DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Investigating the capacity of dense point cloud photogrammetry to map low rise buildings

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Keywords: Terrestial photogrammetry, Laser Scanning, Dense Point Cloud,

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Abstract

The aim of this project was to produce three dimensional dense point cloud data of a low rise building. To achieve this objective, an entry level Canon SLR digital camera was used together with a reasonably priced photogrammetry software package – PhotoScan.

The Royal Tasmanian Botanical Gardens Conservatory building was selected to test the capabilities and the limitations of close range photogrammetry. The rugged stone walls and white-painted glass roof as well as the various retaining walls in close proximity, garden beds and upright vegetation set a series of challenges during image capturing. Several dense point cloud models were produced with high spatial resolution. The dense point clouds not only produced visually pleasing images on the screen but the georeferenced points constitute accurate fully three dimensional virtual models of the building and the surrounding area. A dense point cloud contains several millions of points. Each point possesses Easting/Northing and AHD values, several additional attributes and RGB spectral information. The dense point cloud data were stored in the ASPRS LAS format or the highly compressed LAZ binary file format. The LAS file format can be directly read by a wide range of professional and scientific software, therefore many existing methods and tools are available to further process the dense point cloud data.

Although this project revolves around the use of digital imagery and PhotoScan photogrammetry software, the Leica Nova MS50 MultiStation was also employed to scan and map the area. MS50 also uses close range photogrammetry in order to assign spectral attributes to the scanned points. The dense point cloud data produced by the laser scanner which proved to be very similar in appearance, was also saved in LAS file format and post processed using the same methods as the point clouds produced using the camera.

This project used the basic features of the LAStools and LISCAD software to post process the data of dense point cloud into a familiar format suitable for presentation to building industry professionals.

The results of the project proved that it is feasible to map and post process dense point cloud data of man-made structures with the use of common digital camera imagery and readily available photogrammetry software.

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Acknowledgements

I would like to take this opportunity to thank everyone who has provided assistance throughout the course if this project.

Supervisors

Dr Jon Osborn	UTAS
Dr Christopher Watson	UTAS

Technical Assistance and constructive comment

Robert Walch	Walch Optic
Jerry Romanski	RTBG
Trevor Parry	UTAS
Eric Daley	UTAS
Ken Webster	UTAS

DOI: 10.4226/77/5b05f9ef54154
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1 Introduction

Photogrammetry as a term was invented and first used in the mid-19th century for surveying various buildings, man-made objects or terrain. The imagery proved to be a valuable instrument in the hands of spatial science professionals ever since (Grimm 2007) .

Architects, civil engineers and other professionals need detailed information of existing terrain and buildings to support the design procedure. Every feature, even a tree or a rock can influence the whole project. A meticulous three dimensional mapping of the area of interest enables more accurate decision making for all stakeholders. Surveyors are the first on every building site; their work is an integral part of the building industry. Moreover there is a growing demand to document the existing or “as built” stage of buildings and their surroundings. Property managers, real estate agencies, financing institutions, insurance companies, city councils, fire departments etc. often require detailed reliable spatial data sets, which can be stored, analysed or distributed digitally. To create a 3D map, usually a great number of points are measured and documented. The latest developments in photogrammetric methods allow transforming semi-automated recordings of high resolution spatial data into a “cloud” of fully three dimensional data points.

The result of a field survey is usually a collection of data with various attributes and their spatial distribution. The collected data determines the 3D positions of points; the x y z values. The more complicated the subject of the measurement is, the more points are selected and measured. Employing photogrammetry or laser scanning technology when it’s needed, the spatial resolution of the point data can be extremely high. The full 3D data produced by these technologies usually is called as point cloud or dense point cloud

Close range photogrammetry and image based processing software can deliver 3D data points with high precision and point density. The product, the dense point cloud data can also be considered as the 3D representation of the terrain and the objects on it. This model can be used as a virtual reality model of the area of interest which represents the original terrain and objects at that epoch. It can be visualised and used as an orthophoto, or 3D perspective, without a need for further processing of the data. Various data can be obtained from the model as requested.

This project is an attempt to find out how point cloud data, mapped by these tools, can be further processed using an interactive workflow to produce data suitable for engineers. Ever since computer networks have been widely used, various computer generated drawing files

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and digital photographs are storing or archiving the spatial data. These documents are usually stored as annotated vector data, in form of maps, plans, sections or in 2.5D raster data, such as a DSM/DEM or an orthophoto. With the recent development of the digital technology, mapping in full 3D has become a realistic option. The common use of networked computers, digital maps, on line land-information services, satellite navigation, the Google Earth and Street View not only has generated more demand for a three dimensional representation, but also built an awareness and a certain level of skills amongst the general public while using these kinds of complex digital features.

The project seeks to investigate the use of dense point cloud photogrammetry and a hand held camera as convenient and capable tools for "*safe and efficient survey*" a description used by a German architect and civil engineer in 1867 (Grimm 2007). The assumption is that the knowledge of a spatial science undergraduate student and some commonly available equipment will allow not only the production of a dense point cloud map of the building, but will also enable the extraction of easy to use information for a potential client who is not too familiar with handling millions of point data in one file.

2 Aims and Objectives

Project Topic

An investigation of the capacity of dense point cloud photogrammetry to map a low rise building for architectural purposes.

The objectives of this project include

i. to create a dense point cloud map of a low rise building using a hand held non metric digital camera and PhotoScan photogrammetry software
ii. to investigate and make some statements about the dense point cloud photogrammetric methods to map low rise buildings
iii. to develop operational workflows to extract useful data for the building industry from point clouds.

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3 Literature review

To obtain detailed information of the surrounding environment or mapping the world in great detail seems to be an everlasting interest of mankind. Visual experience is a very effective and easy to understand "common language" for all of us. To know, to see, to discover the earth from a distance versus from close range seems to merge into one. Image based applications, such as Google Earth in conjunction with Street View not only map the globe, but let us discover the world visually from a perspective of a human. This project attempts to apply a sophisticated image based application, PhotoScan, to survey a man-made object, a low rise building in full 3D.

3.1 Mapping from photographs

The 3 dimensional imagery is almost as old as photography; stereo daguerreotypes were already an attraction at the World's Fair in London in 1851 (French 2014). Three dimensional visualisation attracts the entertainment and gaming industry, the scientific community and the military ever since. In the 20th century photogrammetry has become a mature science and widely used in various fields. The development of the computer technology, computer vision industry and the extensive use of sophisticated mathematical methods, such as

- Direct Linear Transformations (Abdel-Aziz & Karara 1974) (Dermanis 1994)
- Bundle Adjustment (Triggs et al. 1999)
- Structure from Motion (Mathews & Jensen 2013)

has created a suitable environment for new photogrammetry software solutions which try to integrate the results of these developments.

With the rapid development of digital cameras and image processing technologies the 3D capabilities of close range photogrammetry were rediscovered. Archaeology was one of the fields where the full 3D capability of Remote Sensing recently prompted a series of site measurements in order to obtain fully 3D data (Barsanti et al 2011). The methods and the results of mapping of the Archaeological sites are scientifically documented and published. These publications are mostly freely available. Recording archaeological sites in 3D or mapping existing buildings are, in many respects, very similar tasks and require comparable methods and equipment. This project therefore intentionally focuses on the related articles of the archaeological community.

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Close range photogrammetry in combination with a low cost software capable of producing three dimensional data from digital images is a very much needed tool for archaeology (Verhoeven 2011). The use of a software such as PhotoScan (Agisoft-LLC 2014a) which integrates the latest improvements of photogrammetry was immediately embraced and extensively used to map archaeological sites in Western Europe (Verhoeven et al. 2012a). In Trea, Italy, six years of previous low-flying aerial surveys of the archaeological monuments were mapped with the use of PhotoScan software. The result was presented in Digital Surface Model (DSM) and as georeferenced orthophoto (Verhoeven et al. 2012b). At this stage PhotoScan did not allow to extract the data into dense point cloud, a three-dimensional mesh-model was produced using the calculated sparse point cloud data.

Various excavations were recorded and documented in Belgium using close range photogrammetry with PhotoScan software (De Reu et al. 2013). At first a Control Survey network was established at each excavation site in order to record and georeference Ground Control Points (GCP) and reference distances. The images were taken with 10 and 12 Mp consumer grade digital cameras mounted on tripods. The article describes and compares in great detail the methods of the mapping procedure, including tables of comparison of estimated and real X,Y,Z coordinates, with error and RMSE values. The article reinforces the importance of the georeferenced GCPs and the extensive reference list proved a useful source for further on-line research of the relevant literature.

A Canon digital camera was attached to a horizontally movable frame in the ‘x’ direction, and to a movable roof rail in the ‘y’ direction; imitating aerial photography ‘flight paths’ with known geometry and references. The large number of images were processed by PhotoScan with the help of 22 coded targets (Agisoft-LLC 2014b). Image based mapping and laser scanning often are used to complement each other. It is important therefore to compare Laser scanning with automated image based approach of PhotoScan (Fassi et al. 2013). The attached tables are also comparing the different digital cameras according to their usefulness for this type of close range photogrammetry projects. The summary tables contain rarely described details such as ; ‘*Number of used Images’, ‘Resolution’, ‘Object Dimensions’, ‘Number of Points-generated’, ‘Time of Acquisition* ‘.

A high resolution Canon camera, professional RTK-GNSS equipment, Wi-Fi communication system and a ‘blondin aerial ropeway’ were employed to survey a mine site. The ropeway works as a controlled flight-path for close range aerial photography (Cuesta, Lopez-Rodriguez & Esteban 2013).

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Also a high resolution Canon camera was used in conjunction with Laser scanning to map an archaeological site in Spain. The article emphasises the benefits of the combination of Laser scanning with close range photogrammetry. Also, the article recommends the use of the 'public' LAS file format as a suitable alternative for data storage (Lerma et al. 2010).

3.2 Architectural photogrammetry

Following the results of 3D mapping of the archaeological sites, close range photogrammetry methods were used to map significant buildings. Survey grade GCPs, Canon SLR 1100D and the Photomodeler software were employed to achieve 3D photorealistic models of university buildings (Rasam et al. 2013).

An off shelf digital camera was used as a tool to record buildings of historical significance (Cardenal et al. 2004). The year 2000 model of Canon EOS D30 SLR camera was equipped with a 3.1 Mp CMOS sensor. The detailed evaluation of the camera demonstrated that the resolution of the camera sensor strongly influences the accuracy of the results of the 3D mapping.

Canon digital cameras and close range photogrammetry were used to record a very complex building, a Cathedral in Spain with restricted accessibility. The cameras were mounted on various tripods, tall monopods, masts, scaffoldings and cranes in order to be able to capture the scene. Targets or target-markings were surveyed with Total Station. Similar to the PhotoScan solution, the area was divided into 'sub-projects'; the several thousand images were grouped into 45 groups. Dense point cloud was created and transformed into polygonal 3D surface with the use of Photomodeler scanner v.6.3.3. software (Martínez et al. 2013).

Total stations, Laser scanning and photogrammetry were used simultaneously in order to create a " *3D virtual image of the object*" (Fassi, Achille & Fregonese 2011) of the Cathedral of Milan. The article emphasised the importance of surveyor grade control points and the use of the targets. The whole building was divided into "*macro-areas*", which were surveyed separately. The data could be merged using the georeferencing. The dense point cloud data was used for visualisation directly as opposed to most of the other cases, when the point cloud was used to create a surface first and the texture was attached later. According to the article the Pointools View software was successfully used to navigate through the building when 1.6 billion points were displayed. As a final procedure 2D views (drawings) and

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sections were extracted from the 3D model. There was no description of the method used for this procedure, instead a whole paragraph was written about the unavoidable "*architectonical 2D thinking*" of the participants from the building industry. (See also: 6 Communication with Building Industry Professionals)

A Canon SLR with a 25-75 mm zoom lens and close range photogrammetry were used to create the 3D model of a castle in India. (Samad et al. 2012). The description of the method used is similar to the methods, which were used at the archaeological sites. Survey grade control network, close range photogrammetry off shelf SLR camera and professional photogrammetry software were employed, 3D model and finally 2D drawings were produced.

A small district, about a 10 ha urban area was mapped using Laser scanner and close range photogrammetry in Istanbul (Ergun et al. 2010). An extensive ground control network was established using DGPS for georeferencing purposes. Aerial photogrammetry was used to create DEM, which was wrapped with orthophoto to give a texture for visualisation. The dense point cloud data of the street façade was turned from point cloud into solid model. Solid modelling is used by manufacturing industry since the early stage of virtual 3D modelling to drive CAD-CAM milling machines.

3.3 Software / Data file formats / Data Storage

3.3.1 Software

PhotoScan

The Agisoft PhotoScan v.1.0.4 is an advanced professional photogrammetry software for producing 3D modelling solutions. The software is capable of extracting results from aerial photographs and equally proficient in processing images of close range photogrammetry (Agisoft-LLC 2014c). The final product, the goal, according the PhotoScan user manual is a textured 3D model. The ability to export a dense point cloud data, the interest of this project, is just a stage or a by-product, in order to produce a textured 3D model. PhotoScan requires a series of overlapping digital images as an input. The workflow of the image processing is (Agisoft-LLC 2013a). :

- Align photos — Sparse point cloud and camera calibration data created
- Optimisation — Camera calibration , target point settings applied
- Build Dense Point Cloud — Dense point cloud data created
- Build Mesh
- Build Texture

Individual results of each step of the workflow can be saved as separate results or data. Although this project focuses on the dense point cloud data it is beneficial to be familiar with all stages of the procedure (Agisoft-LLC 2013b) (Agisoft-LLC 2014d) (Agisoft-LLC 2014c) (Agisoft-LLC 2014e). The dense point cloud can be exported as ASPRS LAS file, XYZ text file, Wavefront OBJ or Stanford PLY.

LAStools / LASzip / pointzip

As a result of the fast development of LiDAR technology several millions of points were stored in a single ASCII file, which was impractical to use. ASPRS proposed to store the data in a binary format, which was named as the LAS data format. In order to view, edit, filter, clip, convert or compress LAS files (Isenburg 2014a) the LAStools software package have been created and published on-line by Martin Isenburg (Isenburg 2013a). Each tool has a user interface (GUI) which directly reads and writes, LAS , Terrasolid-BIN, ASCII, ESRI Shape files and the compressed LAZ (Isenburg 2014b). The toolsets are directly linked to ArcGIS (Isenburg 2013b) and QGIS (Isenburg 2013c). The tools can be scripted or automated using a simple batch file (Isenburg 2012). The LASzip software and the toolset described in "*Editing LAS or LAZ files 'by hand' with lasview*" tutorial (Isenburg 2014c) can be considered as the most useful instruments for this project.

Pointzip software converts the LAZ file format into 'points' (PTS) file format or vice versa PTS files into compressed LAZ file (Isenburg 2014d).

LISCAD SEE

LISCAD SEE v.11 is a land-surveying software package which can import and handle Point cloud datasets among other functions. This software is used to further post process dense point cloud data (LISTECH 2014) and enable to export the results into DWG, DXF, LandXML or EASRI Shape file formats.

3.3.2 Image file formats

During a close range photography survey a great number, hundreds or even thousands of overlapping images are acquired. The RAW images are stored separately, as a security backup and as a "RAW" data for forthcoming applications (Coupe 2014). Although these images are not used directly in the procedure, the data can be a valuable source of information in the future; consequently it is customary to allocate resources to preserve the data in this form. The collected images should be converted into TIFF-8-bit or TIFF-16bit format before processing in PhotoScan Software. Each camera manufacturer, as well as Canon, prefers its own proprietary RAW image format and image converter software (Canon 2014a).

3.3.3 File formats

LAS

The ASPRS LAS file format was developed to store and exchange LiDAR data between the various proprietary systems used by companies (ASPRS 2014). The LAS is a binary file format. LAS file format has several advantages, like its file size or speed over the other ASCII type file formats intending to store LiDAR data. In addition the LAS file format can maintain and manipulate specific information, for example RGB values, classification, GPS data and projection. The ASPRS LAS 1.4 format allows to further customise the LAS format dataset; enable to add new point classes with attributes. Derived water surface, riverbed and submerged topography classes were successfully embedded into the LAS 1.4 file recently (ASPRS-Activities 2013) as an experiment. It is assumed that in the near future additional classes, such as Depth-'D' (Henry et al. 2012) (Litomisky 2012) , NIR, Thermal IR, or even attributes of building material ; brick, concrete , stone can be added and stored using the LAS file format.

LAZ

The free LASzip software is a loss-less compressor saving the data from LAS into a very compact LAZ file format (Isenburg 2014a). The LAStools can process the compressed LAZ file format "on the fly", without the need of decompressing the file before use or compressing the file after use. This practical feature of LAStools and LAZ file does not require above average hardware resources to process dense point cloud files. Isenburg in a web forum[1] suggests to split the big LAZ file into "manageable tiles", the file size of which should be below the 2G limit or less than 4 billion points per file. In this project there is no LAS or LAZ file containing over 100 million points or exceeding 50 Mb in size.

PTS

The 'points' (PTS) file format is used for importing dense point cloud datasets by LISCAD.v.11 (LISTECH 2014). It is also used by the Leica- Cyclone 3D point cloud processing software for laser scanning applications (LEICA-Geosystems 2014). Dense point cloud data can be easily transferred from LAZ to PTS and from PTS to LAZ using the Point zip software (Isenburg 2014d). The seamless data transfer between PhotoScan, LASTOOLS and LISCAD via PTS file format is an important feature of this project. A PTS file which contains less than 10 million points can be 500Mb in file size. The point cloud size limit of LISCAD was not tested in this project, but significant time was required to open a PTS file containing 7 million points.

PDF

The PDF file format, since Adobe Acrobat reader v.8 can handle three dimensional objects. (ADOBE 2014) . PhotoScan can directly export dense point cloud models into PDF file format. A dense point cloud over 10 million points however can create an "e-mail unfriendly" PDF file size (over 25 Mb).

LandXML

The LandXML file format was designed an predominantly used for exchanging intermediate or final products or data which were already processed (ICSM 2014). Although LISCAD is capable to export data into LandXML, this project has no intention to explore this option.

