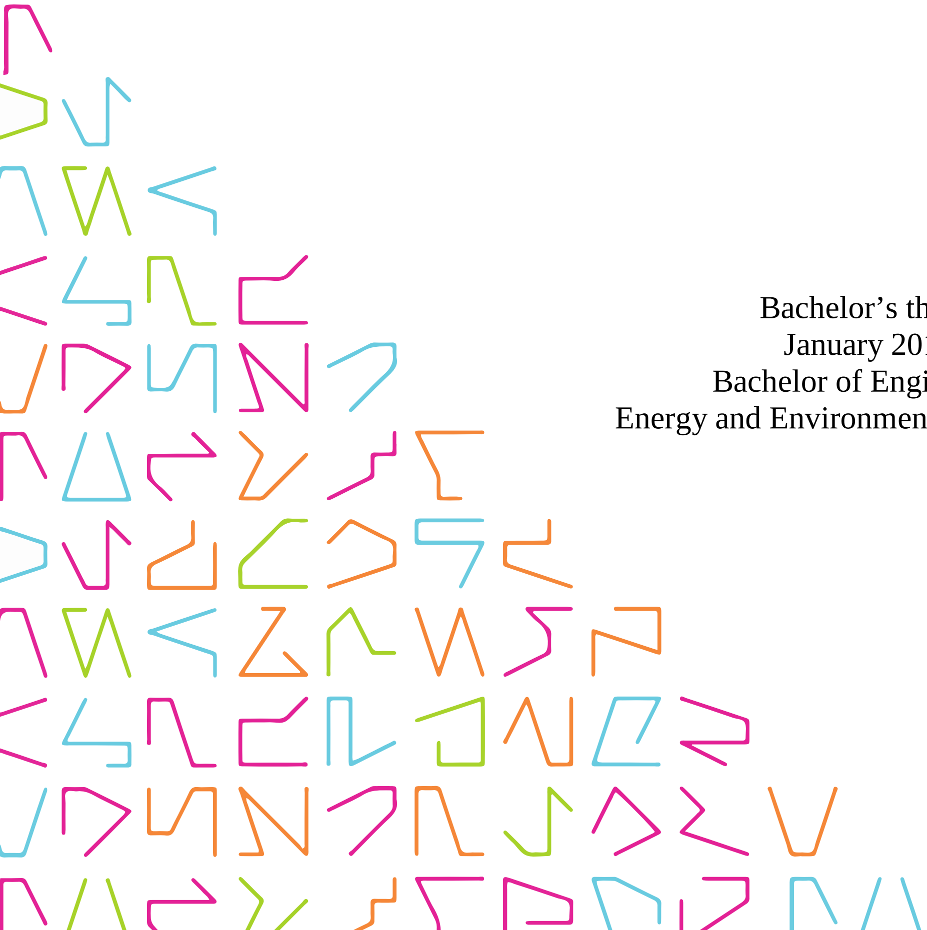
TAMPERE UNIVERSITY
OF APPLIED SCIENCES

A Comparative Case Study between Agisoft Photoscan and Autodesk Recap Photo-To-3D Web Services

Cam Nhung Duong



Bachelor's thesis
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Bachelor of Engineering
Energy and Environmental Engineering

ABSTRACT

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In the era of blooming information technology development, photogrammetry as a science is gaining massive public interests for its proven cost-efficiency and usefulness. At the moment, there are various software and hardware commercially available for consumers to select based on their own preferences. However, the abundant availability also comes with a difficulty in selecting of suitable options without allocating significant effort and resources on trials and errors. Fortunately, studies and reviews have been conducted to provide partial references to help the selection. With the same purpose, this study gave insights into two (02) different photogrammetric software and acted as reference material for future researches by carrying out a comparative case modeling between ReCap Photo-to-3D web service and Agisoft PhotoScan Professional.

Materials for this study were aerial photographs acquired from a separately organized UAV project of an area in Hiedanranta, Tampere. In addition, ground control points were created to help in geolocating the plot of land during modeling. The same data set was used in the photogrammetric applications to build two (02) 3D models. Results were collected for comparison with the assistance of a 3D data analyzing engine named CloudCompare. The workflows were thoroughly documented and user experiences were also discussed.

With a step-by-step guide from scratch to finish, ReCap web offered an almost effortless modeling process with minimum control over the project. On the other hand, PhotoScan, with a variety of commands and functions, provided users additional control over a project while closely assist through comprehensive tutorials. Despite dissimilar workflows and modeling tool sets, results including point clouds, mesh models, DEMs, and orthophoto were in good quality and comparable between two (02) photogrammetric programs. It could be seen that ReCap web is a good tool to get to know photogrammetry and 3D modeling, and PhotoScan by Agisoft is undoubtedly an excellent alternative engineering tool to actively manage workflows and results throughout the projects. However, the choice of software relies heavily on different factors including requirements of the projects as well as of the users.

