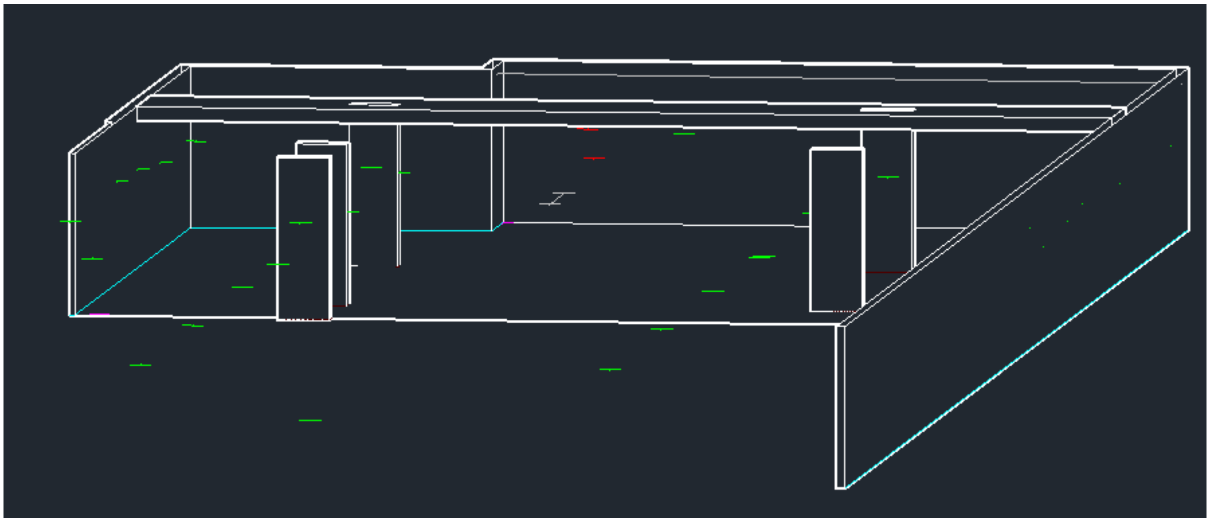

Figure 3.5.1 - 3D projection of Disto Measurements

3.5.2 Photogrammetry data

As stated within the Literature review, the photogrammetric data will be exported as a JPEG image format, providing the highest quality of image without distorting the pixels or compress the ratio to a value where it is unusable. The images are imported into Photomodeler where the orientation process is initiated. Features are recognised and distinctive points (control targets) are referenced between each photo. This process auto collates each tie point and generates a model based on the coordinated targets and 'Smart Points' (Common arbitrary marks produced within Photomodeler within multiple photos). Ensuring there is a maximum residual less than 5 pixels, the photos should be orientated, allowing a 3D model of low quality pixels to be produced. Processing the model through Photomodeler's Multi-view scanner system allows a higher quality surface model to be produced, as show within Figure 3.5.2.

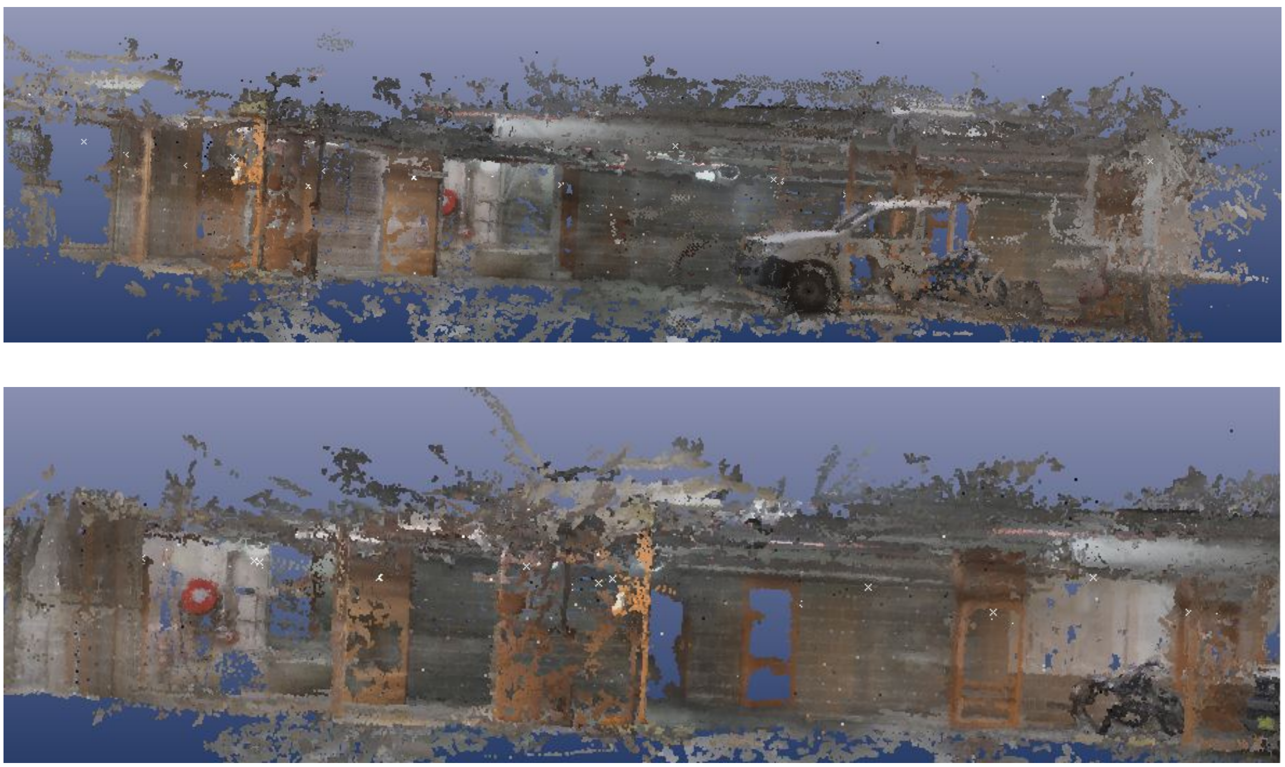

Figure 3.5.2 - 3D projections of Photogrammetric Measurements

Once completed the data will be coordinated based on the same control target in the Civilcad model and modified relative to the other points. The coordinate will adopt Cartesian coordinates 1000.00, 1000.00, 100.00 (XYZ) with the remaining points to be adjusted relatively. The point cloud can be edited and trimmed if systematic errors occur and points are in the incorrect positional. This can be amended by analysing the referencing between common points throughout multiple photos. Once all points have been edited, the target coordinated layer can be isolated and exported with the Easting, Northing, Elevations and Point name, which will be imported into Excel for comparison.

Surface lines can be drawn onto the photos which will then be referenced within the 3D model, showing a wireframe that can be isolated for comparison. Figure 3.5.3 and Figure 3.5.4 shows the marking of lines within the photos and an aerial view of the completed 3D wireframe of the area. The 3D wireframe can be measured to determine the area and volume of the basement, to be used for comparison with the AutoCAD model.

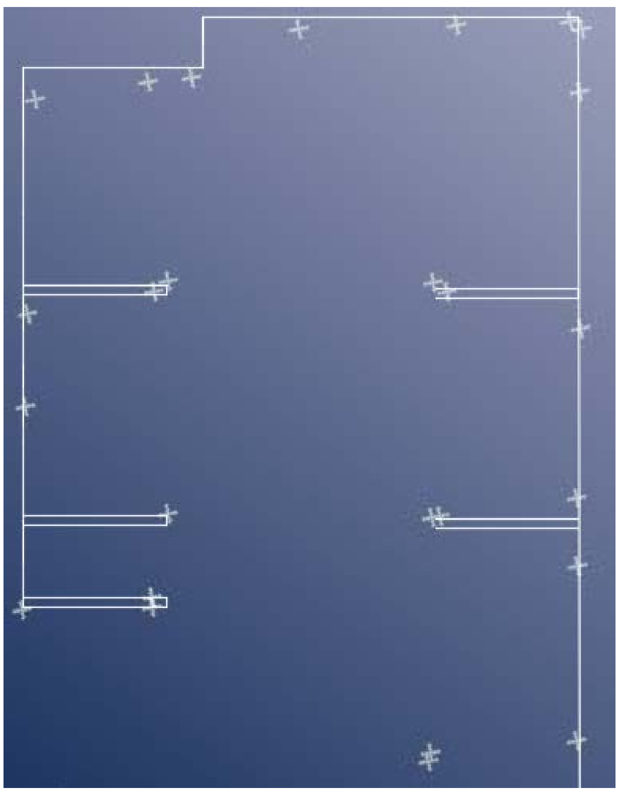

Figure 3.5.3 - Aerial view of basement with surface wireframe from photos

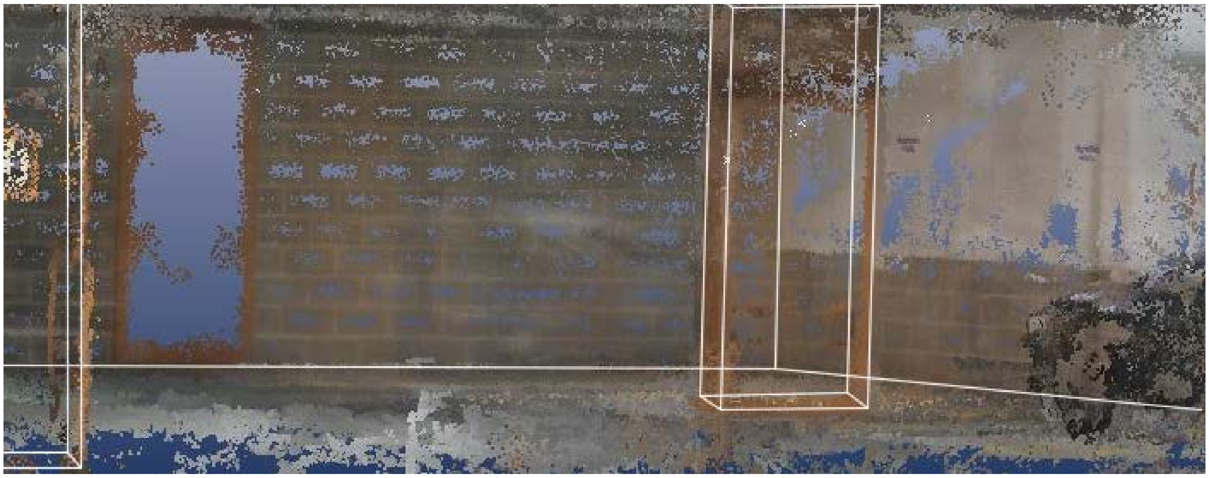

Figure 3.5.4 - Lines drawn onto the surface photos to be referenced within the 3D model.

The coordinates of the control targets are to be exported from excel as a Text File and imported into Civilcad to be used as another method of generating a model to determine area. Due to the positioning of control targets, placed on the faces of parallel and perpendicular columns and straight walls, the structures of the site can be manually drawn within Civilcad. Figure 3.5.5 shows the computed measurements of the basement using the coordinates of the control targets exported from Photomodeler.

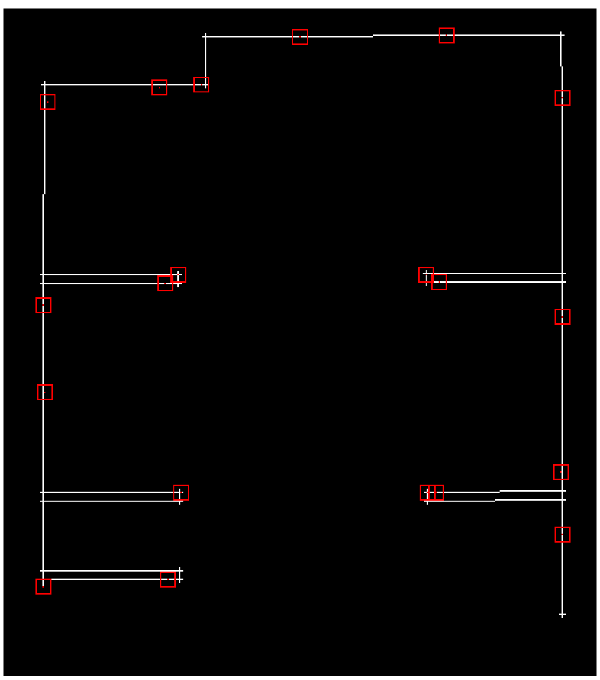

Figure 3.5.5 - Manually computed model from Photomodeler Coordinates.