BIMx

The BIMx file format was designed for 3D data exchange between different architectural, engineering (Gleason 2013) and other software platforms via internet. The BIMx file format (Khemlani 2014) is also capable of presenting interactive 3D models on mobile devices with small screens for non-professional audience.

[1] https://groups.google.com/forum/#!topic/lastools/ob2l_rOIlrw

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3.4 Summary

The literature review demonstrated that the latest technological advances can be applied successfully in projects with limited resources. Also it seems that the various remote sensing and mapping methods such as laser scanning and photogrammetry are routinely used together and can seamlessly complement each other. When high resolution 3D data collection is required the articles above advocated the extensive employment of

- georeferenced GCPs
- widespread use of targets or coded targets with known positions
- off-the-shelf high resolution Canon digital SLR camera / RAW image format
- telescopic (monopod) support
- PhotoScan software solution
- LAS/LAZ file format for data storage
- Laser scanning as a secondary or control measurement

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4 Methodology

4.1 Planning and Preparation

4.1.1 Study Site

The Royal Tasmanian Botanical Gardens is the second oldest gardens in Australia. It comprises 16 hectares of parkland with large trees, numerous feature gardens, plant and herb collections and buildings. The Conservatory (Figure 1) is a permanent indoor display for a rich selection of flowering plants. The building has ~450 square metres footprint, rectangular shape and pitched roof. It has sandstone walls salvaged from the demolished section of the Hobart General Hospital (Tasmania-attractions.com 2014). The roof structure contains timber and steel trusses. The building is surrounded with garden beds and retaining walls with various heights.

The Conservatory can be considered as a fully functional, well maintained building with cultural and heritage significance. The size of the building, the various geometric features, and the stately surface of the rugged stone wall may require a survey with full 3D with RGB capabilities. The moderate but constantly present obstacles and occlusions, such as the height of the building, the closely located retaining walls, the various plants and the constant flow of visitors may give a useful feedback about the close range photogrammetry survey methods. This study presents an opportunity to create an up-to-date digital record of the building while it is in prime condition.

Figure 1 Royal Tasmanian Botanical Gardens - Conservatory

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4.1.2 Reconnaissance and Control Survey

The following steps were planned and executed:

- On-line Reconnaissance survey (10.1 Figure 19)

  The available data from *Google Earth* and *TheLIST* web sites was used for planning the Reconnaissance Survey (http://maps.thelist.tas.gov.au/listmap/app/list/map).

- Site Reconnaissance survey (10.1 Figure 20)
  - Two local Survey Control Marks were identified ; SPM 8964 and HCC 1167
  - Several existing steel spikes implanted into the concrete kerb of the walkway were located
- Establishing a baseline
  - A base station over HCC1167 and a rover (Topcon GNSS RTK-GPS/GLONASS) was used to locate the position of the two closest steel spikes; named as PM-1 and PM2
  - A baseline of the local control survey network was established

    The PM-1 steel spike was nominated as a temporary benchmark (TBM). The distance and the height difference between PM-1 and PM-2 were re-surveyed using Leica TS06 total station with laser plummet and a prism with optical plummet. The bearing of the baseline was adopted from the GPS survey. The baseline with stable permanent marks can be used for a swift reconstruction of the local control survey network points if required
- Establishing local control survey network (10.1 Figure 21)
  - Beside PM-1 and PM-2, two control points (CPs); Station-3 and Station-4, were established and marked with nails between concrete paving tiles around the building using closed loop traverse with Leica TS06 total station and two prisms on tripods. The results were adjusted with LISCAD least squares control file editor
  - When further CPs were needed, the four local control points were used as backsight for the total station

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4.2 Data Acquisition with Terrestrial Laser Scanner

The courtesy of Walch Optics allowed us to try the Leica NOVA MS50 MultiStation (MS50) to conduct several scans of the Conservatory building. Robert Walch was not only kind enough to give his unconditional support but his expertise also gave the confidence much needed at the very first steps of this project.

Portable terrestrial laser scanners provide reliable 3D data almost instantaneously. Most of the laser scanners however have to be used in conjunction with a total station or GPS in order to establish the precise location of the scanner and with a camera in order to be able to register the RGB values of the measured points. Leica combined these functions into a new class of a surveying instrument; the MultiStation.

The MS50 MultiStation combines several surveying hardware (LEICA-Geosystems 2013)

- High precision Total Station (EDM,)
  - Measurements using prism on tripod (optical plummet);
range from 1.5 m to 10 km
  - Reflector-less measurements onto any surface;
range from 1.5m to 2km
- Digital Imaging
  - Wide angle ‘overview’ camera; 8x zoom, 5 Mp CMOS / 19.4 ° field of view
  - ‘Telescope’ camera; 30x zoom, 5 Mp CMOS sensor / 1.5 ° field of view
- Terrestrial laser scanner
  - 1000 Hz mode; range max. 300m , signal-to-noise ratio (STN) 1mm@50m
  - The on-board computer automatically synchronises the imagery with scans and measurements. The point cloud data is georeferenced and the relevant RGB values are registered to every point.
- Optional GPS extension (not used in this project)

The almost automatic combination of laser scanning with close range photogrammetry has become a reality.

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4.2.1 Instrument settings

It is essential to obtain a very precise position for a laser scanner. Therefore when the position of the scanner is determined a clear line of sight for any two of the CPs of the control survey network is needed. The following procedure was executed:

- Determine the location of the scanner: *Resection*
  - The *Resection* procedure uses the total station function of the instrument and the two prisms on tripods above known CPs. The position of the scanner is automatically registered and the positions of the CPs are stored in the on board memory of the device.
- Determine the scanning density
  - The closest and the furthermost distances of the object were measured and the average distance was determined.
  - 10x10 mm dot grid was applied at the average distance of 10 or 15 m
  - The scanning speed was set to maximum, which is max 1000 measurements per second, using wave form digitising (7.2.1) and visible red laser.

4.2.2 Laser scanning procedure

- Control over the designated area of scanning: *Masking*
  - The '*overview*' camera (Grimm & Zogg 2013) is recording the area of the future scan while the on board touch screen presents the image. With the help of a pointer a polygon is created in order to determine the designated area of the scan (10.2 Figure 22). The area outside (or inside) of the polygon is not scanned.
- Automatic close range photogrammetry
  - The '*telescope*' camera automatically captures approximately 50 overlapping high resolution images of the designated scan area (10.2 Figure 23).
- Laser Scanning
  - The MS50 laser scanner automatically scans the designated scan area. In case of temporary obstruction or traffic the procedure can be set to pause. A scan takes from 30 to 100 minutes to execute depending on the size of the designated scan area and the scan settings. The RGB values of the images

obtained by the telescope camera are automatically assigned to the corresponding points measured by the laser scanner

- Data Storage / Data transfer
    - All the data, including the images is stored on a removable on-board 8G sized SD memory card.

4.2.3 Data storage, data transfer

The results of the scans are stored in various file formats including JPG and BMP image files or SDB and XCF Leica Nova file format data files. The dataset, created by MS50, can be considered as a dense point cloud as it is. Leica Infinity software was used to visualise and transform the data into PTS file format. In the PTS data file format each point has X, Y, Z, 'i' (intensity), R, G, B values. The PTS file format is directly readable by LISCAD, also it can be easily converted into ASPRS LAS (v.140301) file format (Figure 2) using '*pointzip*' software (Isenburg 2014d).

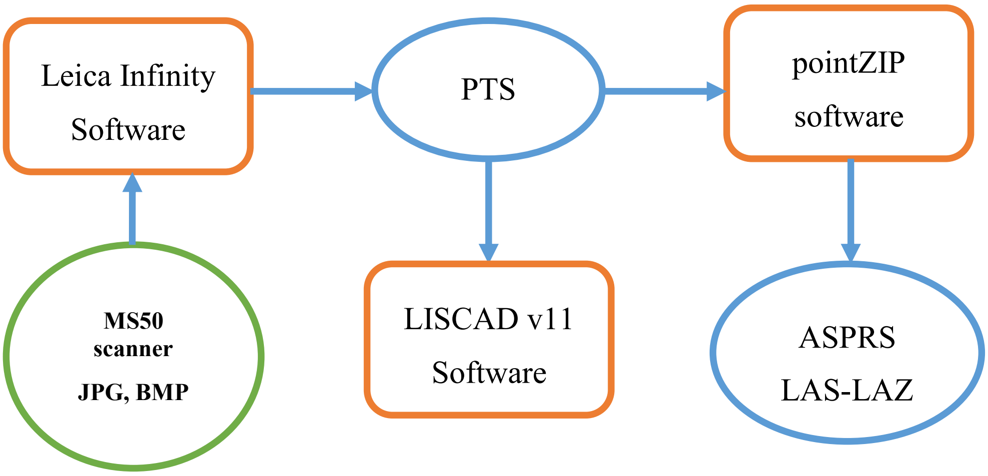

Figure 2 The flow chart of the data transfer from MS50 scanner to LISCADv11 and LAStools software

4.3 Data Acquisition with Digital Camera

4.3.1 Camera

A Canon EOS 600D SLR (Canon 2014b) camera was employed with a EF-S18-55 IS II zoom lens with 1.6 crop factor. During the image taking the camera was manually set to

- The zoom lens minimum of 18 mm and left unchanged. If required manually set to the ~35mm mark on the zoom lens and rigorously left unchanged during the image capturing of that particular 'chunk'. The careful use of zoom-lens can yield acceptable results, a fixed focal length lens is recommended by the PhotoScan manual.
- Image stabilisation, Exposure compensation was set to "off" in order to avoid unnecessary lens movements
- Program-AE mode or Landscape mode; these settings gave the required colour contrasts
- RAW image format (CR2)
- Maximum ISO set to 200 (The minimum possible ISO value is recommended)

The images were taken manually, one by one, with an average 85-90% overlap along the building façade. Each image is captured facing toward the object, with parallel optical camera axis (Figure 3). The sequence of the images are similar to a scanning motion, first left-to right, then back at slightly higher level guided by the geometry of the objects. A monopod was employed to keep the camera higher than 2 m. The overlap was controlled with the help of the grid on the LCD viewfinder. When required, the Canon wireless remote controller was

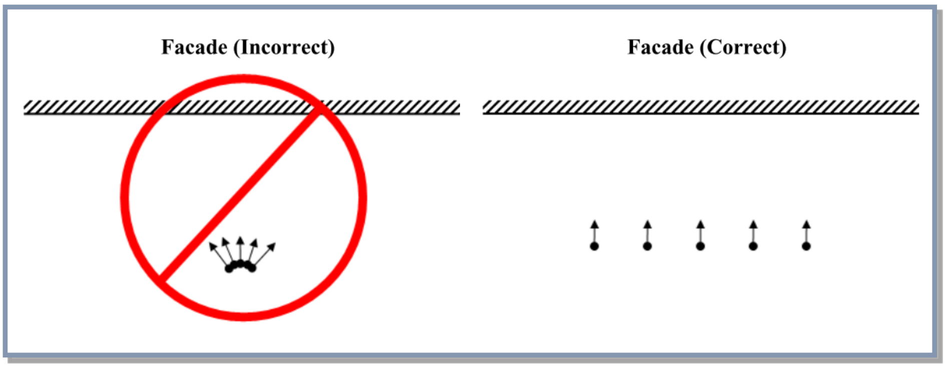

Figure 3 Capturing Scenarios (Agisoft-LLC 2013a)

used to take images from the pole (monopod). Eye-Fi memory card (10.4 Figure 33) can be employed (Eye-Fi 2014a) (Eye-Fi 2014b) to transmit the image to an "Android" mobile phone in order to be able to monitor the procedure. In this project 2 or 3 horizontal photo-strips were taken, usually at ~0.8m, ~1.8m or ~2.8m height from the ground.

The images were assembled into groups or 'chunks', as the software manual recommended (Agisoft-LLC 2013a). A 'chunk' contains 20 to 100 images, representing a certain part of the building. The individual images were saved and archived in RAW file format.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

4.3.2 Targets

Coded targets were distributed along the lawn and the walkway (10.3 Figure 27). The shape, size and the colour of the targets matched the PhotoScan software recommendations (Agisoft-LLC 2014b). Each set of images or 'chunks' was equipped with 3 to 6 Coded targets and another set of 10 tie points. The 'marker' is a pointer-icon used by PhotoScan to mark the centre points of the targets or the tie points. A minimum of 3 targets should overlap with the next 'chunk' in order to be able to merge the 'chunks' if required.

The exact positions of minimum 3 targets for each 'chunk' were measured with the use of reflector-less total station (Leica TS06). The measured target locations were recorded in MGAz55 with Easting / Northing and AHD values. During the image re-alignment procedure the 'markers' were used to fine tune the alignment. Although it is a labour intensive procedure, the use of wide spread tie points and targets can compensate or improve the imperfections of the camerawork. The PhotoScan automatic target detection feature was not used due to the lack of sufficient targets.

4.4 Generating Dense Point Cloud using Close Range Photogrammetry

Generating the point cloud is a resource hungry task. Although PhotoScan successfully integrates a series of multifaceted methods, the procedure requires several steps to be executed. The results of each stage can be individually exported if required. The work-flow of the process can be partially automated using the batch process or Python scripting option.

4.4.1 Photo Alignment / Sparse Point Cloud

Following the recommendations of the PhotoScan user manual, the first step is the use of the *'Align Photos'* option. The photo alignment procedure identifies and matches common points on the images to determine the 3D geometry of the point in the point cloud. This process determines the positions of each camera and the camera calibrations as well. At the end of this procedure a 'sparse point cloud' is created .In order to assist the photo alignment procedure the software uses the relevant EXIF data as a supplementary information. The EXIF contains the metadata about the lens, the camera settings and the other particulars as a part of the image file.

The image-set, the 'chunk' requires at least 3 targets (CPs) with known Easting-Northing and AHD values (10.3. Figure 27). In this project the coordinate system had to be set to MGA zone 55. After the photo alignment procedure is finished, the x, y z axis of the sparse point cloud should coincide with the MGA grid. Setting the coordinate system into MGA will set the proper scale and orientation of the model. The end results of the *'Align Photos'* procedure:

- 'Camera' and 'marker' locations and the initial errors calculated (Figure 4). Camera calibration data calculated
- Sparse point cloud dataset, the initial geometry of the 3D model is created

The camera and the marker locations, the error values and the camera calibration data can be individually saved to a separate file.

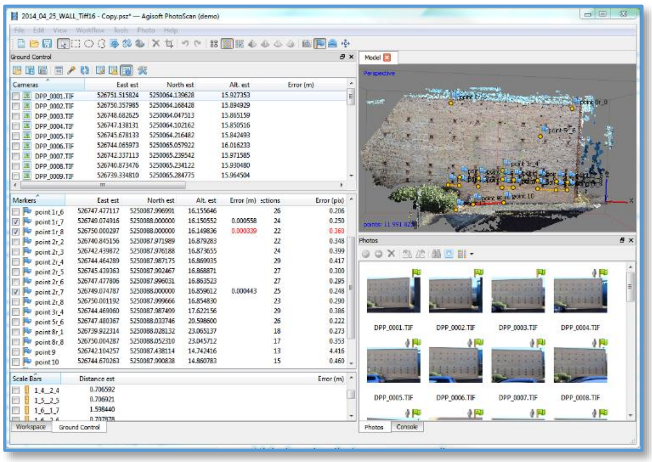

Figure 4 'Camera' and 'marker' locations and error values

4.4.2 Fine tuning the Photo Alignment

A marker location on the photo can be either the centre point of coded targets (Figure 6) or an easy to identify small object on the image (Figure 5). When the markers are positioned on the first two images within the 'chunk' during *'Align Photos'* procedure, the software automatically places the markers onto all images. It is necessary to manually check and if needed to fine tune the position of each marker on each image. The marker icons (the small flags) are colour coded. The grey coloured markers might need fine tuning, and the green coloured markers should be in the proper position. The proper positioning of the markers greatly increases the accuracy of the 3D model and significantly reduces computer processing time.

Figure 5 Manually selected targets;
Coded Target / Phillipshead screw (tie point)

The fine-tuning of the alignment of the markers and setting the proper projection should be double checked. When the re-alignment is finished, the 3D Sparse Point Cloud and the markers are visualised again on the screen. The software quantifies the accuracy of the 3D model RMSE values. Also the distances between markers can be obtained from the screen and compared with known values.

4.4.3 Optimization of the Alignment

Several steps can be executed in order to be able to optimise the 3D model.

- Manual editing: the sparse point cloud, the RGD coloured dots visualise the 3D model. Zooming in and out, or rotating the model enables to identify, highlight and delete the obvious outlier points.
- Masking: 'Resizing the region'; setting bounding box size and orientation was used as a mask in order to reduce the extent of the dense point cloud when required. The area or space outside the box will be omitted from dense point cloud creating procedure.
- Using the Scale Bar optimization: the known or intentionally chosen distance value between any of two markers can be used to scale the whole model.
- Using the Optimize Photo Alignment tool; which corrects the 3D model using the camera calibration data and the known (and activated) coordinate values of the markers.
    - Calculated Camera Calibration Data: Focal length: fx, fy,

      Principal Point coordinates: cx, cy Tangential distortion: p1, p2
      Radial distortion coefficients: k1, k2, k3 and k4, and Skew

4.4.4 Creating Dense Point Cloud

The dense point cloud obtained from PhotoScan software is a fully 3D dataset. It contains the X,Y,Z, i (intensity), and RGB values of each point. The '*Build Dense Cloud*' task is using all the available, previously attained information in order to produce a dense point cloud data. There are several setting options to utilise the resources of the computer hardware to achieve the required accuracy. In this project the 64G RAM and the multi core processor OpenCL parallel computing allow us to use computer resources to produce high spatial resolution point cloud data (Figure 7). When small details are important, than '*Mild*' depth filtering is

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

recommended, otherwise the '*Aggressive*' setting was used. A 'chunk', a segment of a low rise building (the Conservatory), can contain several million points. All 'chunks' of the building were stored as separate individual PhotoScan PSZ files.

As it was mentioned, in this project the following minimum conditions should be satisfied for each point in order to classify the data as "dense point cloud" dataset.