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Key words: aerial, photogrammetry, photogrammetric software, 3D model, point cloud

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GLOSSARY

2D	2 Dimensional
3D	3 Dimensional
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
ECEF	Earth-Centered, Earth-Fixed
ETRS89	European Terrestrial Reference System 1989
GCP	Ground Control Point
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ISPRS	International Society for Photogrammetry and Remote Sensing
RAM	Random-access memory
RTK	Real Time Kinetic
SfM	Structure from Motion
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
WGS84	World Geodetic System 1984

1 INTRODUCTION

1.1 Overview

Photogrammetry is gaining remarkable popularity as a versatile discipline of which the results are used in various applications such as: land survey and mapping, crime scenes investigation, environmental survey and investigation, medical imaging analyses, design and architecture, etc. It is favorable for generating good quality products at relatively affordable costs and commercially accessibility (Matthews 2008, 3). Especially in the midst of blooming technology development, tools and equipment are being developed continuously to make the science even more approachable to different consumer groups, giving out extensive selections based on budgets, requirements, and features.

However, the abundant availability often comes with difficult decision making, particularly when it involves financial aspect. Luckily, as the science attracts more users, many are willing to share their personal experiences over trials and tests to the public. This coupled with remarkably details marketing brochures and guidelines of software and hardware producers has made it slightly easier in making purchases.

At Tampere University of Applied Sciences, photogrammetry is incorporated into a few study programs to equip students with up-to-date knowledge and to assist in-house R&D projects. ReCap photo-to-3D web services was one of the photogrammetric software which had already been employed by the educational institute; in order to catch up with current development, a need to explore for alternatives arose, and thus, this study was conducted as a case-specific review of the photogrammetric software.

The study explored the applicability of Agisoft PhotoScan Professional edition (education license) in comparison with Autodesk ReCap photo-to-3D web services by carrying out a comparison study between two (02) 3D modeling cases of the same terrain model. Within this study, detailed workflows of modeling cases is documented, the modeling results are presented and compared with the assistance of a third software, and user perspectives concludes the findings. A briefing on material acquisition is also included to provide complementary information as it belongs to a separate project and is not the focus of this study.

1.2 Organization of the paper

This section provides a walk through to the topics which the paper covers. Chapter 2 explains relevant terminologies and concepts used within the paper; and followed by brief introduction to software used for the study in chapter 3. Chapter 4 presents the data acquisition through a separately organized fly project. Details of workflows are documented in chapter 5. Chapter 6 shows the modeling results of the surveyed land area as well as the comparison between them. Own experiences (including problems encountered) throughout the modeling processes are discussed in Chapter 6; and conclusions are drawn out in Chapter 7.

2 TERMINOLOGY AND CONCEPT

2.1 Photogrammetry

The ISPRS has published a guide paper to provide common ground for the international use and definition of photogrammetric terminologies. It defines photogrammetry as the science of “deriving accurate and reliable 3D measurements from images” (Granshaw 2016, 238). Going through a long historical development, photogrammetry has transformed from analytical photogrammetry to analogue photogrammetry, and ever since mid-90s till the current date, photogrammetry is well-known to be in its digital era (Granshaw 2016, 221). According to the same paper, it could be classified as two (02) main branches: topographic and close-range application (Granshaw 2016, 238). Topographic (or aerial) photogrammetry utilizes a sensor mounted to a flying aerial vehicle (aircrafts, UAV, drones) to capture multiple overlapping photographs of earth surface and topographic features. Close range (or terrestrial) photogrammetry uses a stationary camera on/near ground to capture elements at a closer perspective (Kar 2014).

This study experimented on materials obtained from an aerial survey project. It produced the main products of aerial photogrammetry: point cloud, 3D terrain model, DEM, and orthoimagery.

2.1.1 Principle of aerial photogrammetry

When a single aerial photograph is taken (ideally camera lens is in near-perfect vertical position to the ground and the ground is plane), light rays from camera lens travel in a straight line and run through focal point, image point, and real ground point. With the information of focal length and the flight height, the length of light rays as well as (x,y) coordinates of ground points can be calculated (Schuckman n.d).

The obtained information is, however, in a metric coordinate system and is not relevant to the real world coordinate; additionally, camera tilts exist in real life and must be taken into account in order to make accurate measurements. Therefore, a need to introduce points with real-world 3D coordinates is necessary to tie the position of images to their actual position. From these known points, the true photograph spatial position and angular orientation are determined (Schuckman n.d; McGlone 2016).

In real world situation, the ground is nowhere near flat and there is always ground elevation which makes it difficult to calculate the true point height above the sea level. To solve this problem, principle of stereo photography is utilized as aerial photographs are taken in certain overlapping manner so that points appear in at least two (02) images. Then, intersections between light rays happen as seen from figure 1 and certain exact points could be located in 3D space (Schuckman n.d).