3.5.3 Analysis

Excel will be used to analyse both data sets of coordinates from the respective projects, comparing the calculated coordinates in a Cartesian format. This will determine whether the accuracy of the model is acceptable for the intended use.

A 3D visual representation of both models will be also be created to display the position of control points, locations of line markings and services located on ground and ceiling level. Areas will be measured in square metres and cubic metres where available for both models to determine the accuracy of the photogrammetric process and test its viability in modern surveying.

3.6 Risk Assessment

A risk assessment should be completed to assess all possible hazards when undertaking the project. The risk assessment will be divided between the physical risks on site and in the office and will assess the possible risks that are associated with the overall project.

Table 3.6.1 outlines the risk assessment guide showing the risk severity of potential risks that may occur during the project.

Table3.6.2 outlines the potential risks associated when conducting the field work

Table 3.6.3 outlines the potential risks associated when conducting the office work

Table 3.6.4 outlines the overall potential risks associated with completing the projects, including special and unforeseen circumstances.

Table 3.6.1- Risk Assessment Guide

0-5 = Low Risk		**Severity of the potential injury/damage**				
6-10 = Moderate Risk		**Minor injury 1**	**Non-Reportable injury 2**	**Reportable Injury 3**	**Major Injury 4**	**Fatalities 5**
11-15 = High Risk						
16-25 = Extremely High Risk						
Likelihood of the hazard happening	**Extremely Unlikely 1**	**1**	**2**	**3**	**4**	**5**
	Remote Possibility 2	**2**	**4**	**6**	**8**	**10**
	Possible Occur 3	**3**	**6**	**9**	**12**	**15**
	Will probably Occur 4	**4**	**8**	**12**	**16**	**20**
	Almost Certain 5	**5**	**10**	**15**	**20**	**25**

Table 3.6.2 – Risks when completing Field Work

Task	Hazard	Risk	Minimization
1	Injury from being hit by a vehicle within the basement	8	1. Wear fluorescent safety clothing 2. Make drivers aware of area that is being occupied by surveyor with signage and by excluding the zone.
2	Hazardous materials on site	6	1. Safety boots 2. Site inspection
3	Pollutants (Carbon Monoxide)	6	1. Ensure the basement is well ventilated 2. Do not work for longer than 1 hour without taking a break outside the area.
4	Flooding	5	1. Have a perimeter around heavy machinery 2. Check floor drains and pits to ensure nothing is blocked
5	Flora (Spiders)	3	1. Take precaution when in corners or areas with noticeable spider webs
6	Hazardous Terrain (Mould build up on floor)	9	1. Safety Boots 2. Site inspection 3. Take care in areas with water/mould
7	Laser from Disto	6	1. Ensure there is no one in the direction of the laser 2. Laser proof goggles 3. Signage - make others aware of the risk

Table 3.6.3 – Risks when completing Office Work

Task	Hazard	Risk	Minimization
1	Stress	5	1. Set goals that are achievable to reduce stress 2. Have breaks from working
2	Poor Posture	4	1. Setup correct workstation 2. Make sure the correct posture is used
4	Equipment Hazards (sharp edges, exposed power cables)	4	1. Setup safe workstation with no exposed power cables. 2. Be cautious when walking around the office

			3. Tape down any cables that run along the floor to avoid tripping.
5	**Eye Stress**	**3**	**1. Take breaks** **2. Look away** **3. Correct lighting** **4. Possibly acquire glasses**

Table 3.6.4 – Overall risks of the Research Project

Task	Hazard	Risk	Minimization
1	**Corruption of Photos**	**MEDIUM RISK**	**1. Ensure the memory card is new with sufficient space to be used.** **2. Backup photos onto the computer as well as an external hard drive**
2	**Equipment malfunction**	**LOW RISK**	**1. Use other equipment** **2. Get equipment serviced**
3	**Corrupt data from equipment**	**LOW RISK**	**1. Try to take equipment to data expert to recover data within the instrument**
4	**Writing down wrong measurement/taking wrong measurement**	**MEDIUM RISK**	**1. Implement check to make sure distances are correct** **2. Ensure distances are measured correctly**
5	**Time Management**	**LOW RISK**	**1. Complete a Project plan** **2. Stay ahead of schedule**
6	**Photo Overlap**	**LOW RISK**	**1. Ensure there is sufficient overlap for each station**

While in the office and the field a first aid kit will be available for all minor injuries. This will reduce the risk of a more serious injury occurring by attending to the minor injury as soon as possible. Ensuring another person is aware of the activities taking place will ensure an emergency contact if needed. Also having emergency contacts displayed within the office will help minimise risk.

3.7 Summary

This section has provided a summary on the necessary resources required to complete the project. It details the calibrations and services required for each piece of equipment to ensure the methodology is completed with accuracy. The software used and data files to be exported is briefly explained which is then referenced within the body of the methodology.

An extensive methodology is included, describing the practices needed to complete the project for both the electronically collected data and photogrammetric processed data. It discusses the locations of control marks and the function it has in both methods. This section continues to explain the methods of obtaining field data and the post processing of data to generate 3D models for both sets of data.

A detailed risk assessment is included to analyse the physical and systematic risks to the project. It assesses the risks involved with the field and office work components as well as problems with the equipment or software.

4. RESULTS

4.1 Introduction

This section of the report will cover the results attained from the actions within the methodology which will provide the necessary data to assess the viability of the project’s aim. The analysis of a project's results is essential in determining the practically of the aims and objectives for the project. The section provides a detailed correlation to be made between the project aim and methodology as justified by the literature review, providing a statistical analysis on the outcomes from the methodology.

It will analyse the data attained from the Electronic tape measurements, assessing the position of control targets within the 3D model completed with AutoCAD. This will be presented within excel and further compared with the equivalent data collected through the Photogrammetric method. This section will also include the deduction of area and volume for the site to provide an accurate base model to be later compared to the photogrammetric measurements.

The section will additionally analyse the data attained from the Photogrammetric measurements, assessing the position of control targets within the 3D model, completed with Photomodeler. The coordinates will be presented within excel and compared with the corresponding points from the previously recorded data. The excel coordinates will be imported into Civilcad where the area will be reduced by measuring line work based off the control points. Area and volume will also be calculated from the 3D model within Photomodeler by producing a surface wireframe within the coordinated photos.

Overall, this chapter will analyse the efficiency of the methodology, comparing the results from both methods throughout various processing software. This will provide a comprehensive analysis and comparison between the eastings, northing and elevations from the congruent control points. The data will be used to assess the quality of each control point in order to test its relevance to modern surveying applications

4.2 Electronic Tape Results and Comparison

The recorded data from the Electronic Tape was completed using a Leica Disto D510, with the distances manually calculated into Civilcad. The data was edited relatively such that each point had a coordinated Easting, Northing and Elevation to which additional line work was completed to create a 3D model for analysis.

The coordinates of the control points have been exported from Civilcad into Excel for data comparison and analysis. This has been shown within Section 4.2.1.

The coordinated 2D wireframe has been exported from Civilcad into AutoCAD for the representation of the 3D model and to deduce the area and volume of the site for data comparison and analysis. This has been shown within Section 4.2.2

4.2.1 Deduction from Coordinates

Point ID	Easting	Northing	Elevation
C1	1000.116	945.128	99.991
C2	1000	1000	100
T2	1004.439	954.294	100.096
T3	995.834	954.292	100.081
T4	995.846	961.778	100.084
T5	1004.43	961.793	100.119
T6	1004.426	969.291	100.098
T7	995.827	969.228	100.079
T8	995.818	974.384	100
T9	992.374	974.673	100.039
T10	991.179	981.077	100.092
T11	995.352	981.274	100.094
T12	995.849	984.238	100.02
T13	991.193	987.732	100.193
T14	991.182	990.732	100.125
T15	995.351	991.482	100.14
T16	995.842	991.738	100.031
T17	991.184	994.038	99.932
T18	991.337	997.734	99.971
T19	995.187	998.231	100.362
T20	996.601	998.34	100.293
T21	1005.045	999.975	100.177
T23	1008.986	997.804	100.083
T24	1004.334	991.763	100.044
T25	1009.001	990.315	100.127
T26	1004.805	991.492	100.072
T27	1008.999	984.971	100.251
T28	1004.639	984.294	100.104
T29	1004.343	984.257	100.086
T30	1009.01	982.806	100.135
T31	1004.405	976.751	100.022
T32	1004.353	976.5	100.033
T33	1009.012	979.207	100.023
T34	1009.019	977.357	100.539
T35	995.358	981.573	100.049

4.2.2 Deduction from Area

The figure below is the completed strata plan in accordance with the Strata Schemes Act 1973 plotted from the measurements within civilcad. The areas have been determined by measuring between the structures and providing the required car spaces for each lot.

CP denotes common property which although has been measured, will not affect the designated areas for each car spot. PT denotes the total area for the parking spot required by each lot. The areas shown are rounded to the nearest two decimal places and taken to the centre line of the columns, with the extent of the column not included in the area calculation for each spot.

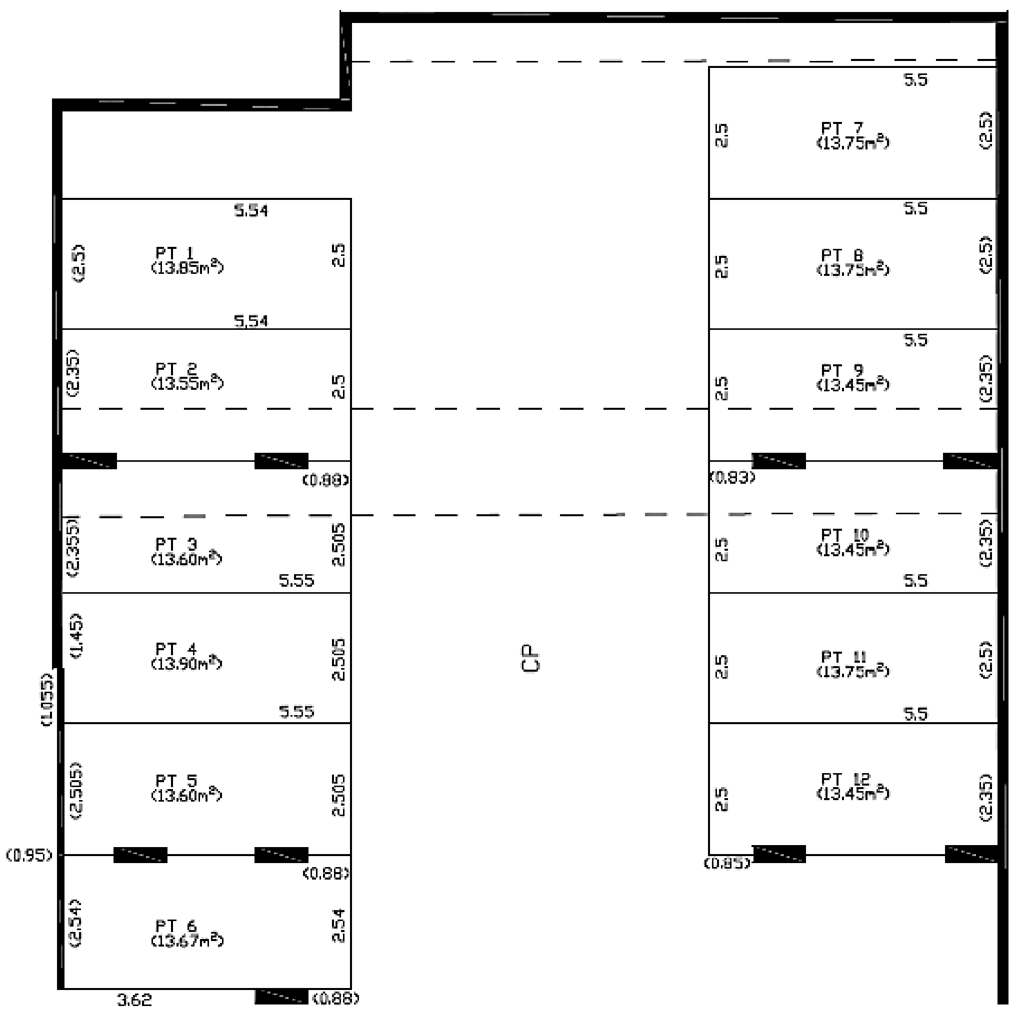

Figure 4.2.1 - Strata of Basement

Although it is not necessary to define stratums for individual car spaces, for the purpose of this project in assessing the viability of stratum measurements it has been completed. The dashed line denotes the concrete beam which will overall affect the volume for the affecting lots. Measurements were taken from the ground to the ceiling and beam to complete the volume calculations which are shown in cubic metres to the nearest two decimal places. Figure 4.2.2 shows the stratum measurements for the required lots based on the measurements taken with the Disto.