- Easting (x), Nothing (y), AHD (z), values in MGA zone 55
- intensity (i) , Red (R), Green (G) and Blue (B) values
- minimum one point per 50x50 mm on the 'apparent surface' of the computer generated 3D model

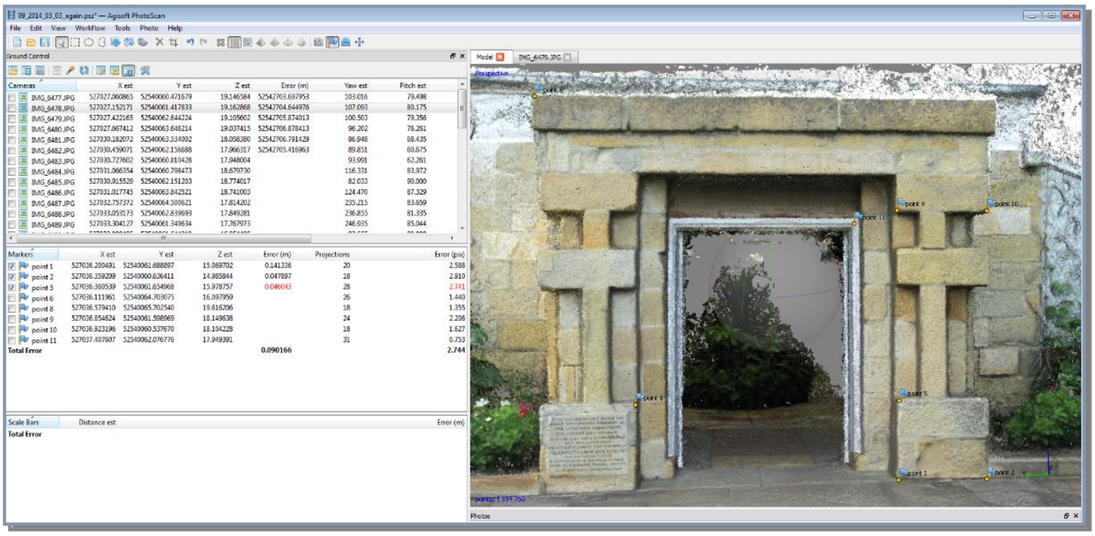

Figure 7 RTBG Conservatory - Entry Detail - Dense point cloud test image PhotoScan generated perspective. Note: This dense point cloud was created using JPEG images with a Sony DSC-H5 compact camera.

4.4.5 Data validation

There are 64 retro-reflective targets in 8 x 8 array mounted on the UTAS Law building East façade for camera calibration purposes. This existing test site was used to explore some aspects of the performance of the various image file formats, the software and the hardware settings used to create dense point cloud. The horizontal and vertical distances between the first and second row of the retro-reflective targets were manually measured. This data served as an independent dataset.

Several overlapping images in RAW format were captured along the array from 11 and 22 m distance, using the previously used hand held Canon EOS600D camera. Also the same camera settings were applied as it was used at the Conservatory building. The RAW images were converted into three different image sets with different file formats, JPEG, TIFF 8 bit and TIFF 16 bit, using the Digital Photo Professional v.3.14.15.0 (DPP) software.

Each set was separately processed by PhotoScan software applying the settings used earlier for the processing of the Conservatory building.

During the image alignment procedure 'markers' were placed over the lowest two rows of the targets (Figure 8). The distances between the 'Markers' were digitally measured and compared with the independent dataset. The results were copied into an Excel spreadsheet in order to calculate preliminary RMSE values (4.4.5. Table 4).

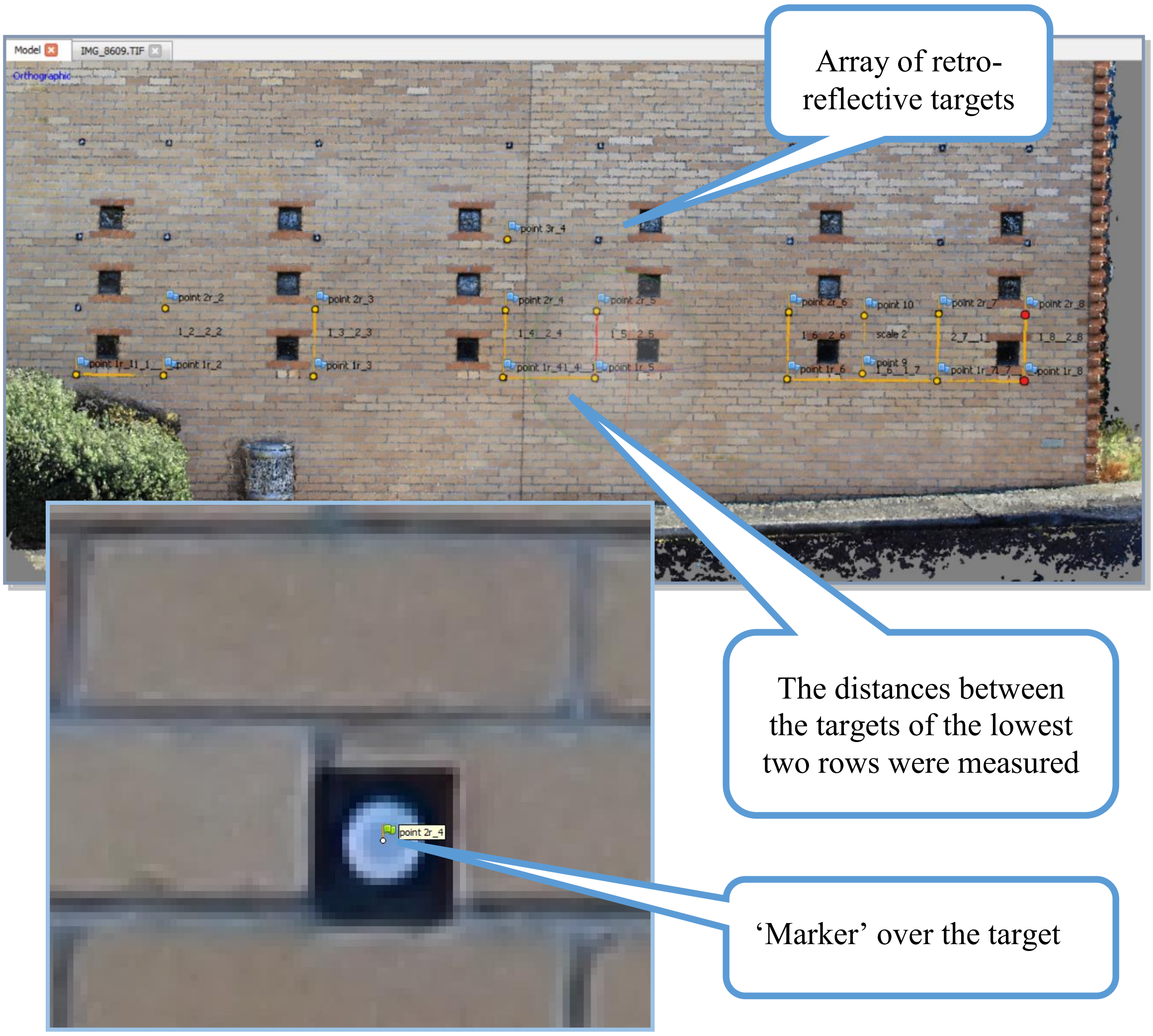

Figure 8. Screen capture of the dense point cloud image of the UTAS Law building Eastern façade. Distances between the existing retro-reflective targets of the first two rows on the wall were used for data validation.

4.5 Data storage and export

4.5.1 Archived Files

- RAW / TIFF8 file format

The original RAW file format images are archived on secure hard drives. The RAW images are converted to TIFF-8 bit in order to create the dense point cloud dataset. The TIFF image files may be stored for a shorter period of time according to company policies. The suitable TIFF images can be used for other purposes which are not related to the survey.

- PSZ file format

PSZ file format is the proprietary format of PhotoScan, it contains the settings and the details of the procedure. The other related files, such as calibration data, camera and marker locations, log-file and accuracy report of data are filed under the same project folder.

4.5.2 Exported Files

- ASPRS –LAS file (ASPRS 2013)

The images were split into related groups or 'chunks'. Each 'chunk' produced its own separate dense point cloud dataset. Each dense point data was separately exported directly from PhotoScan into ASPRS LAS file format and compressed into LAZ file format via LASzip. (Figure 9).

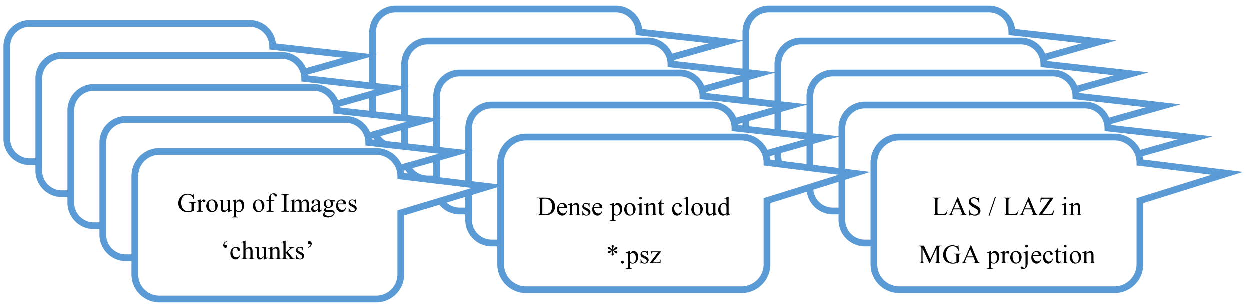

Figure 9 From 'chunks' of images to LAZ compressed files

The dense point cloud stored in LAS/LAZ file format has the following advantages:

i. File sizes are significantly reduced; a 500 MB point cloud data in PTS file format can be compressed into ~30 MB LAZ file.
ii. LAZ compression and decompression is loss-less and extremely fast, the required software is free
iii. All data and data attributes including proper projection are maintained
iv. The separately processed ‘chunks’ can be merged, viewed, clipped, assessed as required. Basic information and metadata can be easily obtained.
v. The LAZ file format can handle terabytes of data on a common hardware
vi. LAS / LAZ file formats are directly linked to LAStools, ArcGIS, QGIS, ENVI
vii. LAS file format is part of the UTAS Spatial Science undergraduate curriculum

- PDF file format

For presentation purposes the dense point cloud data can be exported into PDF file format, which is an interactive 3D model readable with the freely available Adobe Reader.

5 Analysis and Results

5.1 Control Survey Network

A control survey network was established around the building (10.1 Figure 21). The control survey points (Table 1) were used as a backsight when the positions of the targets were surveyed or the position of the scanner was determined.

Table 1 Control Survey Easting/Northing/AHD (MGA-GDA94)

Pint ID	EASTING	NORTHING	AHD	Description
PM-1 (TBM)	527,017.573	5,254,073.790	17.223	Metal pin
PM-2	527,046.844	5,254,007.508	17.074	Metal pin
Station-3	527,059.942	5,254,032.235	15.581	Nail
Station-4	527,043.625	5,254,068.282	15.793	Nail

The position of PM-1 and PM-2 was observed at two different occasions, two days apart, with the same RTK-GPS equipment using the same HCC1167 survey control mark as base station to receive corrections. The GPS receiver on the pole was set to measure the average of

50 observation, than the fix was 'lost' the receiver was turned around 180 degree and the observation was repeated. At PM-1There was a 11 mm horizontal and 23 mm vertical difference between the observation results. There were no further corrections or post processing applied, the averaged results were used and applied as TBM. Also the bearing was calculated from PM-1 to PM-2 using the RTK-GPS observation results.

The baseline (PM-1 to PM-2) of the control survey network was measured using a Leica TS06 total station and Leica prism with optical plummet; the bearing was adopted from the RTK-GPS observations. Nails were used marking the new CPs and closed-loop traverse was applied to establish the coordinates and the height values of the points. The observations were fixed by the LISCAD least squares control file editor tool and the fixed values were used as CPs coordinates (Table 1).

5.2 Results of the laser scanning procedure

In this project four scans were executed around the building. The results (Table 2) were directly saved to a SD memory card within the MS50 scanner. The following digital data was produced from each session of scanning:

Table 2 File formats and file sizes produced by MS50 terrestrial laser scanner after each scanning

Images			
	File Format	Average file size (KB)	Average amount per scan
'Overview' panoramic images **(Appendix 10.2 Figure 22)**	JPEG	6,000	1
'Telescopic' overlapping images **(Appendix 10.2 Figure 23)**	JPEG	1,200	~50
'Depth Map' overlapping images **(Appendix 10.2 Figure 24)**	BMP	300	1
Digital data			
'Depth Map' data	SDB	60,0000	1
Leica Nova MS50 survey data	XCF, X01…	~50	~10
ASCII point cloud file format	PTS	92,000	1

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

The data structure, although it looks complex, can seamlessly be handled by MS50 on board computer or the Leica Infinity office software. The MS50 on board computer integrated the data into point cloud. The same software was used to export the point cloud data into PTS file format which is required by LISCAD v11 surveying software.

5.3 Results of the close range photogrammetry

5.3.1 Results of Data Acquisition with Digital Camera

Over one thousand images were captured during several sessions. The trial and error procedures with PhotoScan software influenced the image capturing methods, consequently the majority of the images were not used or had to be captured again. With time, the procedure evolved to the point when a certain standard which was suitable for the site could be established. An image taking session usually covered a certain part (‘chunk’) of the building.

One ‘chunk’ usually covers 10% to 20% of the Conservatory building (outside) and the surrounding area. Regardless of which part of the building was measured the same amount of resources were needed to produce a ‘chunk’ (Table 3).

Table 3

The necessary resources to produce a ‘chunk’ of image files of the Conservatory building				
No. of images	No. of measured (coded) targets	Hours on site	Hours of office preparation	Hours of file conversion
From 30 to 100	From 3 to 5	2 to 4	1 to 3	1

Although the average image capturing distance was 8 m, the closest distance was 2 m (indoor) and the furthermost 30 m (outdoor). Most of the time the camera zoom lens was set to the minimum 18 mm which is close to the 30 mm full frame lens. The camera was set to “Program-AE” mode, where the shutter speed, the aperture and the focus were set to automatic, the ISO was set to 200 and all other corrections were switched off. All the RAW images were archived and the TIFF-8-bit version images were further processed in order to create 3D dense point cloud datasets of the Conservatory building.

The collection of the captured RAW images can be considered as a multi-purpose data which can be reprocessed using different methods or to use for entirely different purposes than originally intended. A comprehensive and high resolution digital photo documentation of a building can be considered as a product of its own.

5.3.2 Data validation of the image taking procedure

The existing camera calibration prism array on UTAS Law building façade was photographed in RAW image format. Altogether 39 overlapping images were captured; half of them from 11m and the other half from 22 m distance. The images were converted into three different sets of images; JPEG, TIFF-8-bit and TIFF-16-bit using the DPP batch option. Dense point cloud datasets were created from each set of images and the distances between the lowest two rows of the prism array were measured with the use of the ‘markers’ (4.4.5 Figure 8). A steel tape measure was used to measure the point-to-point distances. An initial RMSE was used to compare the results (Table 4).

Table 4 Comparison of measured distances between prisms on the UTAS Law building façade

Actual Dist. Between Markers .		Digital Dist. measured by PhotoScan v1.0.4		Digital Dist. measured by PhotoScan v1.0.4		Digital Dist. measured by PhotoScan v1.0.4	
point to point	Steel tape	**JPEG**	Tape – JPEG	**TIFF-8bit**	Tape - TIFF8	**TIFF-16bit**	Tape - TIFF16
	m	m	m	m	m	m	m
1-1 to 1-2	0.929	0.9274	0.0016	0.9285	0.0005	0.9286	0.0004
1-4 to 1-5	0.978	0.9760	0.0020	0.9774	0.0006	0.9776	0.0004
1-6 to 1-7	1.599	1.5977	0.0013	1.5984	0.0006	1.5984	0.0006
1-7 to 1-8	0.926	0.9245	0.0015	0.9250	0.0010	0.9257	0.0003
1-2 to 2-2	0.709	0.7141	-0.0051	0.7112	-0.0022	0.7078	0.0012
1-3 to 2-3	0.706	0.7083	-0.0023	0.7070	-0.0010	0.7045	0.0015
1-4 to 2-4	0.709	0.7118	-0.0028	0.7090	0.0000	0.7066	0.0024
1-5 to 2-5	0.709	0.7122	-0.0032	0.7091	-0.0001	0.7069	0.0021
1-6 to 2-6	0.709	0.7125	-0.0035	0.7106	-0.0016	0.7079	0.0011
1-7 to 2-7	0.711	0.7132	-0.0022	0.7110	0.0000	0.7091	0.0019
1-8 to 2-8	0.706	0.7095	-0.0035	0.7074	-0.0014	0.7050	0.0010
RMSE			**0.007235**		**0.002888**		**0.003340**

Although various data validation procedures were planned and partly executed this project did not proceed further than calculating the initial RMSE values.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

5.3.3 Dense Point Cloud datasets generated by photogrammetry

The whole of the Conservatory building was photographed several times. Most of the image taking sessions could be considered as tests; the procedure developed session by session. The same apply when the images were processed by PhotoScan software. There are several point cloud datasets where the sizes of the created 'chunks' were modified and settings fine-tuned. At this stage for example the North end of the building and the front lawn are covered by five 'chunks' (Table 5). During the 'Built Dense Cloud' procedure the quality was set to 'Mild' due to the limited amount of available processor time. The 'High' or 'Ultra High settings most likely would result in different point number values.

Each 'chunk' is a separate file and stored in ASPRS LAS/LAZ file format

Table 5 point cloud datasets covering the North part of the building

			Image File Format
'chunk'	Markers	Targets	TIFF8
NE-1 **(10.5 Figure 36)**	13	4	Y
NE-2	20	4	Y
N-1	10	4	Y
NW-1 **(10.5 Figure 34)**	13	5	Y
NW-2 **(10.5 Figure 35)**	12	6	Y
N-Int **(10.5 Figure 40)**	22	4	Y

There were several attempts to quantify the density of the generated point cloud. At the current stage of this project minimum 1 point should be generated within a 50x50 mm area on the surface of the object to qualify the data as a 'dense' point cloud. The known position of targets were also tested and the dense point clouds with several outliers were deemed unsuccessful.