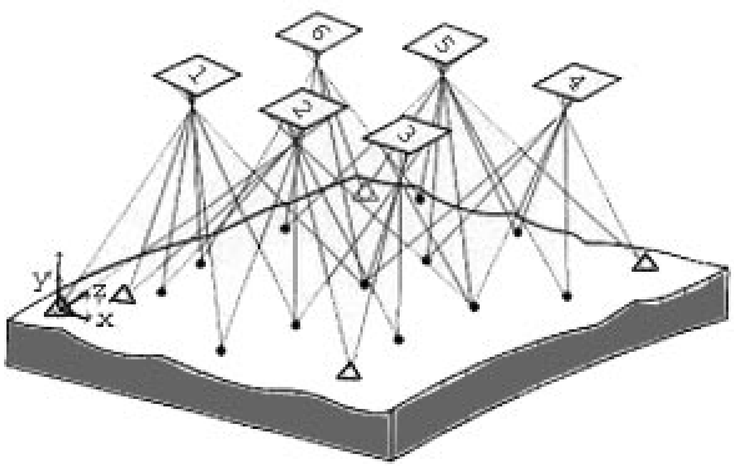


FIGURE 1. Overlapping aerial photograph and intersecting light rays to ground (Aerial Triangulation n.d)

2.1.2 Photogrammetric software

The development of photogrammetric software has allowed generation of photogrammetric products to be significantly less labor intensive and time consuming. In order to do so, the software are programmed to perform complicated and difficult mathematical equations. However, to simply explain the general technique which most photogrammetric software employ, Agisoft has included a short description in their PhotoScan User Manual (n.d). The aim was to construct 3D model from a set of 2D photographs of an object taken from different angles. Based on automatically imported camera positions and orientations, the software tries to align the photos and match common points it could find in pairs of photos to establish a tie point cloud or sparse point cloud. Then, a dense cloud is generated based on the camera/GCPs (if available) optimization as the software starts to adjust scaling and build more points onto the sparse cloud. After that, polygons are constructed by connecting points in the cloud to form a polygonal mesh, and a complete 3D model is constructed once the mesh undergoes texture mapping (texture is taken from individual photographs).

2.2 Point cloud, mesh, and 3D model

3D or three dimensional object is an object which has horizontal (x), vertical (y), and depth (z) values. In real life, 3D objects exist physically and in digital space, they can be represented by specialized software using mathematical functions. This act of recreating 3D models is called 3D modeling, and nowadays, it is made automatically with the assistance of 3D CAD software (Slick 2017).

Different software offer distinctive approaches to constructing a 3D model; and among them, a common method is as illustrated bellow in figure 2. Point cloud is a collection of points in a 3D coordinate system and is acquired either through laser scanning or photogrammetry (Benli 2015). Usually, a point cloud is sufficient to display external shape and features of object, even though it might contain noises and different point densities depending on the quality of input scans or the overlapping intensity of photographs (Broomhall 2016).

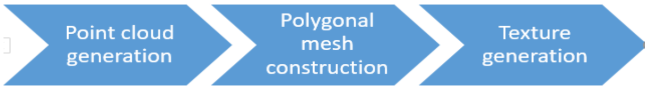


FIGURE 2. General 3D model construction workflow

Mesh construction is done after point cloud generation. Mesh consists of polygons and vertices formed to portrait the surface of an object (Power 2012). Basic notions of a mesh model are: vertex, edge, and face. Vertex (plural: vertices) is a point with (x,y,z) values and is usually the meeting of two (02) lines. In geometric model, it could also be explained as a corner of polygonal shape. An edge is a line created where two (02) polygons meet. Face (or polygon) is a 2D surface which is formed by connecting three (03) vertices (Blender 3D: Beginner Tutorials n.d, 28).

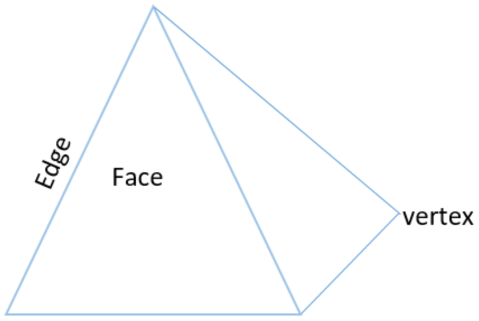


FIGURE 3. Illustration of geometric components including edge, face, and vertex

With those fundamental components, a mesh model is made including a network of vertices, faces, and edges. In order for a mesh to become complete 3D model, textures and shades are added. With current cutting edge tools, meshes could be rendered and refined into figures with realistic details (Slick 2018). Thus, 3D models are widely favorable and utilized in numerous application ranging from designing to multidisciplinary engineering services.

2.3 DEM and orthoimagery

For a better understanding of these terms, raster data should be briefly explained. A raster data set is a special GIS storing data format. It consists of a matrix of cells and usually illustrates real-world phenomena for specific areas. Within each cell, one value (elevation, temperature, natural geographical features, concentration of elements, etc.) is assigned to and it represents the whole cell area (What is raster data n.d). While being grid-based, a raster file is often presented with color gradient or pictures for ease of data interpretation (Digital Elevation Models n.d).