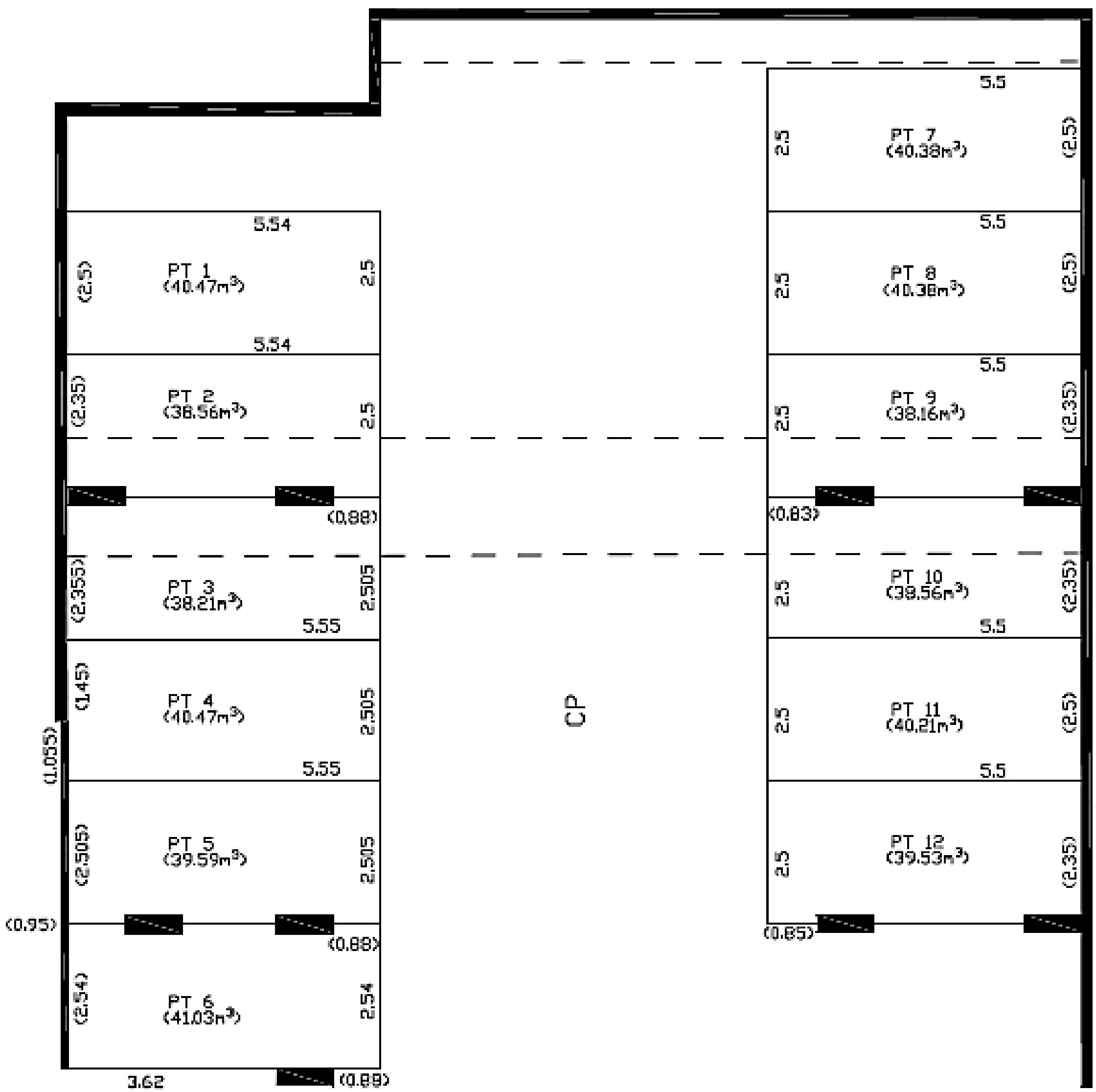

Figure 4.2.2 - Stratum of Basement

4.3 Photogrammetry Results and Comparison

The recorded data using the Photogrammetric method was completed using a Canon EOS 600D, importing and editing the data within Photomodeler. The data was orientated, edited and coordinated to produce a 3D model which was exported into excel for analysis. The model was also edited within Photomodeler to produce a series of measurements for the model.

The coordinates of the control points have been exported from Photomodeler into Excel for data comparison and analysis. This has been shown within Section 4.3.1. The detailed coordinates as exported from Photomodeler are shown within the Appendix.

A coordinated 3D wireframe has been created within Photomodeler exporting the measurements into Autocad for comparison and a visual representation. Based on the amount of photos taken, there was not enough data to accurately identify the ceiling or concrete beam within the model, causing the calculation of volumes to be unfeasible. The causes of this will be further analysed within Section 5 of the report. The area of the model can still be calculated and is shown within Section 4.2.2.

The locations of the coordinates were placed on the faces of columns and walls which allowed a model to be created, using perpendicular and parallel lines. The coordinates were exported from Photomodeler, into Excel where they were modified and later imported into Civilcad where the model was generated. This again only works for the area rather than the volume, however solutions are provided within Section 5 of the report. The area of the model is shown within Section 4.3.3.

4.3.1 Deduction from Coordinates

Id	X (project units)	Y (project units)	Z (project units)	Largest Residual (pixels)
1006	1004.486	969.023	100.121	1.453
1007	995.858	969.503	100.071	1.737
1008	995.814	974.416	99.999	2.474
1009	992.404	974.787	100.038	3.221
1010	991.108	980.985	100.088	3.580
1011	995.415	981.217	100.084	0.587
1012	995.873	984.211	100.014	2.547
1013	991.157	987.688	100.189	2.208
1014	991.134	990.706	100.123	2.908
1015	995.334	991.473	100.142	3.588
1016	995.800	991.760	100.039	1.377
1018	991.261	997.746	99.968	1.630
1019	995.156	998.245	100.359	4.661
1020	996.571	998.350	100.293	3.145
1021	1005.069	1000.033	100.181	3.000
1023	1009.060	997.875	100.089	3.295
1024	1004.359	991.759	100.041	3.827
1025	1009.075	990.321	100.132	3.679
1026	1004.840	991.496	100.074	3.006
1027	1009.035	984.950	100.252	3.595
1028	1004.699	984.247	100.109	1.456
1029	1004.394	984.216	100.089	2.472
1030	1009.073	982.769	100.141	1.553
1031	1004.444	976.683	100.027	1.865
1032	1004.389	976.428	100.036	1.574
1034	1009.126	977.247	100.558	1.666
1035	995.357	981.540	100.046	4.378
2002	999.986	999.999	99.998	2.452

4.3.2 Deduction of Area in Photomodeler

Once the photos were orientated and a model was generated, surface lines were added to the coordinated photos to produce a wireframe using a 3D coordinate system (Cartesian Coordinates). Despite effective horizontal overlap between the photos, there was insufficient photo overlap vertically, with minimal photo cover on the roof and floor. Therefore, the Stratum on the area could not be completed, however line work for major walls and columns were achieved which allowed the area to be deduced.

Once the 3D model was edited, the wireframe was viewed aerially where measurements were taken between structures. Figure 4.3.1 shows the even distributions of area per car spot based on the measurements between structures.

Figure 4.3.1 - Lines drawn on model in Photomodeler

4.3.3 Deduction of Area in Civilcad

Initially the coordinates of the control targets were exported from Photomodeler and compared within Excel; however the coordinates were later exported from Excel and imported into Civilcad to produce a model based on their positions. Since the walls were built flush and columns designed perpendicular and parallel to each other, the targets could be used to generate a surface for the structures. The measurements between the structures provided the necessary data to determine the areas for each car spot as shown within Figure 4.3.2.

Figure 4.3.2 - Lines drawn on model in Civilcad

4.4 Comparison of Electronic Tape and Photogrammetry results

The differences in coordinates as calculated within previous sections of the report will be analysed and compared to determine the variances between both methods, overall testing the viability of using photogrammetry to complete Strata and Stratums. This section will assess the data analytically; through a direct comparison of the data sets and statistically; using a t-distribution table to analyse the overall differences in the coordinates and areas.

Section 4.4.1 will cover the comparisons of the accuracies between control point targets within both methods. It will assess the differences in positioning for all the control points through an analytical perspective and a statistical perspective. This will also be completed when only selecting the targets in proximity to the specific area in focus rather than the entirety of control point.

Section 4.4.2 will cover the comparisons of the accuracies between the areas produced from the various models created. It will assess the differences in area between models created using the Electronic Tape measurements, reduced through Civilcad and Photomodeler results, reduced separately within Photomodeler and also Civilcad. It will determine the mean differences between the areas and also the standard deviations to assess the accuracy of the results within the project.

4.4.1 Accuracies from Coordinates

Table 4.4.1 - Coordinate analysis using all control points

Electronic Tape Coordinates					**Photomodeler Coordinates**						**Differences**		
Point ID	**Easting**	**Northing**	**Elevation**		**Point ID**	**Easting**	**Northing**	**Elevation**			**Δ Easting**	**Δ Northing**	**Δ Elevation**
T6	1004.426	969.291	100.098		**1006**	1004.486	969.023	100.121			0.060	0.268	0.023
T7	995.827	969.228	100.079		**1007**	995.858	969.503	100.071			0.031	0.275	0.008
T8	995.818	974.384	100		**1008**	995.814	974.416	99.999			0.004	0.032	0.001
T9	992.374	974.673	100.039		**1009**	992.404	974.787	100.038			0.030	0.114	0.001
T10	991.179	981.077	100.092		**1010**	991.108	980.985	100.088			0.071	0.092	0.004
T11	995.352	981.274	100.094		**1011**	995.415	981.217	100.084			0.063	0.057	0.010
T12	995.849	984.238	100.02		**1012**	995.873	984.211	100.014			0.024	0.027	0.006
T13	991.193	987.732	100.193		**1013**	991.157	987.688	100.189			0.036	0.044	0.004
T14	991.182	990.732	100.125		**1014**	991.134	990.706	100.123			0.048	0.026	0.002
T15	995.351	991.482	100.14		**1015**	995.334	991.473	100.142			0.017	0.009	0.002
T16	995.842	991.738	100.031		**1016**	995.800	991.760	100.039			0.042	0.022	0.008
T18	991.337	997.734	99.971		**1018**	991.261	997.746	99.968			0.076	0.012	0.003
T19	995.187	998.231	100.362		**1019**	995.156	998.245	100.359			0.031	0.014	0.003
T20	996.601	998.34	100.293		**1020**	996.571	998.350	100.293			0.030	0.010	0.000
T21	1005.045	999.975	100.177		**1021**	1005.069	1000.033	100.181			0.024	0.058	0.004
T23	1008.986	997.804	100.083		**1023**	1009.060	997.875	100.089			0.074	0.071	0.006
T24	1004.334	991.763	100.044		**1024**	1004.359	991.759	100.041			0.025	0.004	0.003
T25	1009.001	990.315	100.127		**1025**	1009.075	990.321	100.132			0.074	0.006	0.005
T26	1004.805	991.492	100.072		**1026**	1004.840	991.496	100.074			0.035	0.004	0.002
T27	1008.999	984.971	100.251		**1027**	1009.035	984.950	100.252			0.036	0.021	0.001
T28	1004.639	984.294	100.104		**1028**	1004.699	984.247	100.109			0.060	0.047	0.005
T29	1004.343	984.257	100.086		**1029**	1004.394	984.216	100.089			0.051	0.041	0.003
T30	1009.01	982.806	100.135		**1030**	1009.073	982.769	100.141			0.063	0.037	0.006
T31	1004.405	976.751	100.022		**1031**	1004.444	976.683	100.027			0.039	0.068	0.005
T32	1004.353	976.5	100.033		**1032**	1004.389	976.428	100.036			0.036	0.072	0.003
T34	1009.019	977.357	100.539		**1034**	1009.126	977.247	100.558			0.107	0.110	0.019
T35	995.358	981.573	100.049		**1035**	995.357	981.540	100.046			0.001	0.033	0.003
C2	1000	1000	100		**2002**	999.986	999.999	99.998			0.014	0.001	0.002
Average Misclose											**0.043**	**0.056**	**0.005**