All dense point cloud datasets were exported individually into a separate ASPRS LAS format file and compressed into LAZ file format using the freely available LASzip software.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

6 Communication with Building Industry Professionals

Architects, especially in small architectural firms usually receive land surveying documentation in PDF and in a CAD file format such as DWG / DXF as an email attachment. The land surveying or the architectural drawings are typically a combination of vector data and text notes (Table 6).

Table 6 Brief description of architectural and land surveying documentation

Land Surveying documentation	
Points	Easting / Northing / AHD height values and notation
Lines	with lengths, bearings and notation
Polylines	usually used as contour lines
Raster data	such as orthorectified aerial photo used as a background
Architectural or engineering documentation	
Site Plans	specific map of the building site
Plans	horizontal sections; ~1 m above the current Floor Level
Sections	vertical, longitudinal and cross-sections
Elevations	which can be considered as special case of a Sections
Detail	which can be considered as a special case of a Section

The plans, sections, elevations are mostly composed from points, lines and polylines. The recent architectural CAD systems however are working in a full 3D environment. The virtual 3D model, which is an integral part of the CAD system, is used as a powerful ‘aid’, in order to receive exact and interactive 3D reference for the design procedure. The 3D model is an always present feedback about the “mass” of the building, it helps to solve complex 3D tasks, and it is a vital tool to create or understand sections and elevations. Also the 3D model can be used as a powerful presentation tool. Although the use of the 3D model can be considered as an indispensable part of the everyday working routine of the design procedure, the main communication tools between the professionals of the building industry remained the 2D drawings; *plans, sections and elevations*. It seems that the points, lines, numbers (dimensions) and textual notes on plane projection are a cost and time efficient form of communication.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

The 2D (vector) drawings merits are:

- Fast to produce,
- Uses basic geometrical elements, therefore is easy to comprehend,
- Simple, exact and difficult to misinterpret.

Moreover by tradition as the primary tool of communication within the building industry 2D line drawings are used on a plane paper. The PDF versions of the drawings are treated as 'electronic hardcopy', and the PDF documentation strongly resembles, if not identical with the 'hardcopy' on paper.

It is assumed therefore in this project that most customers may require some form of assistance to interpret the three dimensional dense point cloud dataset. A professional from the building industry most likely would appreciate if next to the millions of points, the basic geometry of the building were also produced in the familiar form of line-drawings; in the form of scaled plans and sections. In terms of the spatial science the dense point cloud data requires some form of post processing and classification.

6.1 **Post Processing in LAStools**

The very first aim of this project was "*to create a dense point cloud map of the RTBG Conservatory*" building. The realization of the map can be presented as a 3D dense point cloud virtual model in conjunction of a Feature Survey Plan. In terms of the building industry it is the Site Plan.

The dense point cloud map is a full 3D dataset; as opposed to the 'top-view' 2.5D nature of the Site Plan. If the vital 3D information is attached to the Site Map in the form of Sections, Elevations and Floor Plans than the dense point cloud data and the virtual 3D model can became more familiar, therefore workable for the professionals in every level of the building industry.

The dense point cloud 3D model, for practical reasons, should be stored in the highly compressed LAZ file form (4.5.2). Consequently further processing or post processing of the data can be accessed by all the resources the ASPRS LAS file format user environment can offer.

6.1.1 Define Boundary

The Cadastral Survey Plan precisely defines the boundaries of the site plan. The Cadastral Survey plan usually is tied to the nearest SPM, therefore the Easting/Northing data of the boundary pegs are available. If the dense point cloud data covers bigger area than the boundary, the LAStools *'lasclip'* tool can be used to reduce the data to the area of interest. This tool can be used to separate or clip any area from the dense point cloud data directly from its compressed LAZ file format.

6.1.2 Identify and Separate Buildings

When the area of interest is relatively small and the terrain is littered with man-made objects such as buildings, retaining walls, garden beds, walkways than the use of semi-automated classification tools can be a time consuming task. The interactive use of specialised software such as LAStools however can give satisfactory results. The '*lasview*' tool is able to visualise the whole dense point directly from the compressed LAZ file format. Its user friendly interface (Figure 10) contains a series of tools which enable the user to obtain sufficient visual and data information. The '*lasview*' interface was used to identify and visualise the point cloud dataset. The interface can be activated with a simple double-click on the selected toolset file. The scripting window automatically generates the script which can be interactively modified or copied into the batch file if required.

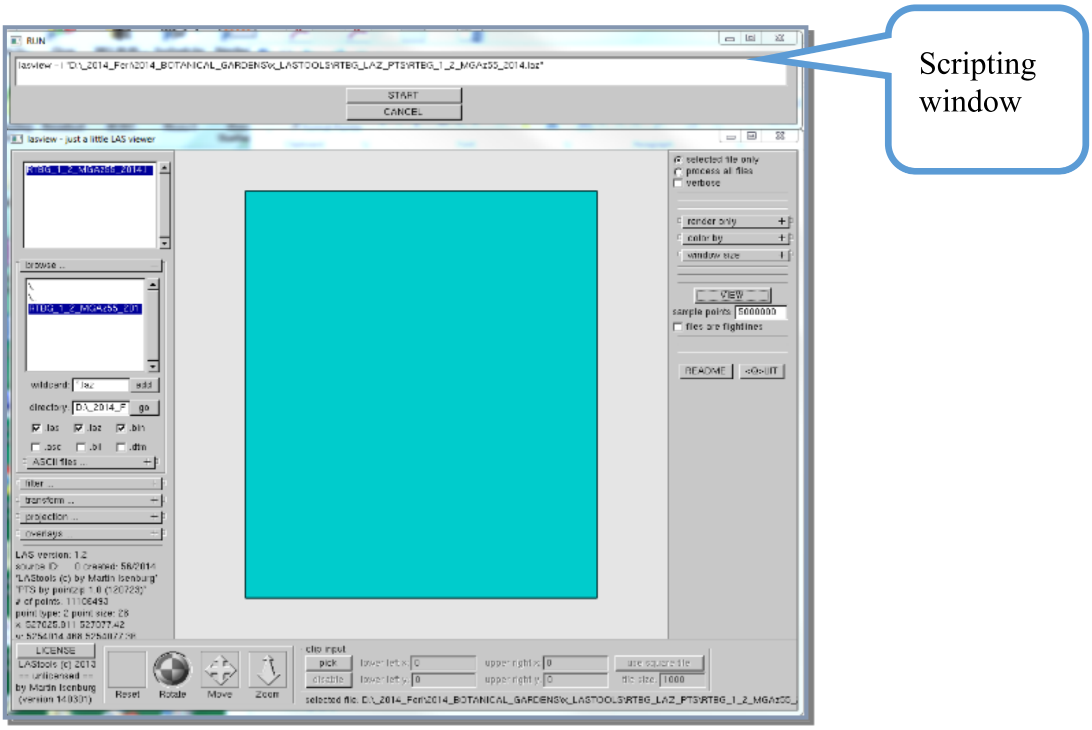

Figure 10 LAStools 'lasview' interactive interface

The buildings within the same lot can be identified using the height values of the points. In case of the Conservatory building the following steps were performed using the '*lasview*' interface.

- Locate the LAZ file - activated with 'directory' and 'go' buttons
- Activate the section window - with 'x' key on the keyboard
- Locate the section detail - 'tilt', 'pan', 'zoom' and 'translate' options
- Make inquiry (Figure 11) - 'i' key and the tip of the arrow on the screen

In the '*lasview*' window every point of the dense point cloud data can be located and its attributes extracted manually. In the example (Figure 11) the height value of the terrain, next to the building was necessary to obtain, in order to establish the height level of the horizontal section.

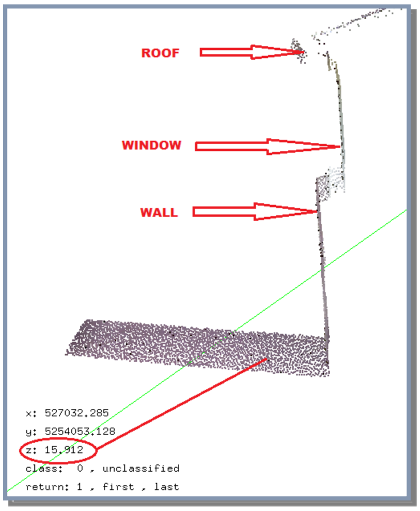

Figure 11 Interrogating a section of the dense point data using ***'lasview'*** *tool;*

The section within point cloud can be zoomed in until the point of interest located. The relevant data is semi-automatically (mouseover+keystroke) shown on the screen. It is possible to locate an individual point within seconds, from a data which may contain several million points

On architectural documentation, the ground floor plan usually represents a horizontal section of the building approximately 1 m above the terrain. If all points below 16.900 m and above 16.901 m height (~1 m above floor level) are clipped out from the example shown above, than the result will contain a very thin layer of dense point cloud which is exactly representing the shape of the building. This thin layer of points can be considered as a result of a specific classification procedure The '*las2las*' tool is capable of executing such a filtering procedure. The result, a subset of the point cloud, consists of only several hundred points instead of ten millions of points (Figure 12). This greatly reduced dataset will contain all the information needed to produce the footprint of the building (10.5 Figure 39). The result should be exported into LISCAD for further processing, in order to define the ground floor plan of the building and represent it in a line-vector drawing.

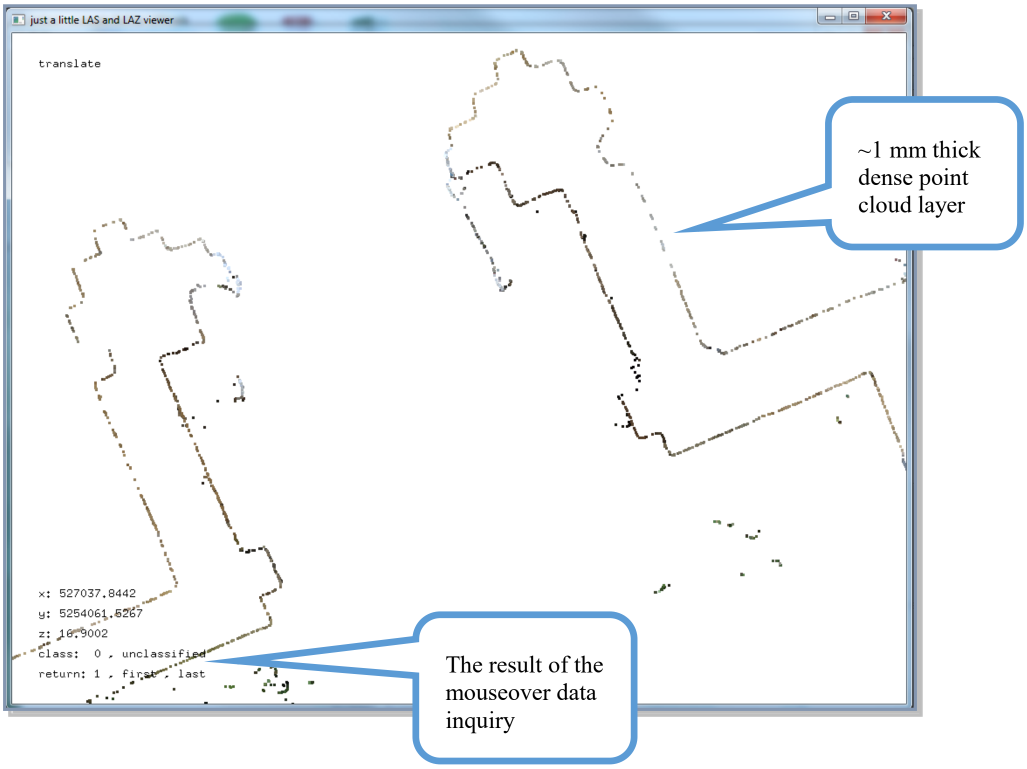

Figure 12 A layer of dense point cloud dataset. It was created using LAStools tool : ; ***las2las –i densepoint.laz –o floorplan.laz –drop_z_below 16.9 –drop_z_above 16.901*** *script. The clipped layer of dense points is 1 mm thick. The numbers in the left-hand corner are the result of a mouse-over enquire tool. When the arrowhead of the mouse is moved over a point, the attributes of the particular point can be studied.*

The extracted dense point cloud layer represents the exact shape of the ground floor plan and the shape of the building; consequently a footprint polygon can be created.

The ***'lasclip'*** tool can be used to clip out the footprint of the building from the dense point data re-using the previously created polygon. This method is the inverse of the previous procedure. The shape of the footprint-polygon of the building can be geometrically simple or complex. The ***'lasclip'*** is able to read the ASCII file or an ESRI shape file which describes the shape of the footprint from corner point to corner point all around the building (10.7 Figure 42). With the same manner other objects of the area, in case of the Conservatory building the shape of the retaining walls can be clipped-out from the dataset.

A very similar procedure was executed in order to extract vertical sections from the dense point dataset. Using the *'lasclip'* tool the dense point cloud can be reduced to a thin long "stripe" of 3D dense point cloud data, which follows the intended line of section (Figure 13 Figure 14). The section can be cross section, longitudinal section or section in any angle as required.

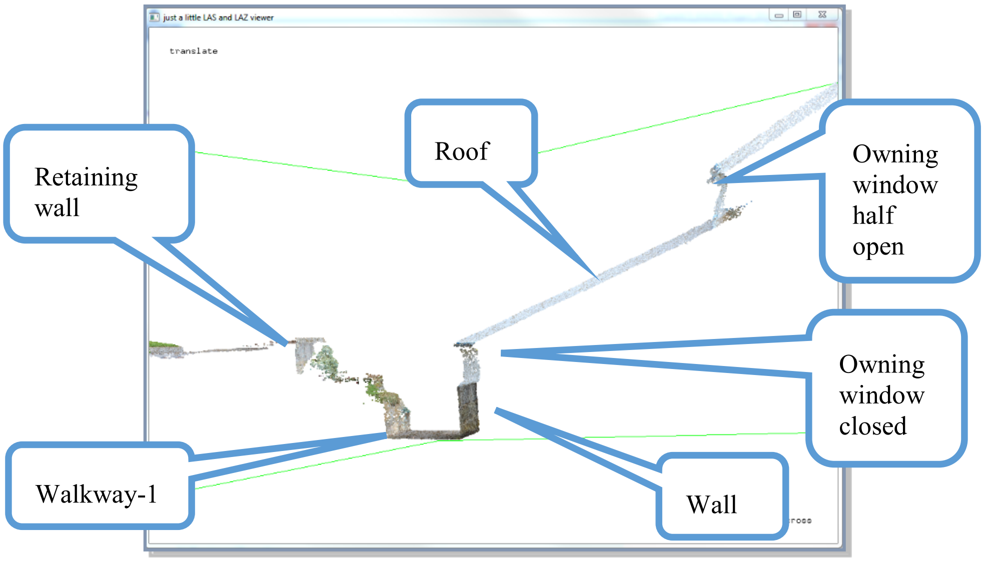

Figure 13 Dense point cloud data - horizontal section. The clipped stripe of the section is wide for demonstration purposes

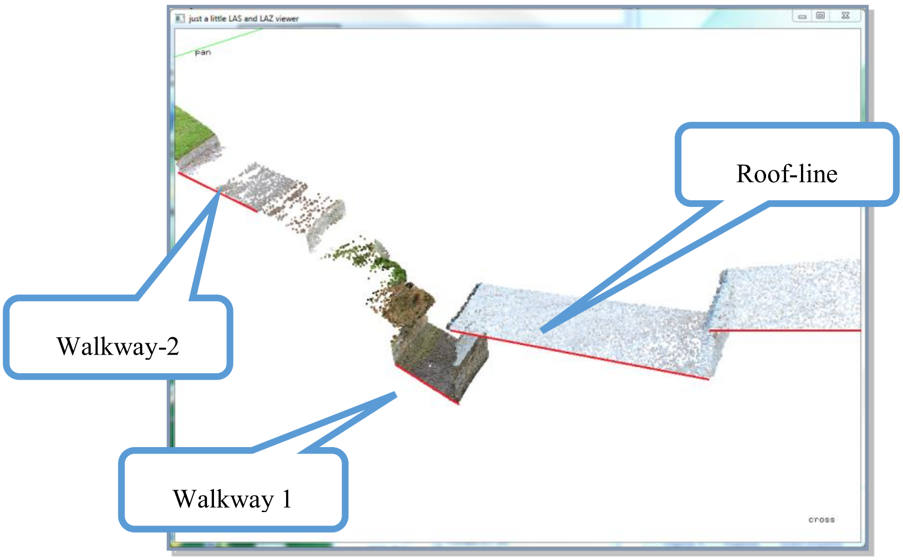

Figure 14 Dense point cloud data - horizontal section. The clipped stripe of the section is from a semi top view. The red lines (two endpoints) were used to indicate and determine the length and the slope.

A simple batch file can instruct the tool to make several parallel sections in any given interval.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

The results of post processing described above can be saved to independent point cloud data files stored in LAS file format. These LAS files containing significantly less points therefore allow faster processing for CAD software systems such as LISCAD.

The post processed point cloud data is exported to LISCAD via PTS file format. LISCAD is used to define the exact shape of the sections and if required turning the post processed point cloud points into vector-line drawing (6.2).

This project used the LAStools and LISCAD software for post processing of the dense point cloud data. It is assumed that this additional service may increase the value and the usefulness of the supplied data for most of the participants of the building industry. The very latest versions of the engineering CAD systems however are prepared to read and process dense point cloud data. The AUTODESK products, such as AutoCAD Civil 3D[2] , REVIT Architecture[3] 2013 or AutoCAD 2013[4] are capable of reading various file formats (Table 7) either directly or using the Autodesk-ReCap utility software (Miyamoto & Ideate 2013)

Table 7 List of the dense point file formats which Autodesk ReCap can read and convert for AUTODESK products.