DEM or Digital Elevation Model is defined as a grid-based raster data to illustrate bare-earth topographic surface digitally (Klinkenberg n.d). This means the model presents elevations (z - values) of only terrain surface, excluding all artificial features and natural elements such as vegetation. The elevation values are obtained in many ways, however, in current digital photogrammetry, they could be derived from incorporated geographical data of stereo digital photographs (GIS Geography 2016).

Digital Terrain Model or DTM has distinct definitions varying between areas. In some countries, it is practically understood as similar to DEM. However, in other countries such as the United States, DTM is not a stand-alone model but an extension to DEM as it contains breaklines to help shaping terrain by introducing interruptions onto the smooth surface which DEM portraits (Heidemann 2014, 18 & 20).

Digital Surface Model (DSM) is a type of DEM which includes the elevation of the top surfaces of artificial (buildings, power lines, bridges) and natural elements (tree canopies) (Heidemann 2014, 20).

In this study, DEM will be treated as a generic term for both DTM and DSM since ReCap web only supports the creation of a general DEM (including all man-made and natural features), while PhotoScan allows the generation of both DTM and DSM.

Orthoimagery, or orthomosaic, is defined as a combination of remotely-sensed and orthorectified aerial photographs. Orthorectification is the process of geometrically correcting aerial images from distortion caused by remote sensing devices such as satellite, unmanned aircrafts. By using mathematical equation, sensor data, elevation model (DEM), GCPs and individual orthophotos, current advance technology allows the automatic generation of these map-quality imagery which could be used in various GIS application and extraction of highly accurate geographical information (Introduction to ortho mapping n.d) .

2.4 Coordinate system and ground control points (GCPs)

In aerial photogrammetry, models and images are georeferenced to a specific coordinate system (Singh 2016). A coordinate system, in general, provides common ground in which different maps, geographical illustrations, terrestrial imagery, etc. could be illustrated together. There are two (02) main types of coordinate system which are geographic coordinate system and projected coordinate system (Coordinate systems, map… n.d).

While geographic coordinate system is a system built on 3D surface (spheroid or ellipsoid) and the coordinates are expressed in latitude and longitude (units of measurement are either degrees or degrees, minutes, seconds), projected coordinate system is the projection of the earth onto a 2D flat surface with the units of measurement in meter or feet. A projected coordinate system is always based on a geographic coordinate system (Coordinate systems, map… n.d). In this study, the inherent camera coordinates were in WGS84 – a geographic coordinate system, but the one which the ground control points belonged to was ETRS89/GKFIN 24 – a projected coordinate system based on reference system ETRS89. WGS84 is a global system and ETRS89 is a reference system built for Europe (Difference between WGS84… n.d).

In the area of interest, points marked on the ground with their geographical coordinates accurately recorded are called Ground Control Points (GCPs) (survey points and markers are also used as interchangeable terms). Aerial images, even those being acquired by the most advanced technology, can contain errors such as geographical location or geometrical inaccuracy. Thus, it is essential to use GCPs to assist the georeferencing and orthorectification of the imagery, especially for tasks which require high precision mapping and global accuracy (Zapata 2015). While there are different guides on how to construct good set of survey points, the main principles are visibility, accuracy, and number. Points should be marked with clear sign to be visible from above/high altitude. Their geographical coordinates have to be recorded using the high accuracy GPS. Also, depending on the survey area, points should be sufficient and distributed evenly to cover the total area (McCarty 2014).

3 SOFTWARE IN THIS STUDY

Agisoft PhotoScan Professional Edition version 1.3.4 (Student license) (or PhotoScan): a stand-alone photogrammetry desktop application which offers fully automated 3D model-building from up to a thousand of 2D still images/laser scans using local computer processing power. With the ability to produce high quality aerial and close-range triangulation, dense point clouds, and accurately georeferenced DEMs and orthoimagery, PhotoScan is widely used in various projects including archaeological studies, aerial surveys, gaming and animation, etc. The program belongs to Agisoft LLC which is founded in 2006 and situated in St. Petersburg, Russia. Even though the product only comes with a subscription, Agisoft allows user to experience the software with a 30-day trial license. For EDU/student license, all features are accessible without limitation (PhotoScan presentation 2016).

Autodesk ReCap 360 Photo-to-3D web application (or ReCap web): a cloud-based photogrammetry engine bundled with ReCap desktop. While ReCap desktop application is used to process laser scans, the web service is built solely to handle photographs utilizing cloud-computing power. Without product subscription, users could access and use the limited features of web service. ReCap web is capable of aerial and close-range 3D model reconstruction with the options to georeference the models and to generate orthophotos (Product Overview n.d).

ReCap desktop: a 3D scanning desktop-based engine which is coupled with ReCap web. While ReCap web focuses on processing digital photographs, ReCap desktop build point clouds and 3D models from scans. This application was used to convert an Autodesk point cloud file into a versatile format (Product Overview n.d).