Table 4.4.2 - Standard Deviation analysis using all control points for Easting coordinates

Easting	
Mean	0.042932893
Standard Error	0.004596364
Median	0.0361485
Mode	#N/A
Standard Deviation	0.024321674
Sample Variance	0.000591544
Kurtosis	0.316224978
Skewness	0.572898333
Range	0.105762
Minimum	0.001245
Maximum	0.107007
Sum	1.202121
Count	28
Confidence Level (95.0%)	0.009430961

Table 4.4.3 - T-Test: Paired Two Sample for Means of Eastings

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	999.9933929	1000.009837
Variance	40.96878662	41.45092873
Observations	28	28
Pearson Correlation	0.999990143	
Hypothesized Mean Difference	0	
df	27	
t Stat	-1.845743965	
P(T<=t) one-tail	0.03796112	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	0.07592224	
t Critical two-tail	2.051830516	

Table 4.4.4 - Standard Deviation analysis using all control points for Northing coordinates

Northing	
Mean	0.056215036
Standard Error	0.012904071
Median	0.0351595
Mode	#N/A
Standard Deviation	0.068281923
Sample Variance	0.004662421
Kurtosis	5.925119266
Skewness	2.407294554
Range	0.273091
Minimum	0.001434
Maximum	0.274525
Sum	1.574021
Count	28
Confidence Level (95.0%)	0.026476966

Table 4.4.5 - T-Test: Paired Two Sample for Means of Northings

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	986.0718571	986.0597697
Variance	85.22643316	85.50586538
Observations	28	28
Pearson Correlation	0.999955724	
Hypothesized Mean Difference	0	
df	27	
t Stat	0.724768246	
P(T<=t) one-tail	0.237414392	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	0.474828783	
t Critical two-tail	2.051830516	

Table 4.4.6 - Standard Deviation analysis using all control points for Elevations coordinates

Elevation	
Mean	0.005075357
Standard Error	0.000973213
Median	0.0034535
Mode	#N/A
Standard Deviation	0.005149757
Sample Variance	2.652E-05
Kurtosis	6.479203874
Skewness	2.455513284
Range	0.023005
Minimum	0.000231
Maximum	0.023236
Sum	0.14211
Count	28
Confidence Level (95.0%)	0.001996867

Table 4.4.7 – T-Test: Paired Two Sample for Means of Elevations

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	100.1163929	100.1178991
Variance	0.014900396	0.015543517
Observations	28	28
Pearson Correlation	0.998551541	
Hypothesized Mean Difference	0	
df	27	
t Stat	-1.117351296	
P(T<=t) one-tail	0.13684425	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	0.273688501	
t Critical two-tail	2.051830516	

Table 4.4.8 - Coordinate analysis using control points in specific area

Electronic Tape Coordinates					**Photomodeler Coordinates**						**Differences**		
Point ID	**Easting**	**Northing**	**Elevation**		**Point ID**	**Easting**	**Northing**	**Elevation**			**Δ Easting**	**Δ Northing**	**Δ Elevation**
T10	991.179	981.077	100.092		**1010**	991.108	980.985	100.088			0.071	0.092	0.004
T11	995.352	981.274	100.094		**1011**	995.415	981.217	100.084			0.063	0.057	0.010
T12	995.849	984.238	100.02		**1012**	995.873	984.211	100.014			0.024	0.027	0.006
T13	991.193	987.732	100.193		**1013**	991.157	987.688	100.189			0.036	0.044	0.004
T14	991.182	990.732	100.125		**1014**	991.134	990.706	100.123			0.048	0.026	0.002
T15	995.351	991.482	100.14		**1015**	995.334	991.473	100.142			0.017	0.009	0.002
T16	995.842	991.738	100.031		**1016**	995.800	991.760	100.039			0.042	0.022	0.008
T18	991.337	997.734	99.971		**1018**	991.261	997.746	99.968			0.076	0.012	0.003
T19	995.187	998.231	100.362		**1019**	995.156	998.245	100.359			0.031	0.014	0.003
T20	996.601	998.34	100.293		**1020**	996.571	998.350	100.293			0.030	0.010	0.000
T21	1005.045	999.975	100.177		**1021**	1005.069	1000.033	100.181			0.024	0.058	0.004
T23	1008.986	997.804	100.083		**1023**	1009.060	997.875	100.089			0.074	0.071	0.006
T24	1004.334	991.763	100.044		**1024**	1004.359	991.759	100.041			0.025	0.004	0.003
T25	1009.001	990.315	100.127		**1025**	1009.075	990.321	100.132			0.074	0.006	0.005
T26	1004.805	991.492	100.072		**1026**	1004.840	991.496	100.074			0.035	0.004	0.002
T27	1008.999	984.971	100.251		**1027**	1009.035	984.950	100.252			0.036	0.021	0.001
T28	1004.639	984.294	100.104		**1028**	1004.699	984.247	100.109			0.060	0.047	0.005
T29	1004.343	984.257	100.086		**1029**	1004.394	984.216	100.089			0.051	0.041	0.003
T30	1009.01	982.806	100.135		**1030**	1009.073	982.769	100.141			0.063	0.037	0.006
C2	1000	1000	100		**2002**	999.986	999.999	99.998			0.014	0.001	0.002
Average Misclose											**0.045**	**0.030**	**0.004**

Table 4.4.9 - Standard Deviation analysis using control points in specific area for Easting Coordinates

Easting	
Mean	0.04467935
Standard Error	0.00456649
Median	0.0390375
Mode	#N/A
Standard Deviation	0.02042197
Sample Variance	0.00041706
Kurtosis	-1.3657665
Skewness	0.21806042
Range	0.061357
Minimum	0.014405
Maximum	0.075762
Sum	0.893587
Count	20
Confidence Level (95.0%)	0.00955778

Table 4.4.10 - t-Test: Paired Two Sample for Means of Eastings

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	999.91175	999.9199
Variance	44.84795451	45.40484
Observations	20	20
Pearson Correlation	0.999991907	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.736327308	
P(T<=t) one-tail	0.235262891	
t Critical one-tail	1.729132812	
P(T<=t) two-tail	0.470525781	
t Critical two-tail	2.093024054	

Table 4.4.11 - Standard Deviation analysis using control points in specific area for Northing Coordinates

Northing	
Mean	0.03017
Standard Error	0.00563
Median	0.024153
Mode	#N/A
Standard Deviation	0.025177
Sample Variance	0.000634
Kurtosis	0.299151
Skewness	0.925806
Range	0.090703
Minimum	0.001434
Maximum	0.092137
Sum	0.603395
Count	20
Confidence Level (95.0%)	0.011783

Table 4.4.12 - t-Test: Paired Two Sample for Means for Northings

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	990.51275	990.502301
Variance	42.1127996	42.53252718
Observations	20	20
Pearson Correlation	0.99999484	
Hypothesized Mean Difference	0	
df	19	
t Stat	1.21587921	
P(T<=t) one-tail	0.11946116	
t Critical one-tail	1.72913281	
P(T<=t) two-tail	0.23892233	
t Critical two-tail	2.09302405	

Table 4.4.13 - Standard Deviation analysis using control points in specific area for Elevation Coordinates

Elevation	
Mean	0.003963
Standard Error	0.000548
Median	0.003453
Mode	#N/A
Standard Deviation	0.002449
Sample Variance	6E-06
Kurtosis	0.994652
Skewness	0.942926
Range	0.010115
Minimum	0.000231
Maximum	0.010346
Sum	0.07926
Count	20
Confidence Level (95.0%)	0.001146

Table 4.4.14 - t-Test: Paired Two Sample for Means of Elevations

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler*
Mean	100.12	100.1202
Variance	0.009567053	0.009628
Observations	20	20
Pearson Correlation	0.998834694	
Hypothesized Mean Difference	0	
df	19	
t Stat	-0.233427987	
P(T<=t) one-tail	0.408962778	
t Critical one-tail	1.729132812	
P(T<=t) two-tail	0.817925557	
t Critical two-tail	2.093024054	

4.4.2 Accuracies from Area

Table 4.4.15 - Difference between Disto area and Photomodeler surface lines

	Models		Difference
Point PT	**Disto**	**Photomodeler Surface Lines**	
1	13.85	13.78	0.07
2	13.55	13.58	-0.03
3	13.60	14.26	-0.66
4	13.90	14.26	-0.36
5	13.60	13.96	-0.36
6	13.67	13.89	-0.22
7	13.75	13.75	0
8	13.75	13.75	0
9	13.45	13.45	0
10	13.45	13.78	-0.33
11	13.75	14.08	-0.33
12	13.45	13.78	-0.33
	Average Difference		**0.2125**

Table 4.4.16 - Standard deviation of differences between Disto area and Photomodeler surface lines

Differences	
Mean	-0.2125
Standard Error	0.063593465
Median	-0.275
Mode	0
Standard Deviation	0.220294225
Sample Variance	0.048529545
Kurtosis	-0.338905005
Skewness	-0.443771999
Range	0.73
Minimum	-0.66
Maximum	0.07
Sum	-2.55
Count	12
Confidence Level (95.0%)	0.139968273

Table 4.4.17 - t-Test: Paired Two Sample for Means

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler Surface Lines*
Mean	13.6475	13.86
Variance	0.024347727	0.060836
Observations	12	12
Pearson Correlation	0.476197384	
Hypothesized Mean Difference	0	
df	11	
t Stat	-3.341538318	
P(T<=t) one-tail	0.003287709	
t Critical one-tail	1.795884819	
P(T<=t) two-tail	0.006575418	
t Critical two-tail	2.20098516	

Table 4.4.18 - Difference between Disto area and Photomodeler targets

	Models		**Difference**
Point PT	**Disto**	**Photomodeler Targets**	
1	13.85	13.85	0
2	13.55	13.55	0
3	13.60	13.69	-0.09
4	13.90	13.97	-0.07
5	13.60	13.69	-0.09
6	13.67	13.78	-0.11
7	13.75	13.75	0
8	13.75	13.75	0
9	13.45	13.45	0
10	13.45	13.56	-0.11
11	13.75	13.86	-0.11
12	13.45	13.56	-0.11
	Average Difference		**0.0575**

Table 4.4.19 - Standard deviation of differences between Disto area and Photomodeler surface lines

Differences	
Mean	-0.0575
Standard Error	0.01503153
Median	-0.08
Mode	0
Standard Deviation	0.05207076
Sample Variance	0.00271136
Kurtosis	-2.1621026
Skewness	0.23267714
Range	0.11
Minimum	-0.11
Maximum	0
Sum	-0.69
Count	12
Confidence Level (95.0%)	0.03308418

Table 4.4.20 - t-Test: Paired Two Sample for Means

t-Test: Paired Two Sample for Means	*Disto*	*Photomodeler Surface Lines*
Mean	13.6475	13.705
Variance	0.02434773	0.023318
Observations	12	12
Pearson Correlation	0.94333741	
Hypothesized Mean Difference	0	
df	11	
t Stat	-3.8252919	
P(T<=t) one-tail	0.00140862	
t Critical one-tail	1.79588482	
P(T<=t) two-tail	0.00281724	
t Critical two-tail	2.20098516	

4.5 Summary

This section has detailed the results attained from completing the methodology, comparing the data taken from the electronic tape measurements and photogrammetry measurements. Both the coordinates and areas formed within the 3D models were exported and compared both analytically and statistically.