File source	**File Format**
ASCII text	XYZ, TXT, ASC
Leica	PTG, **PTS**, PTX
Faro	FLS, FWS, XYB
LiDAR	**ASPRS LAS**
Topcon	CLR, CL3

Although it is most likely that almost all CAD systems will be capable of processing dense point cloud data by default in the near future, it still seems to be practical to use LAStools in order to be able to navigate or post process dense point cloud data.

[2] http://docs.autodesk.com/CIV3D/2013/ENU/index.html?url=filesCTU/GUID-D12A9FB0-D176-4EF9-B779-043D03D626D7.htm,topicNumber=CTUd30e5239
[3] http://help.autodesk.com/view/RVT/2014/ENU/?guid=GUID-B89AD692-C705-458F-A638-EE7DD83D694C
[4] http://docs.autodesk.com/ACD/2014/ENU/

6.2 Data Processing in LISCAD

The dense point cloud data can be considered as the 3D model of the area and the building. The full 3D nature and the high point density of the data suggest that XYZ data values of points can be extracted from every element of the 3D model. This procedure is very similar to the fieldwork when reflector-less total station is used (*Table 8 and Table 9*).

Table 8 The workflow of observation on the field using reflector-less Total Station

The workflow of observation - Total Station	
i.	The surveyor first searches for the area of the interest, the ‘spot’ to be measured on the object
ii.	Than using the telescope of the total station, the surveyor aims the “point”; a very small size surface element on the object
	Finally the position of the “point” is digitally measured, recorded and later transferred into a land surveying software such as LISCAD. The point is visualised on the *Plan View window* of LISCAD.

Provided that the accuracy and the precision of the dense point cloud data is acceptable for the purpose of the survey, similar procedures can be executed using dense point cloud 3D model (*Table 9*).

Table 9 The workflow of observation in the office using 3D dense point cloud model

The workflow of observation – dense point cloud	
i.	The surveyor first searches for the area of the interest, the ‘selected points’ on the “surface” of the 3D dense point cloud object or model.(**10.8 Figure 43**) The 3D model, using LISCAD ‘3D ***Point Cloud window’*** tool can be rotated, zoomed in and out. The dense point cloud points are represented with RGB coloured dots. The dots which are closer have bigger size on the screen, as opposed to the dots which are further back in the virtual space therefore represented in gradually smaller size. This feature helps to navigate within the dense cloud of dots.
ii.	Than using the zoom/pan/rotate/orbit tools the surveyor aims the “point” (dot) of the 3D dense point cloud model of the object (**10.8 Figure 44**)
iii.	Finally the position of the point is digitally recorded (**10.8 Figure 45, Figure 46**) and visualised on the LISCAD *Plan View window*
Note: the virtual surveying suggested in this project is not to replace the field work, the virtual surveying is considered as a value added method of surveying	

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

The results of the process described in *Table 9* are points in LISCAD, represented in 'Plan View' window. These points can be considered as result of a 'Manual Entry' input of a "virtual' field work.

The points which are representing the building envelope might be selected not exactly at terrain level therefore the '*Contourable'* option should be 'unchecked' (Figure 15). The list of the building envelope corner points can be exported using the 'Point Report' option into a text file. This text file is used in LAStools to clip the building's footprints from the terrain described previously (6.1.2).

When more than one dense cloud points were used to represent a "particular spot" on the virtual model (10.8 Figure 46) than standard mathematical methods, should apply to define the exact calculated position of the "spot", similar to the methods used during "Analysis of Observations (UTAS)" practicals.

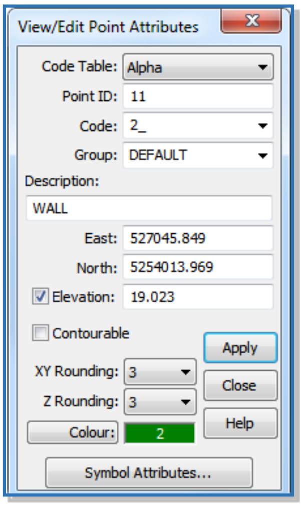

Figure 15 Attribute editing in LISCAD

In this project when the 1 mm deep layer of the point cloud was created (6.1.2 Figure 12) , the walls were represented by several hundred linearly aligned points. These points can be used to create vector lines, which denote the "wall-lines" on the Floor Plan.

The stone walls in this project however possess rugged surface with approximately 15 mm uneven variation. The historic stone block edges are irregularly chamfered therefore to establish the exact line of the wall or the corner points can be a challenge. The architectural site measurement practice, when rugged stone wall is measured, usually applies an 'educated guess' when lines are created from the surveyed points and extrapolation of the lines is used to create the corner points (Figure 47). Similar technique was applied in this project, when a 'best fit' line was created using the points representing the surface of the wall at that particular height. The result of this method is a line drawing in LISCAD 'plan view' window, which can be exported into DXF or DWG file format, as a part of the surveying document.

Manually created 'best fit' lines were used in this project using the "educated guess" method. When required mathematically calculated therefore more accurate methods should apply.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

7 Discussion

7.1 Planning and Preparation

In this project numerous tests were conducted with various settings and targets in order to be able to optimise the dense point cloud. All the tests proved however, that professional quality equipment is essential in case of a survey for a control network with the highest possible precision and accuracy. A properly set local survey control network serves as a skeleton of the whole project (10.5 Figure 41), therefore the slightest inaccuracy will affect the whole project.

The total station function of the MS50 MultiStation was not only used to determine the position of the scanner but also the on board computer automatically compared and checked the accuracy of the control survey network when the CPs coordinates were uploaded to the instrument. This feature allows us to discover the discrepancies before the scanning procedure begins.

The same, already double checked local network CPs were used as backsight for the reflector-less total station measurement to determine the position of the coded targets used for close range photogrammetry. The test results of the hand held camera imagery in conjunction with PhotoScan software suggest that multiple benefits can be achieved if target positions are determined with a total station using Easting-Northing-AHD values (Table 10).

These benefits could be further increased using the PhotoScan automatic target recognition capability. The PhotoScan ‘Print targets’ tool contains the design of hundreds of coded targets (10.3 Figure 29). PhotoScan claims that these targets are automatically detected by the software (Agisoft-LLC 2013a). In this case about 12 coded target positions have to be determined with total station, the others can be used as tie points. It is assumed, based upon the experienced time consuming manual fine tuning of the photo alignment, that the extensive use of the coded targets may offset the extra time spent with Total Station measurement.

If several targets which serve as tie point are also measured with Total Station, than the results can be used as independent data for data validation.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Table 10 The benefits of using MGA projection within dense point cloud

The benefits of using target coordinates in MGA from the start	
Alignment	The alignment of the photos, the very first step in generating point cloud, can be guided directly by MGA coordinates. The projection will be semi automatically maintained during every following procedure
Automatic target recognition	When several coded target is used, and the automatic target recognition is operational (PhotoScan), than an independent data can be produced, which may be suitable for data validation of the generated dense point cloud
Navigation	The MGA coordinate system can be used as a tool to navigate and locate objects within the dense point cloud data
Processing	The Easting-Northing-AHD values can be used within LAStools in order to be able to precisely clip or segment the data as required. When LAStools is used, other 'chunks' or third party data can be simultaneously represented, assessed or processed without physically merging or decompressing the files

7.2 Laser Scanning Procedure

7.2.1 MS50 MultiStation terrestrial laser scanner

The MS50 laser scanner is based on the wave form digitizing (WFD); a special form of time-of-flight measurement (Grimm & Zogg 2013). The WFD system has several advantages compared to a regular time-of-flight system. The laser spot size is similar to phase-shift system, which is usually smaller than the regular time-of-flight laser spot sizes. During each measurement a small part of the pulse, the start-pulse is redirected to photo detector for internal calibration in order to reduce the SNR. In case of MS50 the SNR is 1 mm in 50 m distance. The rest of the pulse serves for measurement. The returning pulse is the stop-pulse. If the shape of the stop-signal is different to the start pulse the measurement is not valid. The final distance is defined by the time difference between the start and stop pulses, digitized by the accumulated signals to the same target multiple times. The MS50 WDF terrestrial laser system scanning speed is max 1000 measurement per second within 250 or max 300 m distance.

In this project several scans were executed around the building. The Total Station mode not only determined the exact position of the scanner, but recalculated and checked the positions

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

of the control network points as well. This feature gives a great deal of confidence about the laser scanning procedure.

The four scanning positions were able to cover the whole building, details and some parts of the building however were not recorded. The scanning procedure requires clear line of sight. Certain building elements plants, trees may cause a "shadow" over other parts of the building (Figure 16). If another station of the scanner also cannot reach the missing building elements than significant gaps may occur in the dense point cloud dataset. In case of higher buildings the limited vertical range of the tripod may further restrict the data acquisition.

Laser scanning usually is not restricted by the lighting conditions but the MS50 scanner workflow requires the involvement of the image taking therefore similar weather conditions apply than the photogrammetry requires

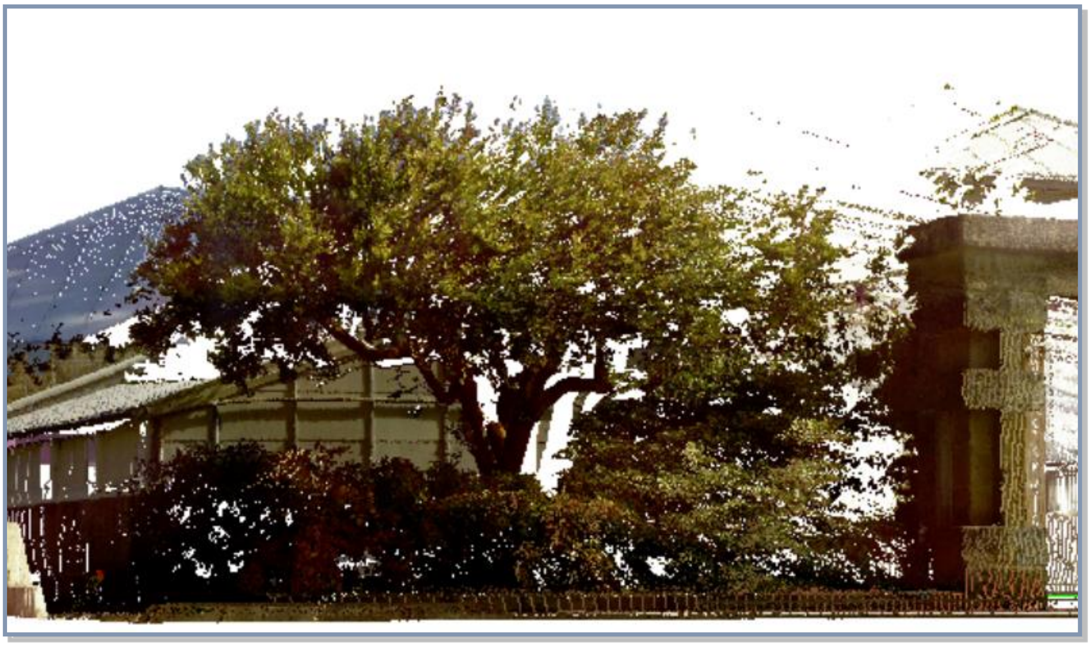

Figure 16 Conservatory building South Entry
Closely planted tree and plants are blocking the line of sight

Unfortunately there was no time for scanning indoor, therefore the wall thicknesses cannot be determined using the laser scanning results. The scans however produced sufficient number of points with the satisfactory density to be able to determine the overall shape of the building for architectural site measurement purposes.

7.2.2 Exporting the laser scanning results

The data transfer from MS50 MultiStation to other data file format is a straightforward procedure. The Leica Infinity software is used to visualise the dense point cloud data and export the result to other file formats. The Infinity[5] is a highly specialised and complex software solution; this project however needs a simple solution for interrogating and archiving the point cloud dataset. The Leica Infinity and the PTS data were similar in size, when over 11 million scanned points were stored in a file about 500 MB in size. The '*pointzip*' software (Isenburg 2014d) can transfer and compress the PTS file into a much smaller file size (Table 11). The ASPRS LAS / LAZ file format allows to view, investigate or post process the point cloud data with a wide range of software, such as: LAStools, MCC, ENVI / IDL BCAL, ArcGIS, QGIS, eCognition, LP360, CloudCompare or MATLAB.

Table 11 Leica Infinity, PTS and LAZ file formats.

Dense point cloud point values		Leica Infinity Data structure	PTS File format	LAZ File format
ID	Identification	Yes	No	Yes
X	Easting	Yes	Yes	Yes
Y	Northing	Yes	Yes	Yes
Z	Height	Yes	Yes	Yes
'I'	Intensity	Yes	Yes	Yes
R	Red	Yes	Yes	Yes
G	Green	Yes	Yes	Yes
B	Blue	Yes	Yes	Yes
c	Class	Optional	No	Yes
At	Additional Attributes	Optional	No	Optional
prj	Projection	Yes	No	Yes
$	Price tag	**Several K**	**Free**	**Free**
t	GPS time	Yes	No	Yes
IX	Indexed structure		No	Yes (LAX)
	Support	Yes	No	Yes
Size	11 million points	**~500,000 KB**	**~500,000 KB**	**~30 to ~50,000 KB**
	User group	Professionals		Professionals and Academic

[5] Data export file formats: SmartWorx, LandXML, HeXML, E57, PTS

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

7.3 Image taking procedure

7.3.1 Producing a 'chunk'

Several testings were conducted in order to be able to find an optimal image capturing procedure. The result of the tests concluded that most of the images should be captured from a hand held camera, at a slightly overcast weather when the direction of the sunlight is roughly behind the camera position. The early morning hours were suitable for image taking of the South-East part of the Conservatory building, the early afternoon relocated the procedure toward the Northerly section and the late afternoon was reserved for the West side of the building. When the sun had its full power, a short break was implemented. Dark clouds or raining are not the preferable conditions.

The speed of image taking with autofocus "on" could achieve around 6 images per minute with the Canon EOS 600D camera. Neither the size of the SD memory card nor the battery reached its limit, the image capturing was restricted by the lighting or weather conditions. The 18-55mm zoom lens was set to the lowest value in order to secure the optimal stable focal length. Also the image stabilizer was set to "off" position, to avoid random lens distortions.

In order to secure the necessary 80 to 90% overlap between images the camera was moved along an imaginary "flight-path" (4.3.1 Figure 3), back and forth parallel with the building facing toward the walls. The camera LCD viewer grid was used to estimate the necessary horizontal and vertical distances between shots. The first series of images were photographed from a greater distance from the wall; imitating a "flight path" from a "higher-altitude". Than the next series of images were taken from a shorter distance in order to mimic a "flight path" at "lower-altitude".

It is important to secure the position of the coded targets and maintain the very exact position during the image taking session. Also it is important that these targets would be visible on several images. The use of additional targets as tie points will increase the accuracy of the 3D model (10.3 Figure 30).

7.3.2 Image File Formats

The measured distances between the prisms at the UTAS camera calibration test array site were used (4.4.5 Figure 8) to explore the influence of various image file formats, such as JPEG, TIFF-8-bit and TIFF-16-bit, when dense point cloud is created using close range photogrammetry.

There are significant differences between the various image format file sizes. While an average Fine-JPEG image is about 6 or 10 MB in size, the 8-bit TIFF image is 50 MB and the 16-bit TIFF image is 100MB in size when converted from a 26M RAW image using DPP. Although the fact is that a simple hard drive can easily store 2 or 3 terabyte data, there are certain inconveniences occurring during data transfer if USB3 file transfer format is not available.

During the ‘photo aligning’ procedure the considerably increased image file size using TIFF image file format (~100 MB/image) instead of JPEG (~10 MB/image) did not slow down significantly the procedure. Also TIFF image file format seems to produce more complete visual appearance. The details are better articulated on the image than on JPEG, therefore it seems to be easier to locate the centre point of targets (Figure 32).

The use of TIFF image file format also may open a window for other image bands than RGB such as RGB+IR. More than three bands within the captured imagery might be an area to investigate. The PhotoScan user group chat sites occasionally are asking for practical advices regarding four band multispectral imagery and receive answer from Agisoft (Agisoft-LLC 2012). It seems that Agisoft might allow to process four band TIFF file format. Also the capabilities of 16-bit TIFF were discussed regarding of thermal infrared imagery (Turner et al. 2014). Finally the preliminary RMSE calculation (5.3.2 Table 4) may demonstrate what the software manual initially suggested (Agisoft-LLC 2013a) , if it is possible the preferable image file format is TIFF.

7.3.3 Density of the Point Cloud

The points in the point cloud are non-uniformly distributed in a three dimensional Cartesian space and do not possess sharp boundary (Otepka et al. 2013). When the point cloud is generated from images using photogrammetry the position of the point is mathematically calculated, provided that the same point is clearly identified on two or more overlapping images. The image matching procedure uses various complex algorithms and procedures, depending on the software manufacturers. The result of the image matching also depends on the quality of the image, the camera, the image file format, the lighting conditions of the image taking the distance of the camera and the physical attributes of the surface of the object. The result is recorded as it is, the software do not force the points to form a pattern or grid, and therefore the visual appearance of the points is scattered (Figure 17). In this project at least 1 point should be recorded on a 50x50 mm surface to qualify to be “dense” point cloud and 1 point within 10x10mm was regularly achieved. The dense point cloud realisation of the coded target (Figure 17) is an example of the scattered distribution of points. This sample was visually investigated zooming in and out randomly and measuring distances between points. The ‘white points’ on the targets have similar colour than the paper and there are bigger gaps between them which therefore seem to be invisible.