CloudCompare: a free and open source software for 3D data processing. It was originally designed for 3D data comparison, and is continuously developed to provide extensive set of tools for data analyses and modifications (CloudCompare n.d).

The main focuses of this study are PhotoScan and ReCap web. CloudCompare is used as an assisting tool to open, view, and compare results of the photogrammetry software.

4 DATA ACQUISITION

A small-scale, independent aerial survey project was organized in the future district Hiedanranta, Tampere. It was decided that this study would utilize the data obtained from the flight for its experiment, and thus, this section provided brief description of the flight.

FIGURE 4. Satellite view of the area (within red boundary) and the surrounding (Google map 2017)

A part of old factory area is situated within the future district Hiedanranta, western Tampere was chosen as the location (figure 4). By locating on the shore of Lake Näsijärvi and not far off from the city center, this future city district was expected to be developed into a lakeside sustainable district which will provide many development opportunities as well as homes for people (Karppi 2017). Therefore, it was receiving special attentions from the public and a part of it was selected as the test subject for this study.

Purposely, the site was chosen with diverse geological settings, elevations, and different man-made properties so that those features could be visible when building the 3D models (Agisoft PhotoScan user manual… 2017, 7).

To assist in georeferencing 3D models, six (06) GCPs are scattered (in red marks) within the project area (figure 5). On site, they were marked with white cross as shown in picture 1a. Their positions (coordinates) were measured using the GPS receiver (picture 1b). The flight took place after setting up GCPs and successfully acquired 214 photographs, in which 2 photos were bad and discarded. Total area covered was 0.258 km^2 or 25.8 ha (Agisoft Processing Report 2018 1).