Based on the results above, through both the coordinate and model area comparison, the use of photogrammetry for strata measurements is plausible. However, using the same method as stated within the project, accurate heights could not be determined to the concrete beam or roof in most areas which resulted in the insufficient information to complete a Stratum. Solutions to this issue will be further discussed within Section 5.

It can be seen that the major differences in coordinate position occurred when all the control point were used. This could be due to the points being captured either at a large angle to the base station or if the distance was too great resulting in lower camera resolution. The comparison with the least differences between areas was taken using the data from the exported coordinates within Excel into Civilcad for the model to be produced. This will be further discussed within Section 5.

5. DISCUSSION

5.1 Introduction

This section of the report will discuss the results that have been obtained through both the field work and data processing component of the project. It will assess the effectiveness of the methodology in achieving the aims and objectives for the report and determine the overall significance the project has in modern applications.

Within this section of the report, the results from the Electronic tape field work and post processing method will be discussed. The methodology will be discussed in relation to the objectives of the project, analysing the time it took to complete both the field and office components. The practicality of the software used will also be assessed for the production, editing and exporting of each model. It will also examine both the analytical and statistical data achieved with the electronic tape measurements and analyse its effectiveness as a base model. Finally, any problems that were encountered during the process will be discussed with viable solutions to each.

This section will also cover the results taken from the Photogrammetric field data and analyse the various methods used to complete the post processing of the information. Similarly, the methodology will be discussed, detailing the time taken to complete each stage. The differing software will be evaluated to determine the usability for the project and for future projects. An exploration of the analytical and statistical data for the Photogrammetry measurements will be conducted, comparing the varying results with different processing methods and the Electronic Tape measurements. Finally, any problems that were encountered during the process will be discussed with viable solutions to each.

A comparison between the different data sets will be included to test the accuracy of the Photogrammetric method compared to the base data from the Electronic Tape measurements. The differing accuracies between the control targets for each model will be discussed, with suggestions on how to improve low quality results.

The location of the control points for the photogrammetric purpose of the report will be discussed, primarily for testing accuracies between models. The camera selection and photo resolution will also be discussed the effectiveness it has in relation to the overall project aims.

Finally, an assessment of the projects aims and objectives will be completed to determine whether the initial problem that instigated the study had been solved.

5.2 Results from Electronic Tape

Overall, the figures and models generated using the Electronic Tape measurements were used as a base model for comparison between the various photogrammetric methods used throughout the report. This is the currently used method within the Modern surveying industry, which has the potential to be improved through the findings within this report.

The process used to complete the field work was tedious and time consuming due to the constant need to check whether the measurements were accurate and written correctly. Measuring the distance between the columns and major walls was a simple process, however to locate the control points in a Cartesian format (X,Y,Z) using the Electronic Tape was an extensive task. In order to locate the centre of the target in relation to the structure placed, two measurements needed to be taken as well as the numerous measurements taken for the dimensions and locations of the columns. This extended the time to complete the task however would not be needed in a practical application. Overall, the time taken to complete the field work, including the placement and location of the control points was approximately one hour.

The reducing of data was simplistic however required the manual input of measurements to be completed. The heights were easily adjusted relatively and the line work for the columns and walls were completed in a short time. Overall the time taken to complete the reduction of data was approximately 30 minutes.

Line work was easily modified within Civilcad, allowing heights to be changed and exported into Autocad for the construction of the 3D model. Autocad provided an efficient modelling program that easily allowed a visual representation of the marks to be generated. It also allowed for the areas to be calculated using inbuilt functions, eliminating the need for multiple calculations. The final strata plan was also illustrated within Autocad which has the ability to classify specific line types into layer codes to make it easier to isolate and edit if needed.

Overall the Electronic Tape data was easily recorded however was very time consuming both during the field and office components. Based on the results, the distance between the structures were at regulation size, allowing the minimum standards for a car spot to be achieved in accordance with local council's development control plan regulations.

The only problem that could be considered would be the additional time needed to transcribe each measurement on a hand drawn plan and reproduce it within the CAD software. If no checks were taken, there is a large potential risk that a measurement was written incorrectly, resulting in an inaccurate plan.

5.3 Results from Photogrammetry

The coordinates and models generated using the Photogrammetric methods were used as a comparison between the Electronic Tape measurements. There were two models created, each using the same set of photographs, however the final dimensions were calculated using two different methods for another comparison.

The process used to complete the field work was simple and quickly completed, taking approximately 15 minutes to take the required photos at the multiple stations. The control points were already placed from the Electronic Tape measurements on the faces of each structure, in the general direction of the camera stations. Overall, the time taken to complete the field work, while factoring in the time taken to place control points was approximately 20 minutes.

The methodology used for the reduction of data was uncomplicated in theory, however when imported into Photomodeler, the process to Auto-orientate the photos took approximately 5 hours. This could be due to the high resolution size of each photograph or the computer's processing speed and Random Access Memory (RAM) capability. Once the photos were orientated, they were then analysed to ensure the program had referenced the correct marks in the desired positions. Despite the quality of the images and easily identifiable targets, the program did not locate the corresponding targets in the correct positions. This required the re-referencing of each control point within most photographs. This process took approximately 1 hour and was very laborious and repetitive. Once the targets were correctly referenced the model was created, taking an additional hour of processing. This again could be due to the high resolution of the photographs or the processing capability of the laptop.

Within Photomodeler the elevation of the coordinates can be easily adjusted and exported as a DXF to be edited within Autocad. This was done to create the first model of the site, basing the dimensions off the positions and known locations of the control points. The model that was created had minimal differences to the dimensions of the base model and was generated within 20 minutes. Since the columns were both perpendicular and parallel to each other, the azimuth for the structures could be determined by joining the lines between targets. Although this produced accurate measurements, the need to place targets on the faces of the structures would be impractical for modern surveying. This method also wouldn't be feasible if the columns changed in size or were not perpendicular to each other.

The other model was completed within Photomodeler, editing the orientated 3D representation of the photographs to produce surface lines along the boundaries of the structures and walls. The line work was drawn across both vertical and horizontal planes, however when assessing the quality of the completed line work, noticed the vertical plane (Cartesian Z coordinate) was not perpendicular to the remaining horizontal planes (Cartesian X and Y coordinates).

Due to this, a stratum could not be completed with the data provided, despite being accomplished using the Electronic Tape method. The horizontal plane was still accurately exported into Autocad and was available for comparison between the remaining models, however it was only considered 2 dimensional with any heights on the structures dismissed. Despite the errors in height, it was a relatively quick process in completing the surface line work on the model, only taking approximately 10 minutes to draw the line work onto the model and export into AutoCAD for measurement.

Overall the Photogrammetric methods used are both plausible for the completion of stratas, however due to the time reducing the data in office, it would be unrealistic to be used in modern surveying. The results between the coordinate and area differences which will be discussed within the following subsection of this report, will analyse which method was the most accurate, however by comparing the final results, it can be seen that the photogrammetric measurements produce dimensions within the minimum standards.

Since the model was accurate within the Horizontal plane, it can be concluded that there was sufficient overlap between the photos across the plane. The stratum was not able to be completed due to insufficient information within the vertical range; therefore when gathering the data in the field, multiple photos in a vertical range should be taken at any one angle.

Problems also occurred with the processing of the images into Photomodeler. Although the system was able to generate a model that was highly congruent to the base model, the time taken to orientate the images, reference the control points and generate a dense point cloud was too long. The lengthy processing could have occurred due to the high resolution pixel count of each photograph; however this could not be sacrificed as it would have been harder to reference and tie together common points. This issue could also be due to the processing capability of the laptop used to complete the task, despite the RAM being constantly monitored during the process. If it were the case, the computer would need to be upgraded which will become an additional cost the user may not want to incur.

5.4 Comparison between Data

The most accurate analytical and statistical comparison between coordinates was achieved when comparing the Disto coordinates with the control points in close proximity to the subject area. This is due to the higher quality images allowing Photomodeler to accurately locate common control points at a range which allowed multiple photos to overlap the same control point. The control points that were measured within less than 3 photos had the least accurate coordinates as shown in the coordinate comparison within Appendix D. Errors in Easting and Northings were up to 0.2m in some circumstances, which doesn't guarantee an accurate model unless there is sufficient overlap between coordinates.

This is can be seen within the data set comparing the control points in close proximity to the subject area. Although the average misclose is minimal, there is less range between the marks since they had been located within multiple photos through Photomodeler. Although there are minor differences in the average misclose, the Confidence interval between both sets of coordinates was affected due to the inaccuracies of the marks furthest from the site.

A stratum was not able to be completed using the photos that were taken due to minimal vertical overlap between each setup. Since there wasn't enough information to accurately deduce the height of each structure, the model that was created through Photomodeler required the point cloud to be edited.

Since the accuracies from the coordinate data were established, the areas were expected to be of high accuracy. Having an inbuilt program within Photomodeler saved time by eliminating the need to export specific coordinate data into a different processing software, however the accuracy of the photos within the program proved not as accurate as the exported coordinates. Despite being not as accurate as the other model, the results still had high accuracy within the 95% confidence interval.

The process of exporting and drafting the coordinated model into AutoCAD was not as time efficient as the Photomodeler Surface line method, however provided a higher precision as it was dependent on the accuracies of the coordinated control points. However, when producing the model in Autocad, there was no need to re-export the job for the final strata plan as it was already there.

As stated within NSW Legislation, strata areas are transcribed as approximations on the final plan, rounding to the nearest whole number when displaying area. For the purpose of the thesis, the results were written to two decimal places in order to compare accuracies. Overall, through both methods of area deduction, there were minimal differences in area when compared to the traditionally recorded strata measurements. Each photogrammetric method had sufficient accuracies to be used for a strata plan as they would essentially be rounded to the same whole number.

5.5 Camera Quality

The camera quality was an essential factor for the project, ensuring adequate detail was recorded within the basement whereby control points could be located and referenced within Photomodeler. Previous studies have been conducted using both higher quality and lower quality camera to complete similar photogrammetric methods, however most have compromised essential goals and objectives within the current thesis. The camera produced high quality images which had allowed features and control points to be easily identified while still maintaining a reasonable price.

Especially with the placement of certain control targets on contrasting surfaces, the pixel quality was good enough to locate the centre of the control point. However when the target was at a larger distance from the base station it was difficult and in some circumstances impossible to locate certain control points. It can be seen within figure 5.5.1 below the difference in quality the images produced when observing control targets at both a close and distant viewpoint.

Figure 5.5.1 - Comparison of Pixel Distortion due to distance (Blurry/Clear)

It was also hard to locate the centre of the control target when at a large angle when compared to the directly perpendicular shots. This generated a large positional error in Easting and Northing, (error in elevation was minimal) when comparing the coordinates of the control points. Although the photos were auto-orientated within Photomodeler, most centres of corresponding targets in each photo needed to be manually adjusted.