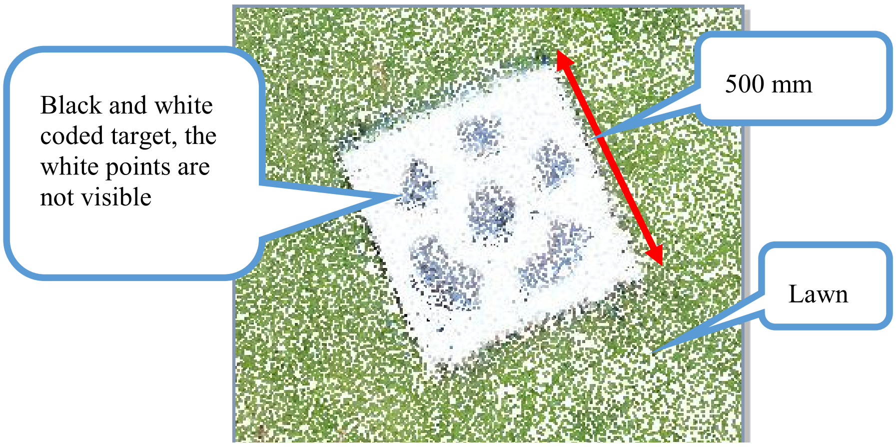

Figure 17 Dense point cloud realisation of a coded target. The red arrow indicates the scale.
The distances between the points along the red arrow varies from 1 mm to 9 mm.
The distances between the points on the white surface varies from 2 mm to 20mm

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

7.3.4 Data Validation

There were several attempts to compare the results of laser scanning and the close range photogrammetry to each other and to an independent dataset. A site measurement of the Conservatory building was conducted with hand-held measuring devices. It is a common and acceptable practice to execute site measurements for architects using hand held Leica DISTO digital measure in conjunction with a steel tape measure. Also a site survey was conducted with a Leica reflector-less total station.

During the dense point cloud generation procedure there were several trials with various image file formats and various settings within PhotoScan software. Due to limited available processor time the 'High' and the 'Ultra High' dense point cloud generating options were not tested. Also the very different site measuring and surveying methods should be evaluated first in isolation, by their own data validation methods before the values can be compared with dense point cloud dataset.

During the data evaluation attempts it has become evident that a proper evaluation of these measurements is beyond the scope of this project, it can be a subject of another project itself.

The position of certain elements of the building in the dense point cloud, such as points on the roof ridge, were however regularly measured (Figure 18) and compared with total station site measurements for testing purposes. When the difference between the x,y,z values observed with reflector-less total station and the corresponding dense point cloud point regularly exceeded 50 mm, than that particular test point cloud data was classified as unsuccessful.

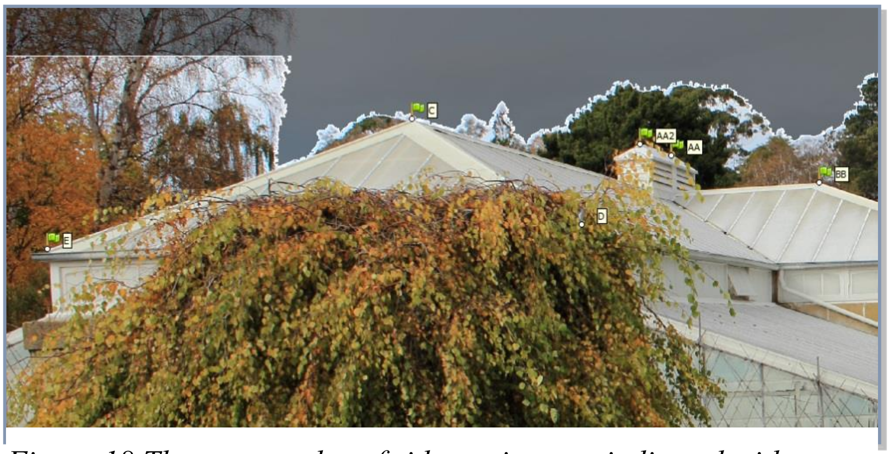

Figure 18 The measured roof ridge points are indicated with markers (green flags). The grey area above the roof indicates the masking.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

7.4 Basic differences between laser scanning with MS50 and close range photogrammetry data acquisition

Table 12 Differences between terrestrial laser scanning (MS50) and the close range photogrammetric (Canon EOS 600D) data acquisition

Terrestrial laser scanning with MS50 MultiStation	**Close range photogrammetry with Canon EOS 600D**
• The scanner position has to be determined with great accuracy	• There is no need to determine the camera position during image taking procedure
• The MS50 scanner can determine its own position with the use of resection and link it to the known control survey network	• The target positions should be determined with a reflector-less total station to the known control survey network • The target position keyed in during the Image Alignment procedure using PhotoScan v1.0. software
• There is no target used	• Several targets and markers are used, preferably over 15 per ‘chunk’ • The position of at least 3 targets has to be determined with great accuracy (with total station) per ‘chunks’
• The scanner positions should be linked to a control survey network.	• At least 3 target position should be in an overlapping position between ‘chunks’, therefore it is practical to determine more than 3 target positions with total station from the control survey network per ‘chunk’

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Table 13 cont. from Table 12

Terrestrial laser scanning with MS50 MultiStation	**Close range photogrammetry with Canon EOS 600D**
• The MS50 laser scanner's position has to be stable during scanning procedure, therefore the scanner usually is mounted on a tripod	• Hand held image taking is a common practice. • The use of a monopod can be an advantage
• If the soil under the tripod is unstable or the scanner moved during the scanning the results will be corrupted	• Image can be taken from an undulating (cherry picker) platform or from a rolling boat.
• The use of tripod usually limits the vertical position of the MS50 scanner from 1 m to 1.8 m	• The hand held camera can be very close to the ground surface. • The use of an average monopod limits the vertical position up to 3 or 4 m. There are professional monopods with the height up to 7m. • An average cherry picker can reach 10 m in height
• The minimum horizontal distance of the MS50 scanner is ~1.8 m • Maximum distance of MS50 is 300 m	• Although the camera can capture image from a very close range, it is practical not to take images closer than ~2.5 m horizontal distance • Maximum distance is limited by the capability of the camera lens.
• The terrestrial laser scanner can work almost in all conditions of illumination	• The strong and uniform ambient light (overcast) is ideal for image capturing.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Table 14 cont. from Table 13

Terrestrial laser scanning with MS50 MultiStation	**Close range photogrammetry with Canon EOS 600D**
• The laser scanning procedure produces xyz coordinates, a digital camera and close range photogrammetry required to register spectral values to each measured point	• The native RGB values of the images are registered to each point. Registering spectral values can be one of the greatest advantages over laser scanning.
• MS50 laser scanner works seamlessly on uniformly coloured smooth surfaces with no texture except highly reflective white coloured surface	• Close range photogrammetry produces high signal-to noise result or no-result on uniformly coloured smooth surfaces with no texture in strong light
• MS50 laser scanner detects thin objects or wires such as power cables between poles if the object does not vibrate or swing	• Close range photogrammetry require additional tie points to narrow and dark objects such as thin metal blade or cables between poles
• The MS50 terrestrial laser scanner or close range photogrammetry produce high noise to signal ratio or no-result measuring o uniformly black or o highly reflective, mirror-like or shiny glass surface o wet surface	
• The MS50 laser scanner is a sensitive, high maintenance equipment with an over $ 120K price tag.	• The Canon 600D is a low maintenance, high performance and versatile camera with an under $ 1 thousand price tag
Mobile platforms are outside the scope of this study	

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Table 15 Basic differences between laser scanners and digital cameras

	Laser scanners	**Digital cameras**
Distance	Usually limited range of use without special target or mirror Different emitter and receiver is required for altered range	The same camera body and sensor can be used from the microscopic distance to a long range telephoto imagery
Measuring method	One shot is enough to measure a distance	Minimum two images needed to determine the position of a point.
Spectral value of the measurement	The measurement gives just the xyz values. Certain additional information can be derived when full wavelength method is used. .	The result of image processing gives the xyz values and RGB spectral bands.
Speed of data capturing	Several 100 thousands readings/sec	Capturing an image : less than a second
Data Reading	Multiple return or “full wavelength”	The intensity values to the closest object and to the sensor pixel are recorded (similar to “First -return” in LiDAR)
Data reading	The result can be read almost immediately	The images should be aligned and processed before the result can be read

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

8 Conclusion

Two sets of dense point cloud models were produced. The first was created using laser scanning together with digital imagery to assign RGB values to each point. The second series of point clouds were created using close range photogrammetry. Reflector-less laser measuring equipment was to determine the exact positions of the coded targets. The coexistence of active and passive systems form a natural partnership.

The products are fully three dimensional dense point clouds containing several millions of points with high spatial resolution, Easting/Northing/AHD values and spectral (RGB) information. The points are well-defined and their realistic visual appearance on the screen appears to accurately match the measured objects. The dense point clouds in this project can be considered as the raw data of the 3D models.

Using the LAS file format a wide range of existing software tools, methods and expert knowledge can be used to further process and utilise the dense point cloud data. In the near future the LAS file format may permit the addition of more attributes, custom classification, time stamps or additional spectral values to each point stored in the same highly compressed file. The nearly photorealistic appearance of the dense point cloud can be used to advantage in communication with other professionals and with the general public.

This project is an attempt to produce dense point cloud data using the cost-effective range of the latest technological equipment and utilising the information available for an undergraduate student of Remote Sensing.

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10 APPENDIX

10.1 Reconnaissance survey / Control survey

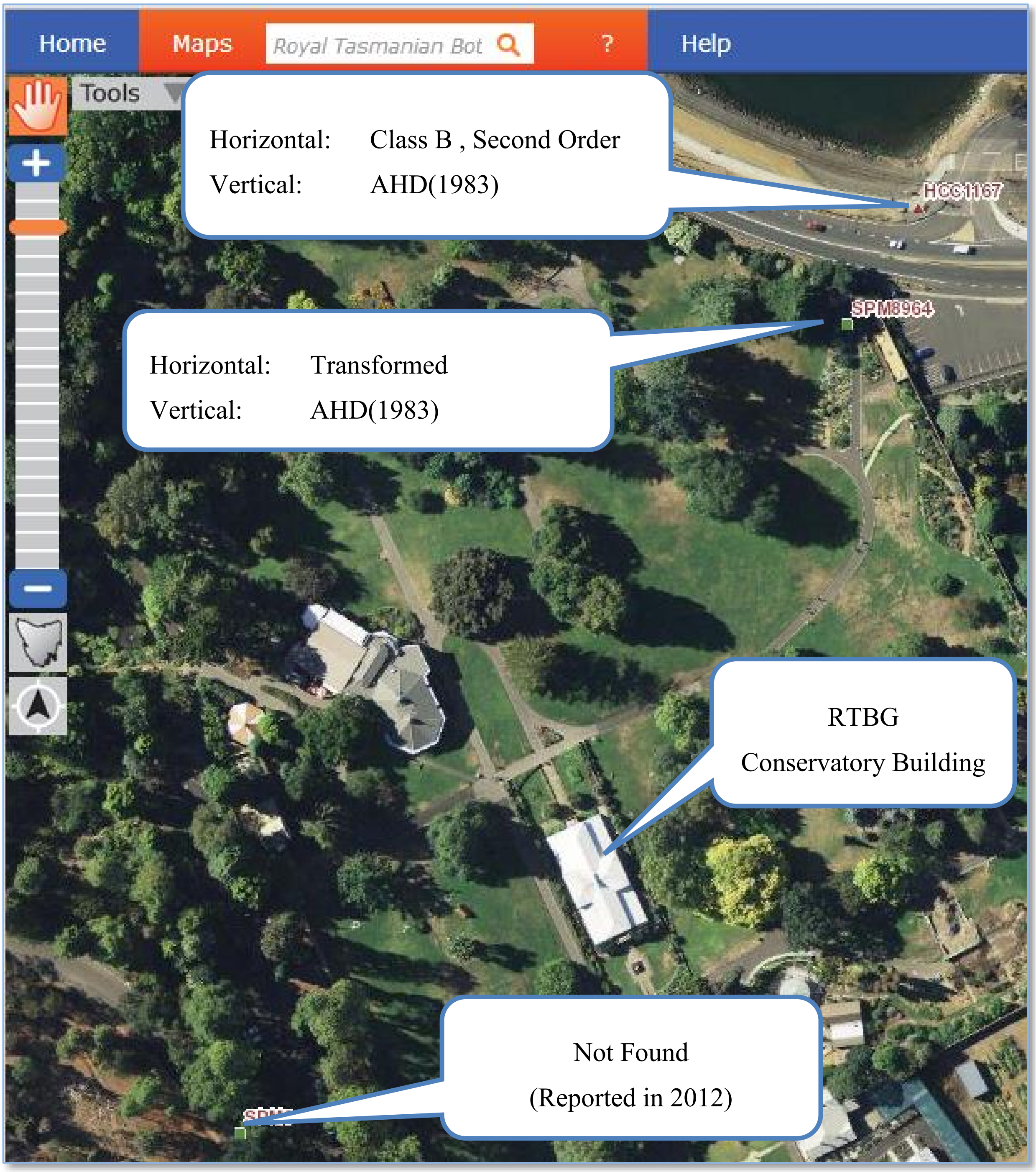

Figure 19 Conservatory – Royal Tasmanian Botanical Gardens - Hobart
On-line Reconnaissance survey

(Image source: TheLIST)

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

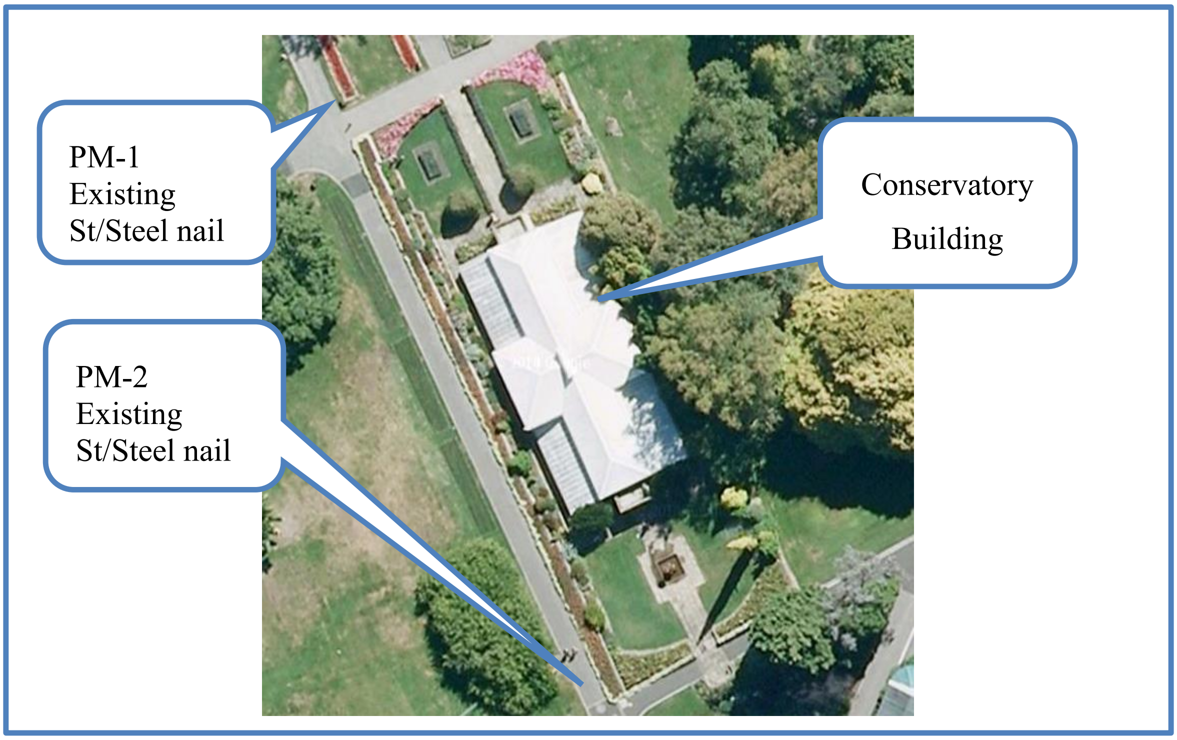

Figure 20 RTBG On Site Reconnaissance Survey (Image source: TheLIST)

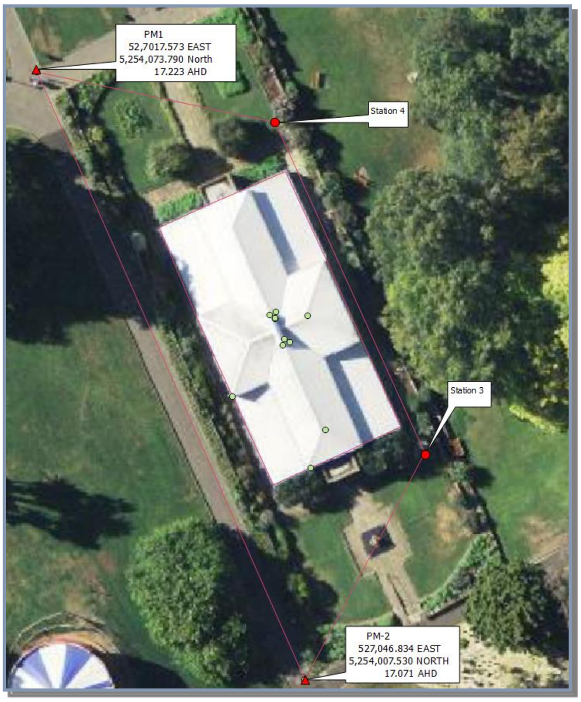

Figure 21 Control survey network around the Conservatory building

The positions and the bearings of PM-1 and PM-2 were established by a GNSS measurement. The distance from PM-1 to PM-2 was re-surveyed and Station 3 and 4 were established with the use of a Leica TS06 total station

10.2 Terrestrial Laser Scanning

Figure 22 Image masking The area outside of the polygon is not scanned. Screen capture of the MS50 'overview' camera on board touch screen.