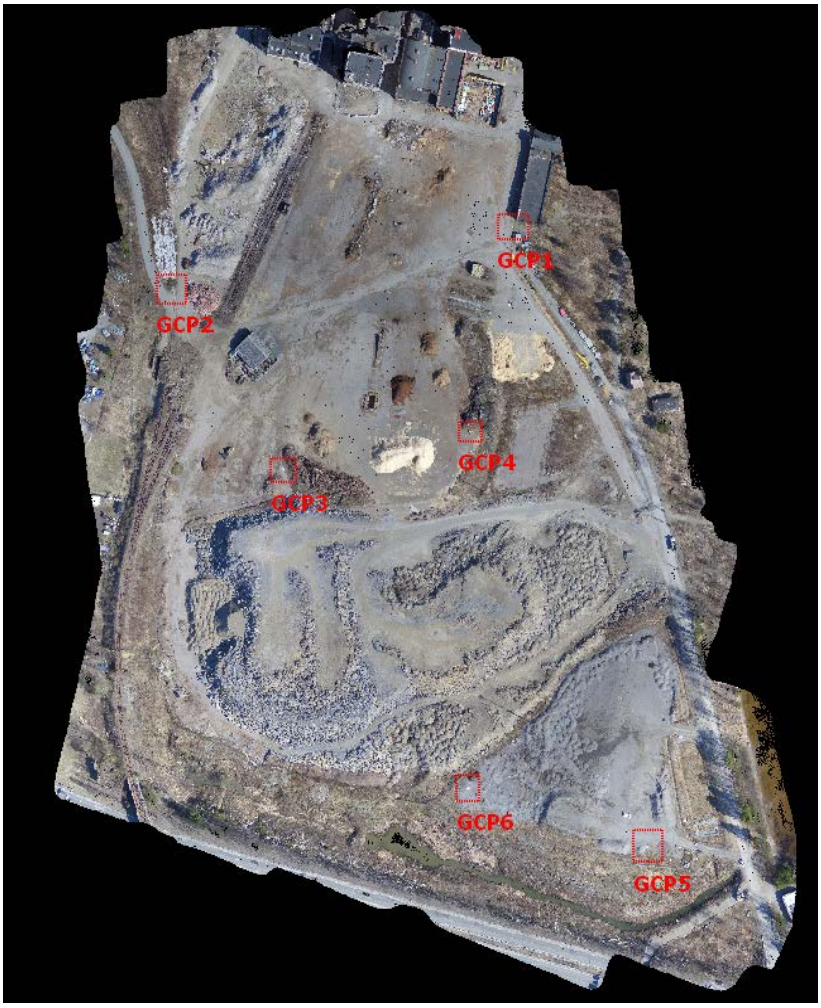
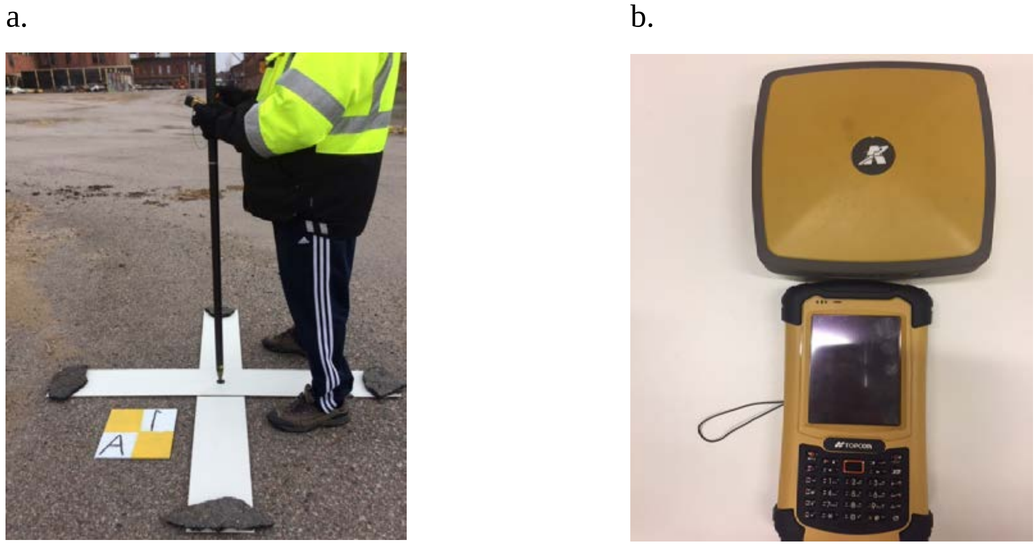
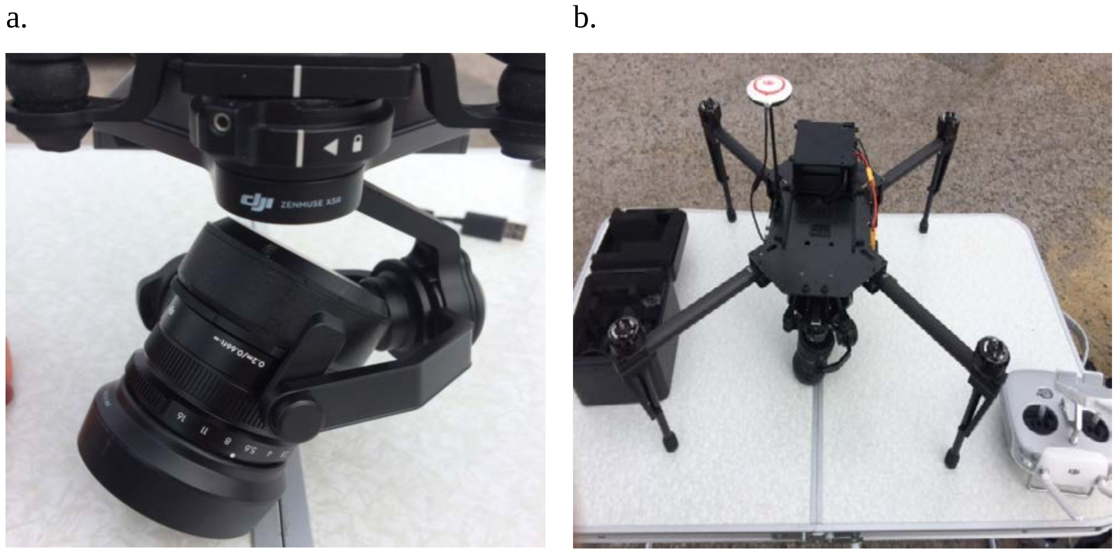


FIGURE 5. Aerial view of the project site with GCP positions marked



PICTURE 1a. White cross to mark GCP position and b. GPS recording of GCP with GNSS receiver Topcon RTK GNSS receiver

The GNSS receiver used was Topcon HiPer SR - a well-known equipment for recording up to mm-level accuracy readings. The drone model and camera can be seen from picture 2. With the integrated GPS/INS system to help navigate and control the unmanned vehicle during the flight, its positions were recorded, thus, the position of each photograph was known.



PICTURE 2a. Lens and b. Drone with foldable GPS tracking antennas & remote control

Table 1 presents complementary technical information of equipment used for aerial survey.

Table 1. Relevant technical information of equipment used

Equipment	**Name**	**Technical information**
GPS receiver	RTK GNSS receiver Topcon HiPer SR (HiPer SR Specification 2017)	RTK (L1+L2) accuracy: Horizontal: 10 mm + 0.8 ppm Vertical: 15 mm + 1.0 ppm
Camera	M100_X5R (Agisoft Processing report 2018, 1)	Focal length: 15 mm Pixel size: 3.76 x 3.76 µm Resolution: 4608 x 3456
Drone	Matrice 100 (Agisoft Processing report 2018, 1)	Quadcopter

5 DATA PROCESSING

Same set of data used in both photogrammetric applications with their corresponding initial coordinate systems are presented in Table 2. Prior to modeling, the positions of GCPs were identified via visual inspection, and their appearances in aerial photographs were documented.