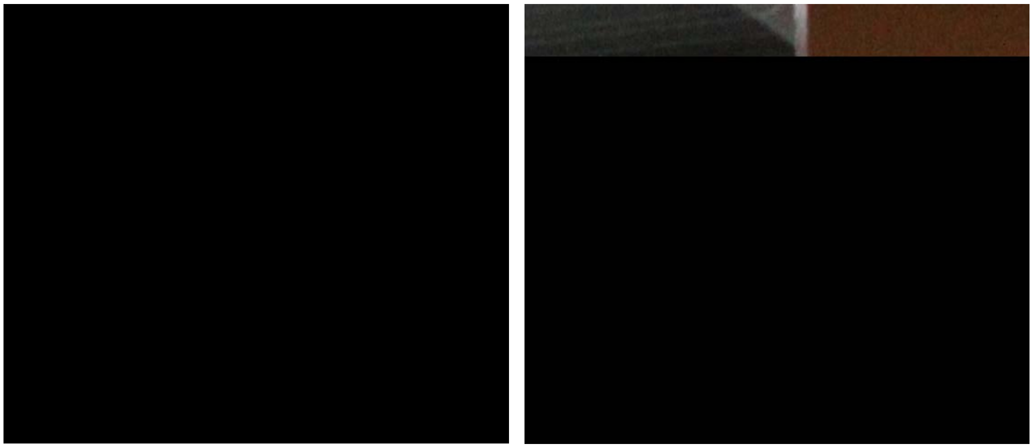

Figure 5.5.2 - Comparison of Angular Pixel Distortion (Blurry/Clear)

Location of Base stations for photogrammetry was good as it allowed a minimum of two stations to overlap photos from different differences to a specific feature. The features with photos from multiple stations were the most accurate and produced the highest point cloud within Photomodeler.

5.6 Location of control points (CP)

The location of the control points were determined when the position and number of base stations used to complete the photogrammetry section of the report were deduced. The control points were placed facing the centreline of the basement and in roughly the same position on the faces of each column making them easily detectable within Photomodeler. Locating the control points with the Disto was more time consuming both during the field and office component than using the Photogrammetric method. It did not take long to place the stickers on the structures, however since the positioning of the targets were strategically placed it took some time to plan where each target would be placed.

By placing the control points on the faces of the structures, generating a model based on the coordinates was simplistic and time efficient. Both the analytical and statistical results show minimal differences between the Disto generated model and the Photogrammetric model based on the exported coordinates.

The use of reflective targets proved very effective in contrasting to the darker or coloured structures within the basement, making them more visible through the camera. They were easily located within Photomodeler which ensured it was coordinated with high accuracy. The targets that were placed on the white wall on the Eastern side (due to low contrast) or at lengthy distances to the base station were difficult to locate and unable to be used during the photo orientation process within Photomodeler.

Based on the site selected, the focal length of the camera and the position of each camera station, a minimum of 3 control targets within each overlapped photograph were achieved. However the proximity of the control points could have been closer together and increased to ensure there was sufficient overlap and minimise the amount of base stations needed for the project.

The control points were placed at approximately 1.7m from the surface, roughly in the centre of the vertical plane. If in the circumstance a stratum was to be completed, warranting the need for multiple overlapping photos in the vertical plane, control points would need to be placed at a higher and lower range.

5.7 Summary

This section provided a comprehensive discussion of the results achieved from the project, the effectiveness of the methodology and briefly stated mitigation strategies in order to improve the project. It has provided an extensive discussion of both the field and office work involved when undertaking both the Electronic Tape measurements and Photogrammetry process, addressing the advantages and disadvantages of both operating and processing systems. Camera quality has also been discussed, assessing the various errors that had occurred during its use. A discussion on the efficiency of the control points has been included to assess the best use of control points in terms of proximity and contrast.

The following section of the report will include a conclusion assessing the overall efficiency and effectiveness of the project.

6. CONCLUSION

6.1 Introduction

This chapter of the report will conclude how well the methodology and results met the aims and objectives as stated within Section 1 of the report. A deduction of the limitations for the project will also be included based on the issues stated within the section 5 of the report.

6.2 Conclusions

Essentially, the use of close range photogrammetry is an acceptable method of measurement of strata plans. The hypothesis of the study is plausible, however not practical as particular aims and objectives as stated within Chapter 1 of the report were not met. The accuracies when comparing the traditional methods to the experimental photogrammetric methods are capable of producing an accurate strata plan, though the time taken to produce the plan is too lengthy, requiring further research for development.

Generally, the time taken when calculating a strata plan using Photogrammetry method was too extensive and impractical. The field work component was completed in 15 minutes (as opposed to an hour when completing it with an Electronic Tape) therefore allowing more jobs to be measured within the day. Conversely, the office component required seven hours to orientate the photos, generate a point cloud and export into the desired processing system (as opposed to one and a half hours). Although this processing was lengthy and impractical, if an employer wished to undertake multiple strata projects and run the systems simultaneously overnight, it may be a more practical approach. Processing the photos to auto locate common points was the longest process undertaken within Photomodeler, therefore the computer's RAM must be upgraded to avoid systematic errors and increase the efficiency of the methodology.

When comparing the accuracy of the deduced areas through the photogrammetric methods to the areas consistent with modern surveying, the quality of the results were acceptable for a strata plan. Both models generated a true bearing and distance of each wall, structure and feature, with the only limitation being vertically inaccurate. In order for the accuracy to be guaranteed, there must be sufficient overlap between photos with numerous camera stations to ensure the qualities of the images taken are not compromised.

Essentially the initial cost for the equipment, including the services and programs needed to complete the overall task is roughly the same price. Using photogrammetry to complete a strata plan was achievable using only 1 surveyor on site, therefore the employer is able to minimise the expense of sending an additional surveyor for the job.

Although Photomodeler completed the required task with the required quality to allow an accurate model to be generated, the time taken to complete the task was too long. Since the photo quality was substantially high, the processing time was extended within Photomodeler. The pixel resolution from the photos ensured the control points were accurately detected when auto-orientating within Photomodeler. If this quality was lessened the risk of systematic errors occurring would increase, therefore creating an inaccurate model.

Generally, the field work component for Photogrammetry was less complicated and time consuming with the risk of transcribing errors eliminated. If any feature was in need of clarification, there were multiple photos that provided evidence, reducing any risk of issues on the final plan. Despite the significant benefits of the field work, the office work was time consuming and provided no guarantee that all photogrammetric data was collected. As discussed previously, the computer’s RAM could not operate with the processing software which occasionally caused the program to quit unexpectedly.

Overall, the methodology to complete a strata plan using close range photogrammetric methods was successful. Models were able to be generated within Photomodeler which had primarily corresponding accuracies with the electronically computed measurements. A stratum plan was not able to be completed due to insufficient information along the vertical plane.

7. RECOMMENDATIONS

This section of the report will provide recommendations for the practical use of the findings of the thesis based on the results concluded. Recommendations for future research will be suggested for the continual development for the research of this project.

7.1 Recommendations for practical applications

As stated within previous studies within the literature review, the use of close range photogrammetry for practical applications is achievable. These results were replicated within the current studying, the accuracies, meeting the standards of a strata plan as set by NSW legislation and the LPI. Although this method has proved plausible, the processing time was too great which is impractical for practical application.

The use of a medium range DLSR camera provided usable photos with appropriate pixel resolution allowing an accurate model to be generated. It produced an acceptable set of results that allowed the capability to determine marks within the photogrammetric processing system.

As stated within the conclusion in section 6, certain aims and objectives were not met therefore requiring the need for the future application of using close range photogrammetry for the use of strata plans. This will be addressed and analysed within section 7.2 of the report.

7.2 Recommendations for future research

In order to continue the research and future development for the purpose of this project, recommendations will be discussed to produce a method that is suitable for practical applications. Below are recommendations that can be used to address the current issues within the thesis or use to address other areas within surveying.

- Processing Time:
    - It is recommended that other processing software be tested to determine whether quicker processing times can be established.
    - Further research should be conducted into improving the hardware capabilities of the computer used for the software processing.

- Site Selection
    - Since the testing in the paper was only completed in a specific site, further testing is required in a variety of other sites and situations.

- External Factors

  - External factors including weather conditions were controlled during the thesis, completing the strata plan in an area with no exposure to the weather allowing external factors to be kept constant.
  - A study testing whether external factors including: Sun Reflection/Glare, Lighting/Shadowing and obstructions has an effect on the quality or accuracy of the model needs to be tested.

- Stratum
  - During this project a stratum was not able to be generated due to vertical information.
  - The need for vertical overlap at each camera station to determine whether a stratum is possible will need to be researched
  - The need to merge multiple strata plans of various sections of a strata plan taken at different times would also need to be tested in the instance of a larger plan.

- Location of Control points
  - Control points were placed on the faces of the walls, columns and structures of the basement, used to help orientate the multiple photos within Photomodeler.
  - An assessment of whether equal or higher accuracy can be produced without the use of reflectorless stickers as control points will need to be researched. This will also minimise the time a surveyor will spend on site.

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Appendices

Appendix A: Project Specification

ENG4111/4112 Research Project
Project Specification

For:	Martin Wahbe
Title:	Qualitative Assessment of Close Range Photogrammetry for the use in measuring Strata/Stratums
Major:	Surveying
Supervisors:	Miss Jessica Smith
Enrolment:	ENG4111 – EXT S1, 2017 ENG4112 – EXT S2, 2017
Project Aim:	To determine whether close range photogrammetry can be used to measure strata/stratum with the same or greater accuracy as traditional methods of measuring strata/stratums.

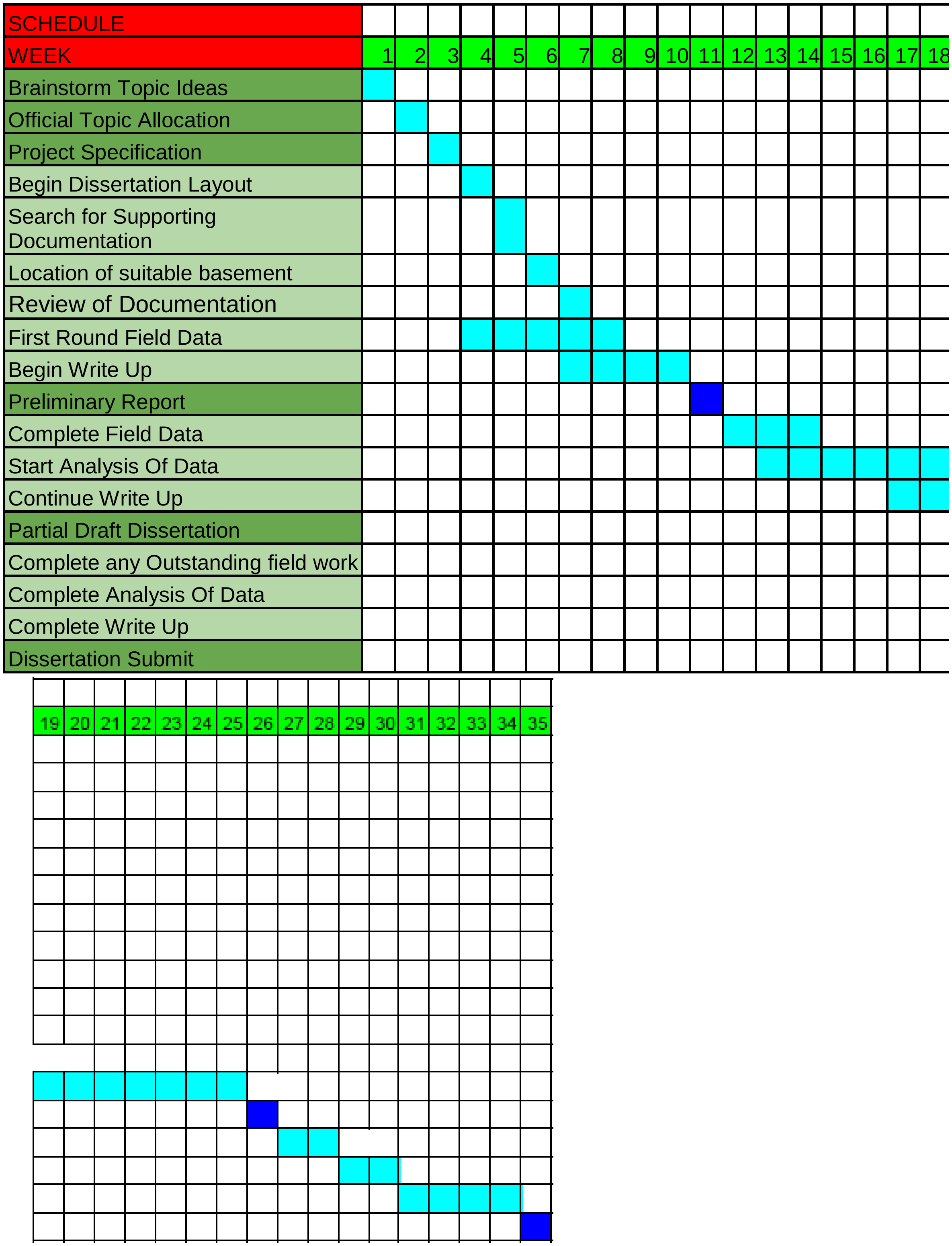
Programme:

1. Search for documentation relating to the topic
2. Plan the process and locate a suitable basement for measurement
3. Complete the strata measurement using the traditional method (Lieca D5 Disto)
4. Review field data and interpret the measurements into processing CAD software.
5. Complete CRP using single station with optimal overlap.
6. Complete CRP using single station with minimal overlap.
7. Analysis and comparison of Single station data.
8. Complete CRP using double stations with optimal overlap.
9. Complete CRP using double stations with minimal overlap.
10. Analysis and comparison of all data generating results
11. Evaluate reliability of photogrammetry in Close Range Photogrammetry.