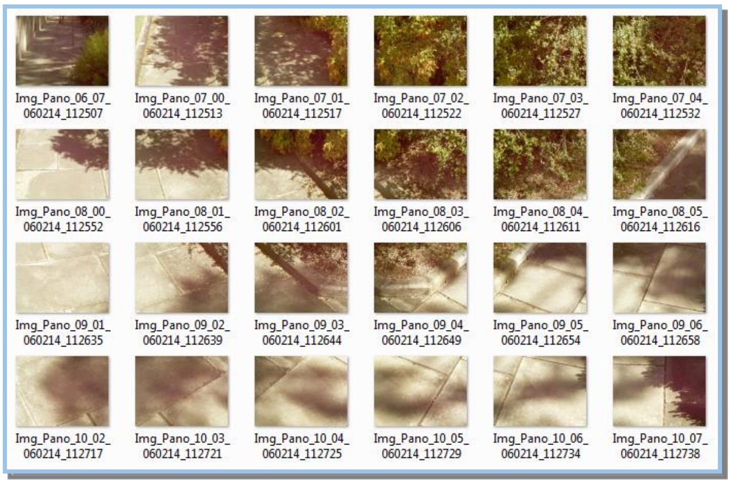

Figure 23 Close range photogrammetry

Screen capture of the MS50 'telescope' camera overlapping images

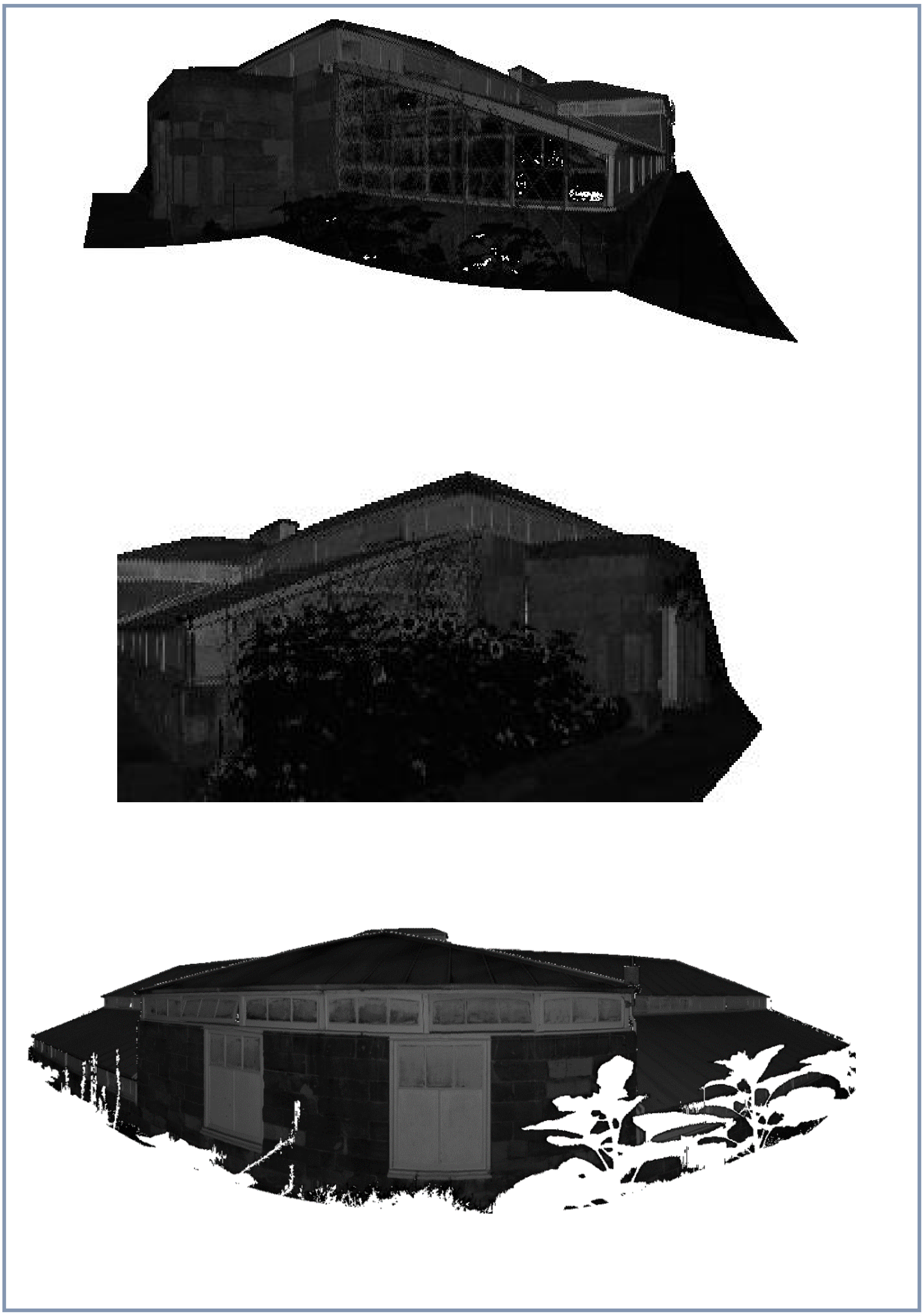

Figure 24 Depth images - produced by MS50 MultiStation

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Figure 25 RTBG Conservatory building South elevation
Screen capture of LISCAD v11 generated perspective. The dense point cloud data consists of over 11 million points with Easting/Northing/AHD/RGB values

Figure 26 RTBG Conservatory building North elevation
Screen capture of LISCAD v11 generated perspective. The point density depends from the settings, the distance and the angle of the object from the scanner. The default setting was 1 point per 10x10mm at the distance of 15m from the scanner. For the areas located closer to the scanner or with more than one overlapping scans the point density can be sub mm.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

10.3 **Targets**

Figure 27 Coded targets and markers (tie points) along the Conservatory building. The automatic target detection option was switched off in this project. The marker icons (small green flags) were manually distributed and aligned during Image Alignment procedure within PhotoScan v.1.0.4

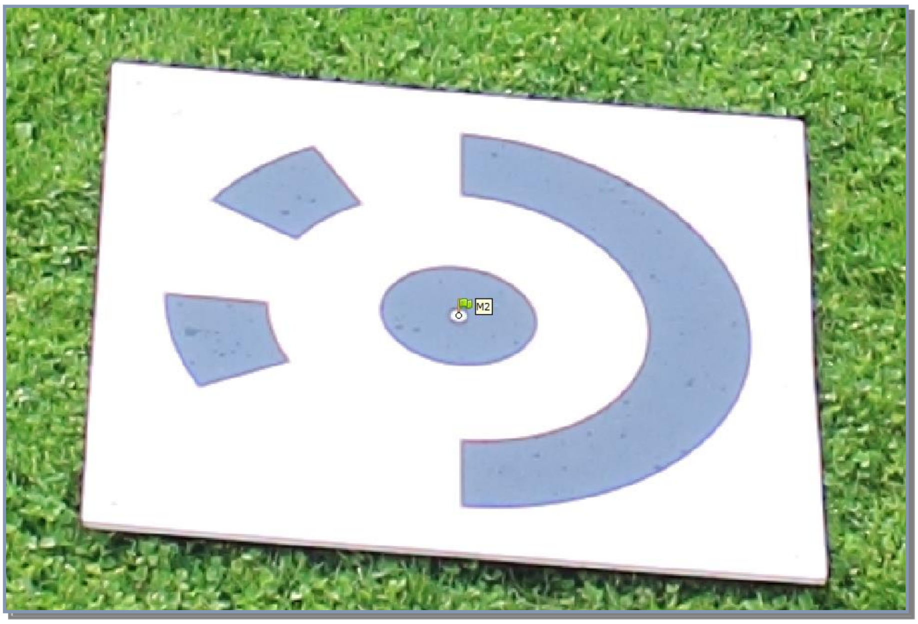

Figure 28 A coded target as it can be seen on the screen of the monitor during Image Alignment procedure. A 'marker' is placed at the centre of the target. The automatic target recognition option was switched off. The diameter of the centre point is 10 mm. The design of the target can be obtained from the PhotoScan v1.0.4 software 'Print Markers' option. This target was borrowed from the UTAS TERRALUMA project group.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

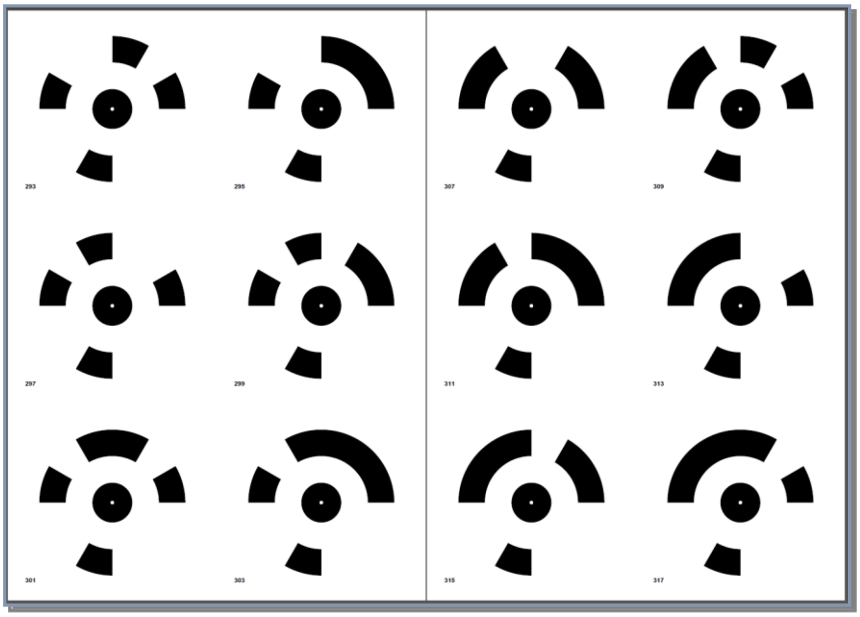

Figure 29 Sample page of coded target design by PhotoScan

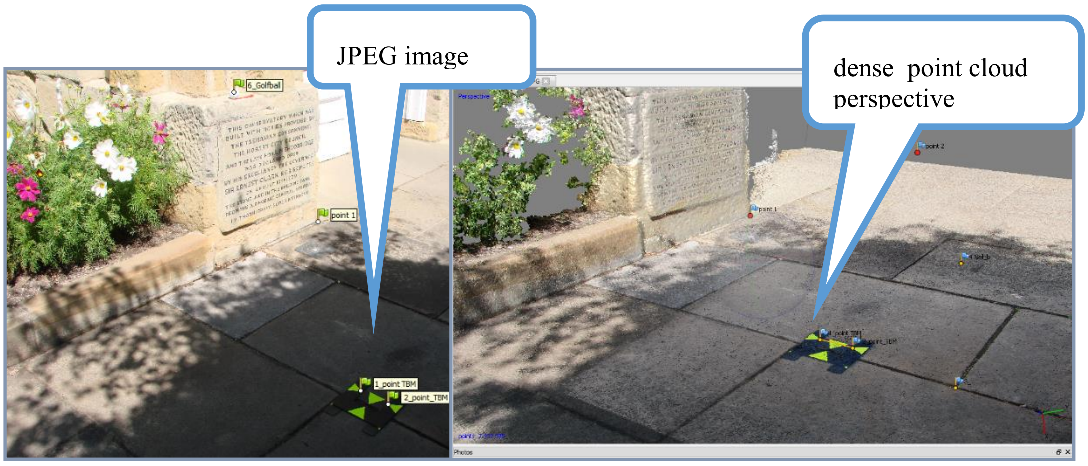

Figure 30 Conservatory building- North entry detail -- Various targets were tried, such as a golf-ball and an aiming plate from a surveyor prism (the yellow triangles on the black metal plate).

Please note that the image and the dense point cloud was produced for testing purposes. At this stage the JPEG image format was used produced by a 7 MP SONY DSC-H5 pocket camera. At the final stage TIFF file format and coded targets were employed.

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

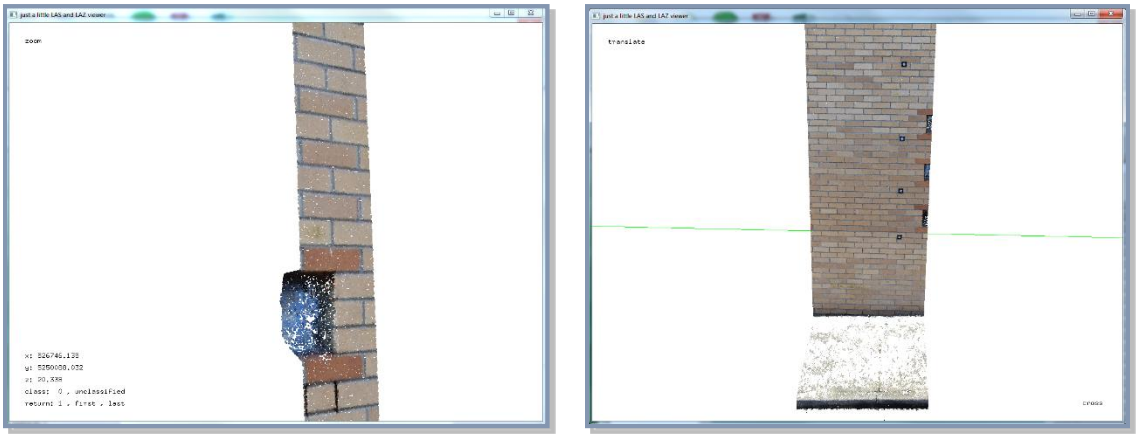

Figure 31 UTAS Law building East façade
Dense Point Cloud (TIFF 16-bit) Perspective Vertical Sections

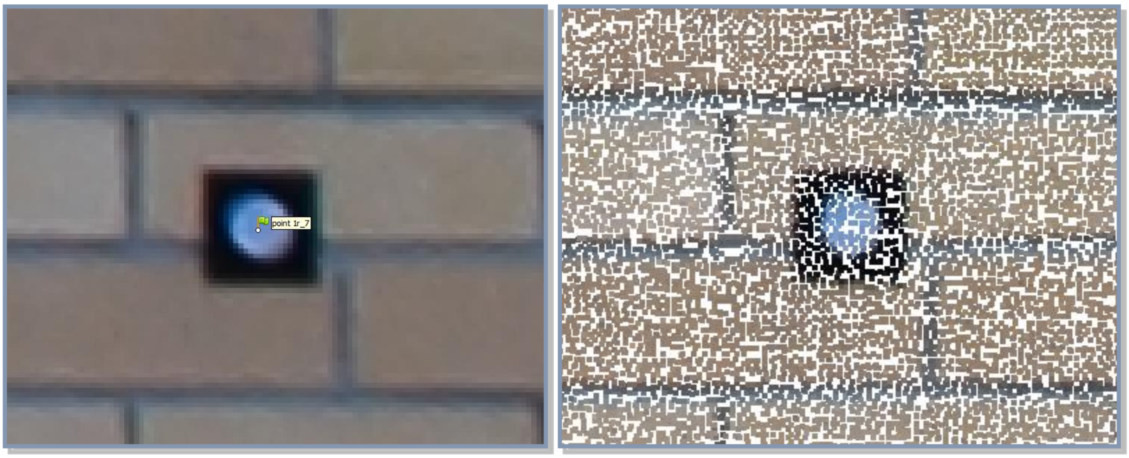

Figure 32 UTAS Law building East façade
Target: A 35 mm diameter reflective film on black plastic plate

TIFF 16-bit image and Dense Point Cloud Perspective

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

10.4 Camera

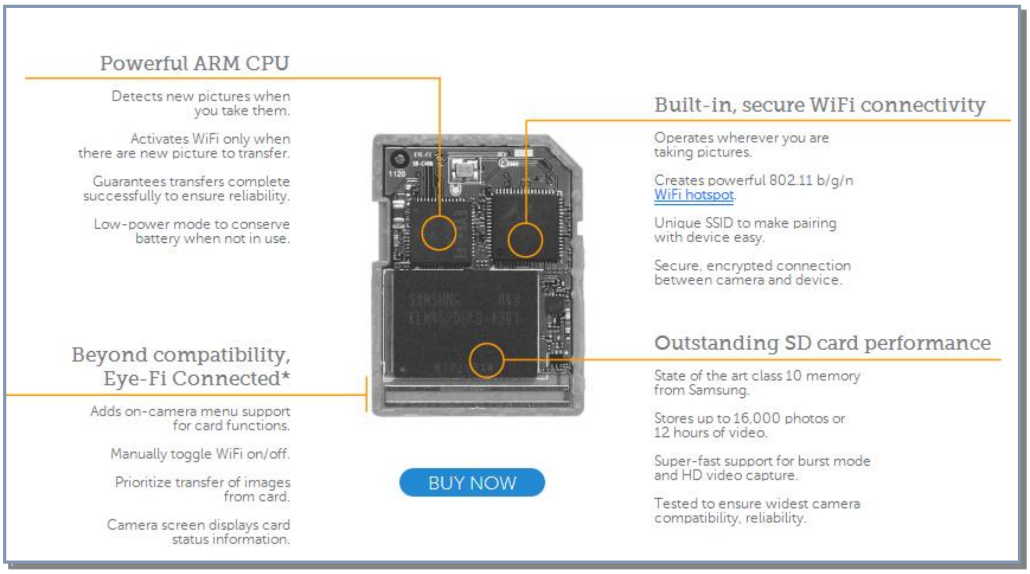

Figure 33 Eye-Fi memory card (Eye-Fi 2014a), (Eye-Fi 2014b)

Table 16 Camera

Camera					
Original Files / Camera Calibration					
Name	**Sensor Size**	**Effective Pixel size**	**File Formats**	**Lens**	**Type**
NIKON D200	23.6x15.8 mm CCD	10.2 Mp	RAW(Nikon), JPEG		Digital SLR
CANON 600D	**22.3x14.9 mm CMOS**	**18.0 Mp**	**RAW(Canon), JPEG, TIFF8, TIFF16**	**EF-S 18-55 IS II**	**Digital SLR**
SONY DSC-H5	1 / 2.5” CCD	7.2 Mp	JPEG	2.8-3.7 Carl-Zeiss Vario-Tessar	Fix lens