Table 2. Information on input materials for modeling

	Quantity	**Coordinate system**	**Appear in photos**	
Aerial photograph	212	WGS84 (EGM96)	n/a	
GCP/Marker/Survey point	6	ETRS89/ GK24FIN (EPSG: 3878)	GCP1	171 – 174
			GCP2	162 – 165
			GCP3	103,104,118,119
			GCP4	107,108,115,116
			GCP5	72,73,77,78
			GCP6	40.41,45,46

5.1 Recap Photo-to-3D web service

Project trials were done during different periods of a day and in different days to test out the optimal time for project creation. A stable internet connection was secured for most of project activities. As mentioned, ReCap web worked based on server processing power, thus, it was irrelevant to consider the local (computer) processing system in this chapter. Google Chrome was the recommended web browser for best ReCap web experience.

Below bullet points outlines the workflow with ReCap web in this study:

- Photo upload
- Project quality setup
- Project submission
    - Results review and download
- Project resubmission
    - Survey points registration
    - Project quality setup
    - Results review and download

5.1.1 Photo upload

To begin, a new photo-to-3D project was created. The first step was to add photos for 3D model reconstruction, and they could either be uploaded from local directory or from A360 drive. As shown in figure 6, the left view is without and the right view photo is with uploaded photos. The aerial images were uploaded to a temporary portal which allowed users to continue modifying the input data as they proceed. After successfully uploading, it was possible to add or remove the unwanted photos.

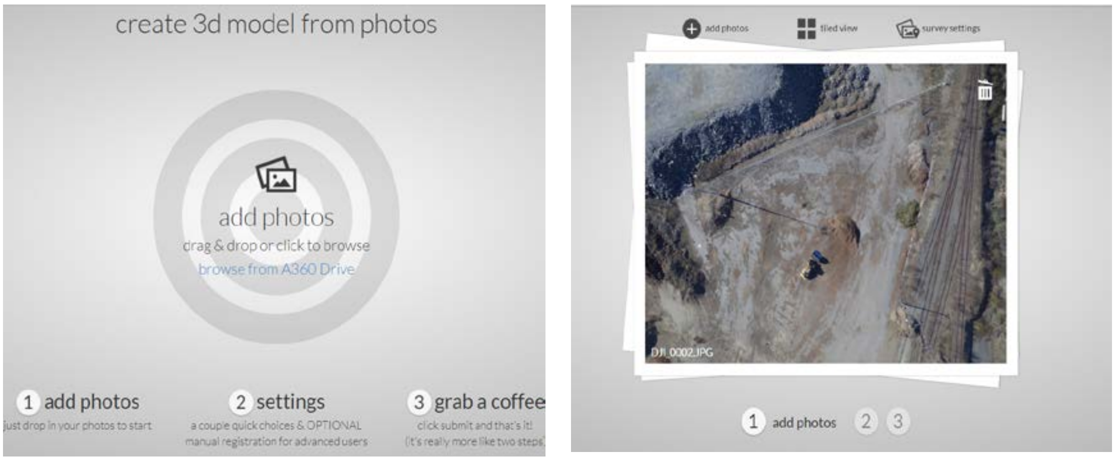
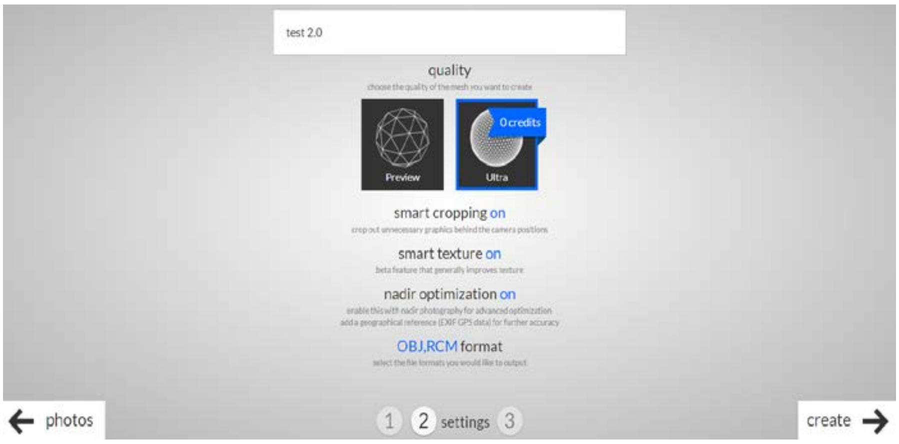

a.
b.