If time and resources permit:

12. Complete strata of residential unit with internal walls and voids
13. The testing of different lightings

Appendix B: Project Schedule



Appendix C: Calibration Report from Photomodeler

Status Report Tree
Project Name: *** Project has not yet been saved ***
Last Processing Attempt: Wed Aug 16 17:07:11 2017
Version: PhotoModeler Scanner 2017.0.2.2137, evaluation (64-bit)
Status: successful
Processing Options
Orientation: on
All photos oriented.
Number of photos oriented: 25
Global Optimization: on
Calibration: on (full calibration)
Constraints: off
Total Error
Number of Processing Iterations: 4
Number of Processing Stages: 2
First Error: 43.469
Last Error: 4.513
Precisions / Standard Deviations
Camera Calibration Standard Deviations
Camera1: Canon EOS 600D [18.00]
Focal Length
Value: 18.613752 mm
Deviation: Focal: 0.002 mm
Xp - principal point x
Value: 11.421393 mm
Deviation: Xp: 0.003 mm
Yp - principal point y
Value: 7.937495 mm
Deviation: Yp: 0.004 mm
Fw - format width
Value: 22.669689 mm
Deviation: Fw: 0.001 mm
Fh - format height
Value: 15.113000 mm
K1 - radial distortion 1
Value: 5.278e-004
Deviation: K1: 2.3e-006
K2 - radial distortion 2
Value: -1.254e-006
Deviation: K2: 1.7e-008
K3 - radial distortion 3
Value: 0.000e+000
P1 - decentering distortion 1
Value: -8.038e-005
Deviation: P1: 2.5e-006
P2 - decentering distortion 2

Value: 9.984e-005
Deviation: P2: 2.5e-006

Quality
Photographs
Total Number: 25
Bad Photos: 0
Weak Photos: 0
OK Photos: 25
Number Oriented: 25
Number with inverse camera flags set: 0
Cameras
Camera1: Canon EOS 600D [18.00]
Calibration: yes
Number of photos using camera: 25
Average Photo Point Coverage: 77%
Photo Coverage
Referenced points outside of the camera's calibrated coverage region:
Point Marking Residuals
Overall RMS: 0.585 pixels
Maximum: 2.715 pixels
Point 46 on Photo 8
Minimum: 0.468 pixels
Point 57 on Photo 30
Maximum RMS: 1.655 pixels
Point 46
Minimum RMS: 0.243 pixels
Point 57
Point Precisions
Overall RMS Vector Length: 0.00011
Maximum Vector Length: 0.000117
Point 43
Minimum Vector Length: 0.000104
Point 29
Maximum X: 5.9e-005
Maximum Y: 7.55e-005
Maximum Z: 7.35e-005
Minimum X: 5.01e-005
Minimum Y: 6.14e-005
Minimum Z: 5.86e-005
Point Angles
Maximum: 90 degrees
Point 3
Minimum: 88.76 degrees
Point 72
Average: 89.71 degrees

Appendix D: Coordinates Exported from Photomodeler

Id	Photos (used)	X (project units)	Y (project units)	Z (project units)	Tightness (percent)	Tightness (project units)	Angle (deg.)	RMS Residual (pixels)	Largest Residual (pixels)
1006	39,40,41,87,88,89,148	1004.486	969.023	100.121	0.016	0.007	10.194	0.880	1.453
1007	64,65,66,67,68,69,88,89,90,91	995.858	969.503	100.071	0.014	0.006	3.781	0.858	1.737
1008	7,8,9,20,21,22,23,40,41,64,65,66,67,69,88,89,90,91	995.814	974.416	99.999	0.021	0.009	16.748	1.313	2.474
1009	68,69,70,90,91	992.404	974.787	100.038	0.003	0.001	9.793	1.458	3.221
1010	22,23,24,161,173	991.108	980.985	100.088	0.010	0.004	79.368	2.040	3.580
1011	120,123,143,173	995.415	981.217	100.084	0.004	0.002	35.312	0.334	0.587
1012	21,22,23,24,69,70,71,93,94,95,128,161,165,167	995.873	984.211	100.014	0.011	0.005	88.448	1.259	2.547
1013	23,24,71,72,123,124,125,161,162,165	991.157	987.688	100.189	0.019	0.009	82.775	1.300	2.208
1014	9,24,72,73,94,95,98,161,162,163,165,167,168	991.134	990.706	100.123	0.041	0.018	78.674	1.678	2.908
1015	72,73,98,99,100,123,124,125,128,143,144,167,168,173	995.334	991.473	100.142	0.034	0.015	31.470	1.991	3.588
1016	72,73,162	995.800	991.760	100.039	0.008	0.004	24.094	1.060	1.377
1018	12,50,51,72,73,159,162,163	991.261	997.746	99.968	0.016	0.007	47.488	0.899	1.630
1019	12,13,29,30,50,51,52	995.156	998.245	100.359	0.014	0.006	42.071	2.804	4.661
1020	12,13,29,30,50,51,52,73,77,79,80,98,99,100,103,123,124,125,128,143,144,159,162,163,167,168	996.571	998.350	100.293	0.037	0.017	61.049	1.765	3.145
1021	1,2,3,4,15,16,33,34,56,57,77,78,80,81,82,99,100,103,104,124,125,128,143,144,146,151,152,153,154,168	1005.069	1000.033	100.181	0.045	0.020	54.631	1.169	3.000
1023	2,3,4,16,17,33,34,35,153,154	1009.060	997.875	100.089	0.012	0.005	33.016	1.846	3.295
1024	5,6,18,19,34,35,36,56,57,58,77,78,81,82,150,151,152,154,155	1004.359	991.759	100.041	0.013	0.006	89.498	1.596	3.827
1025	5,6,18,19,35,36,37,57,58,59,81,82,83,150,151,154,155	1009.075	990.321	100.132	0.018	0.008	75.083	2.109	3.679
1026	56,57,58,80,81,82,103,104,128,144,146,147,150,151,152	1004.840	991.496	100.074	0.018	0.008	52.017	1.534	3.006
1027	59,60,61,145	1009.035	984.950	100.252	0.020	0.009	29.917	2.066	3.595
1028	6,7,60,61,62,155,156	1004.699	984.247	100.109	0.011	0.005	45.089	0.995	1.456
1029	6,7,60,61,62,148,149,150,155,156	1004.394	984.216	100.089	0.014	0.006	44.485	1.649	2.472
1030	37,38,39,60,61,83,84,145,147	1009.073	982.769	100.141	0.010	0.004	52.988	0.908	1.553
1031	20,21,38,39,40,41,62,63,64,65,87,145,148,149,156	1004.444	976.683	100.027	0.023	0.010	51.993	1.090	1.865
1032	87,145,148,149	1004.389	976.428	100.036	0.012	0.005	31.750	1.066	1.574
1034	61,62,63,87,145,148,149	1009.126	977.247	100.558	0.023	0.010	31.969	1.133	1.666
1035	7,8,9,21,22,23,24,41,67,68,69,70,92,93,94,161	995.357	981.540	100.046	0.026	0.011	54.291	2.812	4.378
2002	1,14,15,29,30,51,52,56,77,78,79,80,81,98,99,100,103,104,123,124,125,128,143,144,146,152,153,159,163,168,173	999.986	999.999	99.998	0.029	0.013	79.594	1.025	2.452

Appendix E: Leica Disto Specifications

Leica DISTO™ D510

The original laser distance meter

Precise targeting and reliable outdoor measurement!

The new Leica DISTO™ D510 stands for easy and effortless outdoor distance measurement. The unique combination of digital Pointfinder and 360° tilt sensor allows measurements which are not possible with conventional distance meters. In addition, with Bluetooth® Smart and attractive free apps, you are prepared for the future.

Featured with:

- Pointfinder with 4x zoom
- IP65 water jet protection and dust-tight
- 360° tilt sensor
- Smart Horizontal Mode™
- Height tracking
- Bluetooth® Smart
- Free App – Leica DISTO™ sketch

Available on the App Store

- when it has to be **right**

Leica Geosystems

Simple and precise targeting

With the Pointfinder with 4x zoom, the Leica DISTO™ D510 takes measurements with perfect accuracy and in unfavorable light conditions. This is a decisive advantage when working outside in sunny weather. Even if the red laser point is no longer visible, the target can be seen exactly on the display.

Tough and easy to clean

The housing and keypad are specially sealed against water and dust. Cleaning under running water is also no problem. Furthermore the laser distance meter can be used in all weather conditions, being dust-proof and water jet protected (IP65).

Unlimited measuring options

The Leica DISTO™ D510 is equipped with a 360° tilt sensor. This means that it is not only possible to measure angles, but horizontal distances too! Combined with the Pointfinder, amazing indirect measurement options are provided. Hence, measurements are possible where no reflective target point is available.

Bluetooth® Smart with app

Measurement data can be transferred using the Bluetooth® Smart Technology. The free app Leica DISTO™ sketch supports the creation of ground plans or tables on iPhone or iPad. Dimensions can even be entered onto photographs.

Available on the App Store

Leica DISTO™ D510

Art.No. 792290

- Leica DISTO™ D510 laser distance meter
- Holster
- Hand loop
- Batteries

Technical Data

Accuracy, typ.	± 1 mm
Range	0.05 – 200 m
Measuring units	m, ft, in
Tilt sensor	360°
Color display with Pointfinder	4x zoom
Data interface*	Bluetooth® Smart
Free App*	Leica DISTO™ sketch
Batteries	2 x AA
Dimensions	143 × 58 × 29 mm
Memory	30 Displays
Multifunctional end-piece	automatic recognition
Personalized Favorites	•

Functions

Distance measurement	Inclination tracking
Min/max measurement	Area/volume
Smart Horizontal Mode	Addition/subtraction
Height tracking	Pythagoras
Height profile	Stake-out
Sloped objects	Trapezium
Long Range Mode	Calculator

*) System requirements & details at www.disto.com

Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com

Laser class 2
in accordance with
IEC 60825-1

Register your device within 8 weeks of purchase at www.leica-geosystems.com/registration and extend your no cost period to 3 years.