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

10.5 Dense Point Cloud 'chunks'

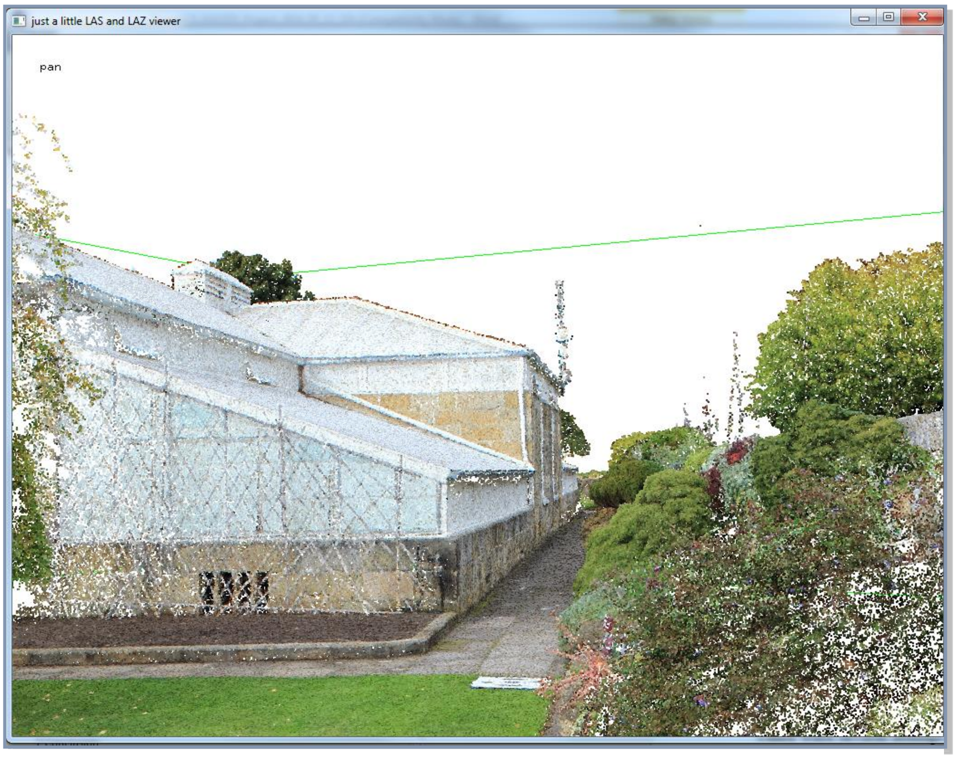

Figure 34 'chunk' NW 1 Dense Point Cloud Perspective

Figure 35 'chunk' NW-2 Dense Point Cloud Perspective

Figure 36 'chunk' NE-1 Dense Point Cloud Perspective (Detail)
Density is more than 2 points per 10x10mm area of the surface model

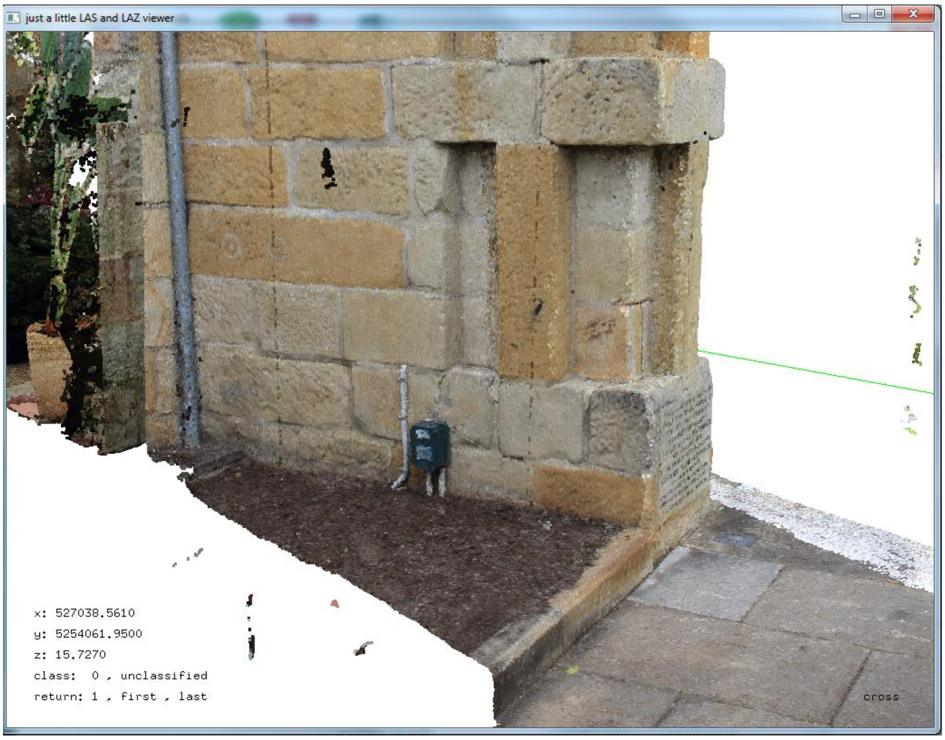

Figure 37 'chunk' NE-1 Dense Point Cloud Perspective (Detail)
The xyz coordinates and attribute values can be obtained with the use of arrowhead of the mouse. The result of the 'mouseover' interrogation shown at the left hand corner of the LAStools viewer

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

Figure 38 Top view of NE-x and NW-x 'chunks'. Dense Point Cloud Perspective. The 'chunks' were opened simultaneously in the LAStools viewer; the LAZ files are not merged.

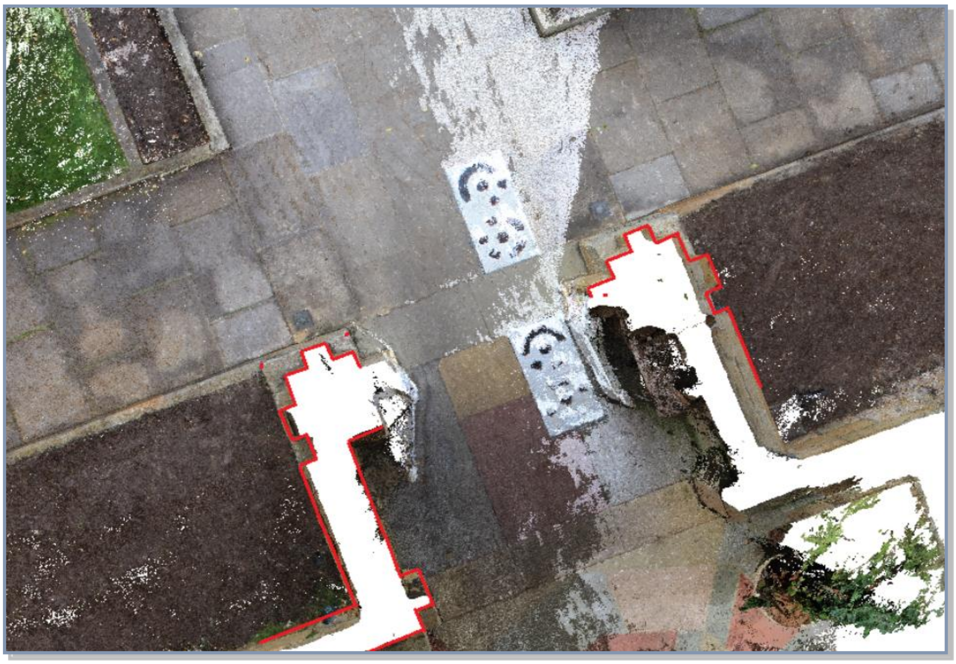

Figure 39 Top view of NE-x and NW-x 'chunks'. – Entry Detail Dense point cloud Perspective. The points above 16.m height were clipped out within LASviewer using < –drop_z_above 16.9 > script command. The red lines were manually added to visualise the wall of the building at this height for demonstration purposes. The endpoint of the lines can be determined with the 'mouseover' inquire tool.

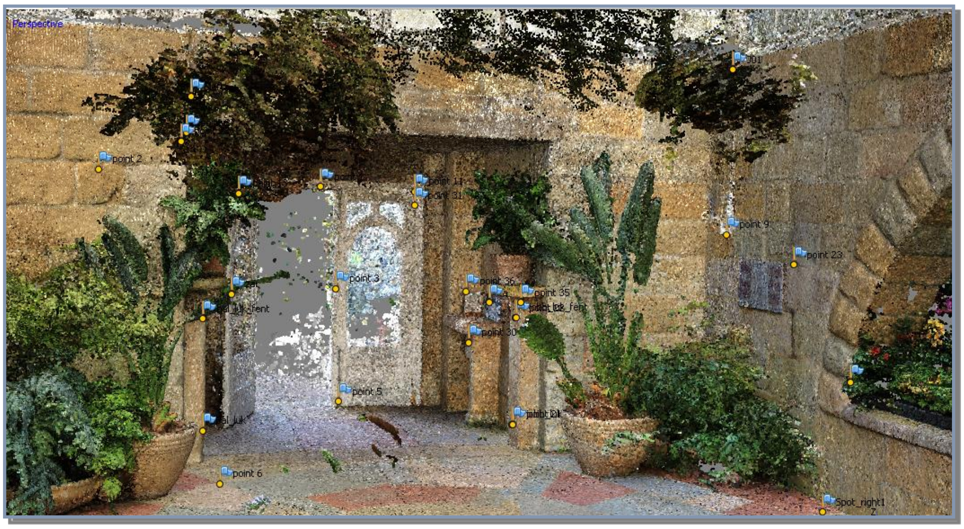

Figure 40 'chunk' N-Interior . Dense Point Cloud Perspective
The image capturing procedure needs improvements to counteract the adverse effects of the indoor lighting conditions

Figure 41 'chunk' N-Interior and NE-1 Dense Point Cloud Perspectives
The 'chunks were opened simultaneously in LAStools viewer. The alignment between 'chunks' rely on the Eating/Northing/AHD values obtained from the Control Survey Network.

10.6 **Hardware – Software**

The list of computer hardware and software used in this project:

Table 17 Equipment (Hardware, Software, Files) used

Available Hardware				
Model	**CPU**	**RAM**	**OS**	**Screen**
Custom Built (Located in Photogrammetry Lab.)	Intel Core i 7 4820 3.7Ghz	64 G	Win7 64bit Enterprise	BenQ 24”

Available Software			
Name	**Manufacturer**	**WEB**	
PhotoScan v1.0.4	AGISOFT	agisoft.ru	Licenced
LISCAD SEE v11	LISTECH	listech.com	Licenced
LAStools v104301	RAPIDLASSO	lastools.org	Licenced (Free up to 1 million points)
laszip	M. Isenburg	laszip.org	Free
pointzip	M. Isenburg	www.cs.unc.edu/~isenburg/**pointzip**	Free
AutoCAD v2007	AUTODESK	autodesk.com	Licenced
ArchiCAD v15	GRAPHISOFT	graphisoft.com	Licenced

DOI: 10.4226/77/5b05f9ef54154
http://dx.doi.org/10.4226/77/5b05f9ef54154

10.7 Post processing - LAStools

>> lasclip -i RTBG.laz -poly footprint.txt –interior^

-o without_buildings.laz

clips the points from the inside of the buildings footprints specified in 'footprint.txt' out of the LAS file 'RTBG.laz' and stores the other points to 'without_buildings.laz'. The text file should have the following format:

757600 3.69270e+006

757432 3.69264e+006

757400 3.69271e+006

757541 3.69272e+006

757600 3.6927e+006

#

757800 3.6917e+006

757632 3.69164e+006

757600 3.69171e+006

757741 3.69172e+006

757800 3.6917e+006

[...]

Sample from 'lasclip_Readme'

Not in MGA

>> lasclip -i RTGB.laz -poly footprint.shp -o output.laz^
-classify 6 -interior -verbose

*Classifies the points falling *inside* the polygon as "Building".*

Source: lasclip_README martin.isenburg@rapidlasso.com

Figure 42 LAStools - The sample script for clipping out the building footprint from the point cloud dataset. The LAStools can read the polygon in the format of ASCII TXT file or ESRI SHP file.

10.8 **Post Processing - LISCAD**

Figure 43 Locating of the area of interest Conservatory building - Entry detail Dense point cloud image, LISCAD generated perspective

Figure 44 Locating of the area of interest Point to be measured on a stone wall Dense point cloud image, LISCAD generated perspective

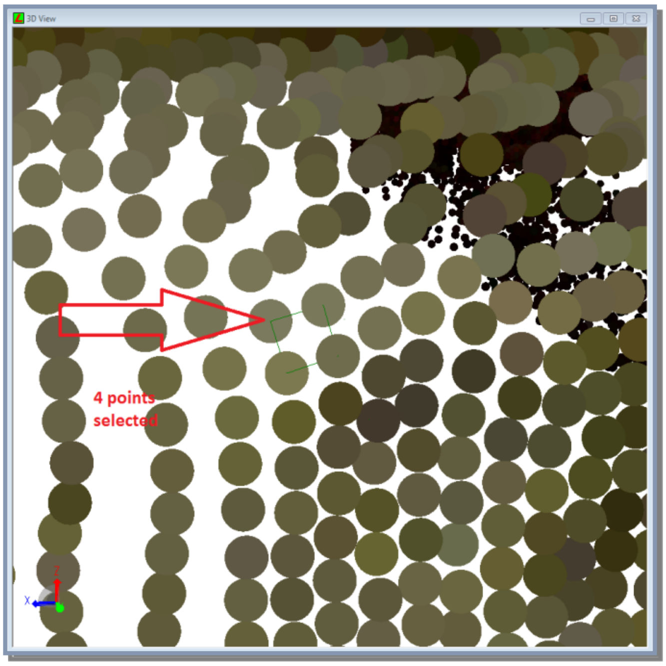

Figure 45 Locating 4 points in the area of interest   Point to be measured on a stone wall (3D model)

Dense point cloud image, LISCAD generated perspective

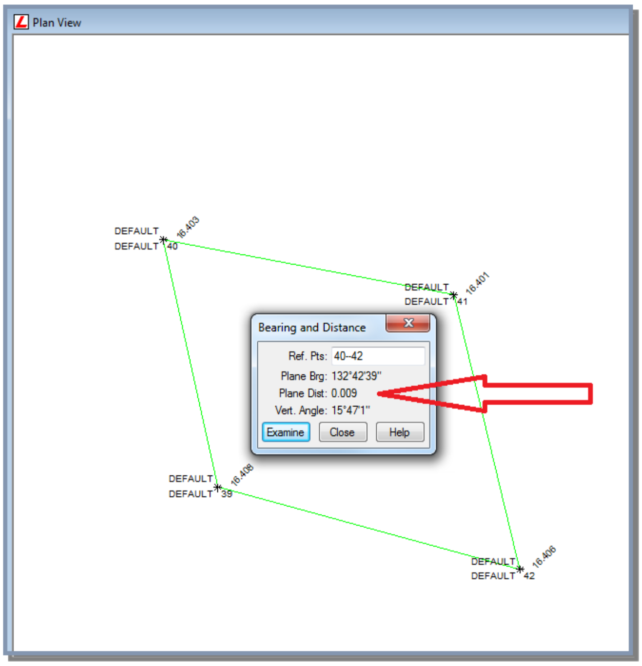

Figure 46 Locating 4 points in the area of interest

Clicking to the 4 selected dense point cloud dots the E/N coordinates and AHD values are recorded and transferred automatically to LISCAD Plain View window.

Note: the longest distance between points is   9 mm

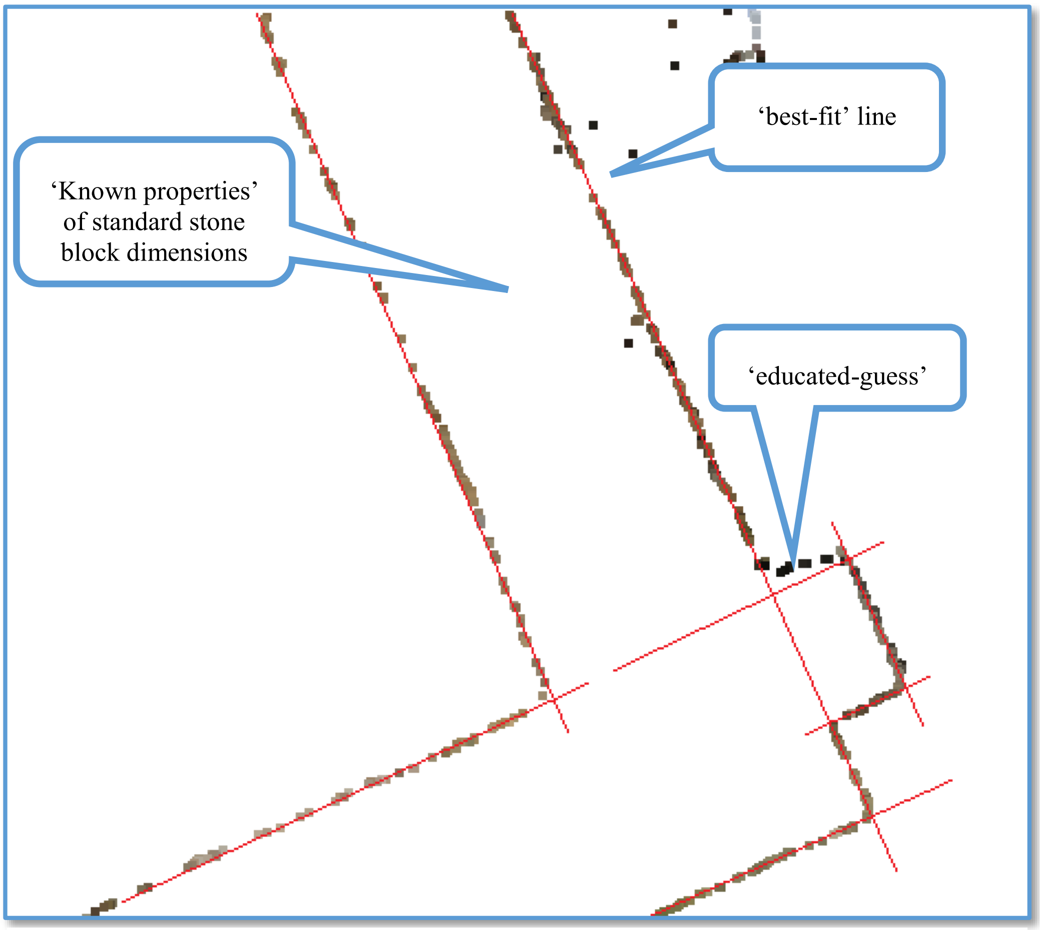

Figure 47 A detail of the 1 mm deep layer of the point cloud, which is representing the wall of the building.

The layer was produced by LAStools 'las2las' tool, was exported to LISCAD as a subset of the dense point cloud data, via PTS file format.

Within LISCAD the subset of points was used to create vector lines in order to produce the Footprint or the Floor Plan of the building