Dealer Stamp

- when it has to be right

Appendix F: Canon EOS 600D Specifications

EOS 600D Specifications new

Product Specification

IMAGE SENSOR	
Type	22.3 x 14.9mm CMOS
Effective Pixels	Approx. 18.0 megapixels
Total Pixels	Approx 18.7 megapixels
Aspect Ratio	3:2
Low-Pass Filter	Built-in/Fixed
Sensor Cleaning	EOS integrated cleaning system
Colour Filter Type	Primary Colour

IMAGE PROCESSOR	
Type	DIGIC 4

LENS	
Lens Mount	EF/EF-S
Focal Length	Equivalent to 1.6x the focal length of the lens

FOCUSING	
Type	TTL-CT-SIR with a CMOS sensor
AF System/ Points	9 AF points (f/5.6 cross type at centre, extra sensitivity at f/2.8)
AF Working Range	EV -0.5 -18 (at 23°C & ISO100)
AF Modes	AI Focus One Shot AI Servo
AF Point Selection	Automatic selection, Manual selection
Selected AF Point Display	Superimposed in viewfinder and indicated on LCD monitor
Predictive AF	Yes up to 8m[1]
AF Lock	Locked when shutter button is pressed half way in One Shot AF mode
AF Assist Beam	Intermittent firing of built-in flash or emitted by optional dedicated Speedlite
Manual Focus	Selected on lens, default in Live View Mode
AF Microadjustment	No

EXPOSURE CONTROL	
Metering Modes	TTL full aperture metering with 63-zone SPC (1) Evaluative metering (linked to all AF points) (2) Partial metering at center (approx. 9% of viewfinder) (3) Spot metering (approx. 4% of viewfinder at center) (4) Center weighted average metering
Metering Range	EV 1-20 (at 23°C with 50mm f/1.4 lens ISO100)
AE Lock	Auto: In 1-shot AF mode with evaluative metering exposure is locked when focus is achieved. Manual: By AE lock button in creative zone modes
Exposure Compensation	+/-5 EV in 1/3 or 1/2 stop increments (can be combined with AEB)
AEB	3 shots +/- 2 EV, 1/2 or 1/3-stop increments
ISO Sensitivity*	AUTO (100-6400), 100-6400 Expandable to H (approx 12800) in 1-stop increments

SHUTTER	
Type	Electronically-controlled focal-plane shutter
Speed	30-1/4000 sec (1/2 or 1/3 stop increments), Bulb (Total shutter speed range. Available range varies by shooting mode)

WHITE BALANCE	
Type	Auto white balance with the imaging sensor
Settings	AWB, Daylight, Shade, Cloudy, Tungsten, White Fluorescent light, Flash, Custom. White balance compensation: 1. Blue/Amber +/-9 2. Magenta/Green +/-9
Custom White Balance	Yes, 1 setting can be registered
WB Bracketing	+/-3 levels in single level increments 3 bracketed images per shutter release. Selectable Blue/Amber bias or Magenta/ Green bias

VIEWFINDER	
Type	Pentamirror
Coverage (Vertical/Horizontal)	Approx. 95%
Magnification	Approx. 0.85x[1]
Eyepoint	Approx. 19mm (from eyepiece lens centre)
Dioptre Correction	-3 to +1 m-1 (dioptre)
Focusing Screen	Fixed
Mirror	Quick-return half mirror (Transmission: reflection ratio of 40:60, no mirror cut-off with EF600mm f/4 or shorter)
Viewfinder Information	AF information: AF points, focus confirmation light Exposure information: Shutter speed, aperture value, ISO speed (always displayed), AE lock, exposure level/compensation, spot metering circle, exposure warning, AEB Flash information: Flash ready, high-speed sync, FE lock, flash exposure compensation, red-eye reduction light Image information: Highlight tone priority (D+), monochrome shooting, maximum burst (1 digit display), White balance correction, SD card information
Depth of Field Preview	Yes, with Depth of Field preview button
Eyepiece Shutter	On strap

LCD MONITOR	
Type	Vari angle 7.7cm (3.0") 3:2 Clear View TFT, approx. 1040K dots
Coverage	Approx. 100%
Viewing Angle (Horizontally/Vertically)	Approx 170°
Coating	Dual Anti-reflection, anti smudge
Brightness Adjustment	Adjustable to one of seven levels
Display Options	(1) Quick Control Screen (2) Camera settings

FLASH	
Built-in Flash GN (ISO 100, meters)	13
Built-in Flash Coverage	Up to 17mm focal length (35mm equivalent: 27mm)
Built-in Flash Recycle Time	Approx. 3 seconds
Modes	Auto, Manual flash, Integrated Speedlite Transmitter
Red-Eye Reduction	Yes - with red eye reduction lamp
X-Sync	1/200sec
Flash Exposure Compensation	+/- 2EV in 1/2 or 1/3 increments
Flash Exposure Bracketing	Yes, with compatible External Flash
Flash Exposure Lock	Yes
Second Curtain	Yes

Synchronisation	
HotShoe/ PC Terminal	Yes/ -
External Flash Compatibility	E-TTL II with EX series Speedlites, wireless multi-flash support
External Flash Control	Via camera menu screen

SHOOTING

Modes	Scene Intelligent Auto, No Flash, Creative Auto, Portrait, Landscape, Close-up, Sports, Night Portrait, Movie, Program AE , Shutter priority AE, Aperture priority AE, Manual
Picture Styles	Auto, Standard, Portrait, Landscape, Neutral, Faithful, Monochrome, User Defined (x3)
Colour Space	sRGB and Adobe RGB
Image Processing	Highlight Tone Priority Auto Lighting Optimizer (4 settings) Long exposure noise reduction High ISO speed noise reduction (4 settings) Auto Correction of Lens Peripheral illumination Basic+ (Shoot by ambience selection, Shoot by lighting or scene type) Creative filters (Grainy B/W, Soft focus, Toy camera, Miniature effect, Fish-eye) - during image Playback only
Drive Modes	Single, Continuous, Self timer (2s, 10s+remote, 10s + continuous shots 2-10)
Continuous Shooting	Max. Approx. 3.7fps for approx. 34 JPEG images[1], 6 images RAW[2]

LIVE VIEW MODE

Type	Electronic viewfinder with image sensor
Coverage	Approx. 99% (horizontally and vertically)
Frame Rate	30 fps
Focusing	Manual Focus (Magnify the image 5x or 10x at any point on screen) Autofocus: Quick mode, Live mode
Metering	Real-time evaluative metering with image sensor Active metering time can be changed
Display Options	Grid overlay, Histogram

FILE TYPE

Still Image Type	JPEG: Fine, Normal (Exif 2.30 compliant) / Design rule for Camera File system (2.0), RAW: RAW (14bit, Canon original RAW 2nd edition), Digital Print Order Format [DPOF] Version 1.1 compliant
RAW+JPEG Simultaneous Recording	Yes, RAW + Large JPEG
Image Size	JPEG 3:2: (L) 5184x3456, (M) 3456x2304, (S1) 2592x1728, (S2) 1920x1280, (S3) 720x480 JPEG 4:3: (L) 4608x3456, (M) 3072x2304, (S1) 2304x1728, (S2) 1696x1280, (S3) 640x480 JPEG 16:9: (L) 5184x2912, (M) 3456x1944, (S1) 2592x1456 (S2) 1920x1080, (S3) 720x400 JPEG 1:1: (L) 3456x3456, (M) 2304x2304, (S1) 1728x1728, (S2) 1280x1280, (S3) 480x480 RAW: (RAW) 5184x3456
Movie Type	MOV (Video: H.264, Sound: Linear PCM)
Movie Size	1920 x 1080 (29.97, 25, 23.976 fps) 1280 x 720 (59.94, 50 fps) 640 x 480 (59.94, 50 fps)
Movie Length	Max duration 29min 59sec, Max file size 4GB
Folders	New folders can be manually created and selected
File Numbering	(1) Consecutive numbering (2) Auto reset (3) Manual reset

OTHER FEATURES

Custom Functions	11 Custom Functions with 34 settings
Metadata Tag	User copyright information (can be set in camera) Image rating (0-5 stars)
Intelligent Orientation Sensor	Yes
Playback Zoom	1.5x - 10x enabled in 15steps
Display Formats	(1) Single image with information (2 levels) (2) Single image (3) 4 image index (4) 9 image index (5) Jump Display
Slide Show	Image selection: All images, by Date, by Folder, Movies, Stills Playback time: 1/2/3/5 seconds Repeat: On/Off
Histogram	Brightness: Yes RGB: Yes
Highlight Alert	Yes
Image Erase/Protection	Erase: Single image, All images in folder, Checkmarked images, unprotected images Protection: Erase protection of one image at a time
Menu Categories	(1) Shooting menu (x4) (2) Playback menu (x2) (3) Setup menu (x3) (4) My Menu
Menu Languages	25 Languages English, German, French, Dutch, Danish, Portuguese, Finnish, Italian, Norwegian, Swedish, Spanish, Greek, Russian, Polish, Czech, Hungarian, Romanian, Ukrainian, Turkish, Arabic, Thai, Simplified Chinese, Traditional Chinese, Korean and Japanese
Firmware Update	Update possible by the user

INTERFACE

Computer	Hi-Speed USB
Other	Video output (PAL/ NTSC) (integrated with USB terminal), HDMI mini output (HDMI-CEC compatible), External microphone (3.5mm Stereo mini jack)

DIRECT PRINT

Canon Printers	Canon Compact Photo Printers and PIXMA Printers supporting PictBridge
PictBridge	Yes

STORAGE

Type	SD card, SDHC card or SDXC card

SUPPORTED OPERATING SYSTEM

PC & Macintosh	Windows XP inc SP3 / Vista inc SP1 and SP2 (excl. Starter Edition) / 7 (excl. Starter Edition) OS X v10.4-10.6

SOFTWARE

Browsing & Printing	ZoomBrowser EX / ImageBrowser
Image Processing	Digital Photo Professional
Other	PhotoStitch, EOS Utility (inc. Remote Capture), Picture Style Editor

POWER SOURCE

Batteries	1 x Rechargeable Li-ion Battery LP-E8
Battery Life	Approx. 440 (at 23°C, AE 50%, FE 50%)[4] Approx. 400 (at 0°C, AE 50%, FE 50%)
Battery Indicator	4 levels
Power Saving	Power turns off after 30sec or 1, 2, 4, 8 or 15mins.
Power Supply & Battery Chargers	AC Adapter Kit ACK-E8, Battery charger LC-E8, LC-E8E
PHYSICAL SPECIFICATIONS	
Body Materials	Stainless Steel and polycarbonate resin with conductive fiber
Operating Environment	0 – 40 °C, 85% or less humidity
Dimensions (WxHxD)	133.1 x 99.5 x 79.7 mm
Weight (Body Only)	Approx. 570g (CIPA testing standard, including battery and memory card)
ACCESSORIES	
Viewfinder	Eyecup Ef, E-series Dioptric Adjustment Lens with Rubber Frame Ef, Eyepiece Extender EP-EX15II, Angle Finder C
Case	Semi-Hard Case EH19-L
Wireless File Transmitter	Compatible with Eye-Fi cards
Lenses	All EF and EF-S lenses
Flash	Canon Speedlites (220EX, 270EX, 270EX II, 320EX, 420EX, 430EX, 430EX II, 550EX, 580EX, 580EX II, Macro-Ring-Lite, MR-14EX, Macro Twin Lite MT-24EX, Speedlite Transmitter ST-E2)
Battery Grip	BG-E8
Remote Controller/ Switch	Remote Switch RS-60E3, Remote Controller RC-6
Other	Hand Strap E2
Predictive AF	[1] with EF300mm f/2.8L IS USM at 50kph
Magnification	[2] with 50mm lens at infinity, -1m-1 dpt
Continuous Shooting	[3] Large/Fine(Quality 8) resolution [3] Based on Canon's testing conditions, JPEG, ISO 100, Standard Picture Style. Varies depending on the subject, memory card brand and capacity, image recording quality, ISO speed, drive mode, Picture Style, Custom functions etc.
Battery Life	[4] Based on the CIPA Standard and using the batteries and memory card format supplied with the camera, except where indicated

*Recommended Exposure Index
All data is based on Canon standard testing methods except where indicated.
Subject to change without notice.