FIGURE 6a. User interface before photo upload and b. User interface after photo upload (Sample)

5.1.2 Quality settings

As soon as no additional data modification was needed, modeling continued directly to quality settings, and adding survey data was skipped. Quality settings platform is seen from figure 7.



test 2.0

quality

choose the quality of the mesh you want to create

smart cropping on

crop out unnecessary graphics behind the camera positions

smart texture on

beta feature that generally improves texture

nadir optimization on

enable this with nadir photography for advanced optimization
add a geographical reference (EXIF GPS data) for further accuracy

OBJ,RCM format

select the file formats you would like to output

FIGURE 7. User interface in quality setting stage (Sample)

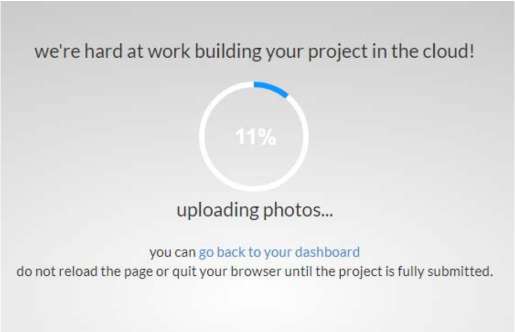
Table 3. Available quality settings & export file formats in ReCap web (Edu license) and their descriptions

Setting		**Description**
Mesh generation	Preview	Build the mesh model in rough accuracy (Schain 2017)
	Ultra	Build the mesh model in higher accuracy (Schain 2017)
Smart cropping	On	Remove the irrelevant geometry before building the final model (Schain 2017)
Smart texture	On	Enhance the ability to filter and choose high quality texture from available photographs to build model optimal texture (Schain 2017) – not available in preview mesh mode
Nadir optimization	Off	Coupled with GPS data to enhance accuracy of model position and scaling (Schain 2017)
Format(s) enabled	OBJ	Versatile 3D file format to use in various 3D applications (About Scan and Photogrammetry… 2018)
	RCM	ReCap mesh file (About Scan and Photogrammetry… 2018)
	RCS	Autodesk 3D/project file for point cloud (About Scan and Photogrammetry… 2018)
	Ortho	Option to generate orthoimagery (About Scan and Photogrammetry… 2018)

From table 3, the project settings along with their description are found. They were available exclusively for subscribed license.

5.1.3 Project submission and results review

As settings were defined, the model was ready to be reconstructed. The project was submitted to Autodesk cloud server; during this process, website interruption should be avoided until successful project submission. ReCap web shows the submission status as seen in figure 8. After successful submission, the data was processed on the cloud server and required no further action until the model reconstruction was completed.



we're hard at work building your project in the cloud!

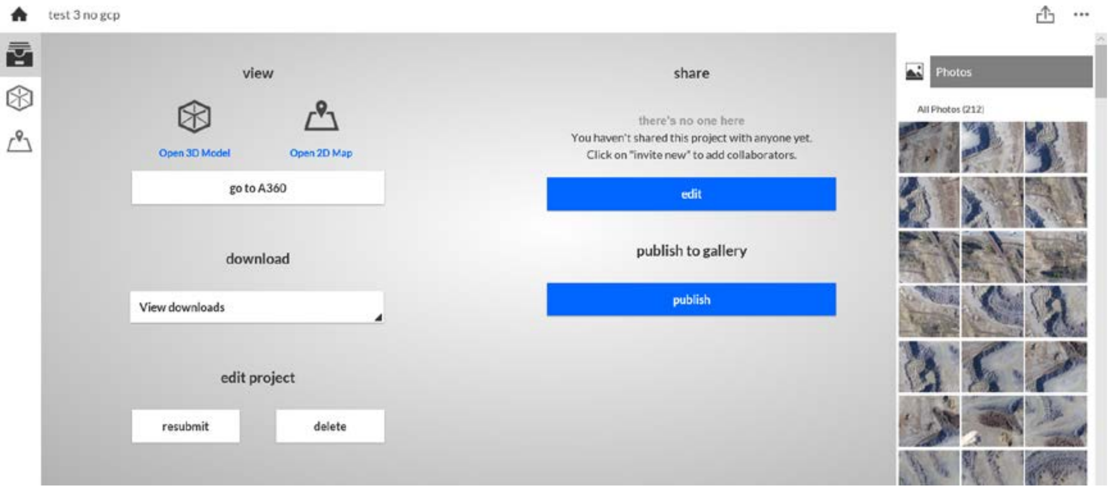
11%

uploading photos...

you can go back to your dashboard
do not reload the page or quit your browser until the project is fully submitted.

FIGURE 8. User interface during project-to-cloud upload

Once the model is built, it is viewable using ReCap web viewer by clicking on project's thumbnail on the home page and web layout (figure 9) offers a few options including: viewing, downloading, editing, sharing, and publishing to gallery.



there's no one here
You haven't shared this project with anyone yet.
Click on "invite new" to add collaborators.

FIGURE 9. User interface of a chosen completed project (Sample)

In 3D viewer, ReCap web enables 3D (mesh) model viewing (solid, shaded, wireframe mode) and navigation using simple tools (figure 10a). In 2D viewer (figure 10b), ReCap web shows a georeferenced photo on main panel and its roughly estimated position on google map on the right-hand side of the page. This would be available only when “ortho format” was selected during quality setting and there were known geographic data. For this trial project, the georeferenced 2D photo was generated utilizing the GPS data embedded in original aerial photographs.

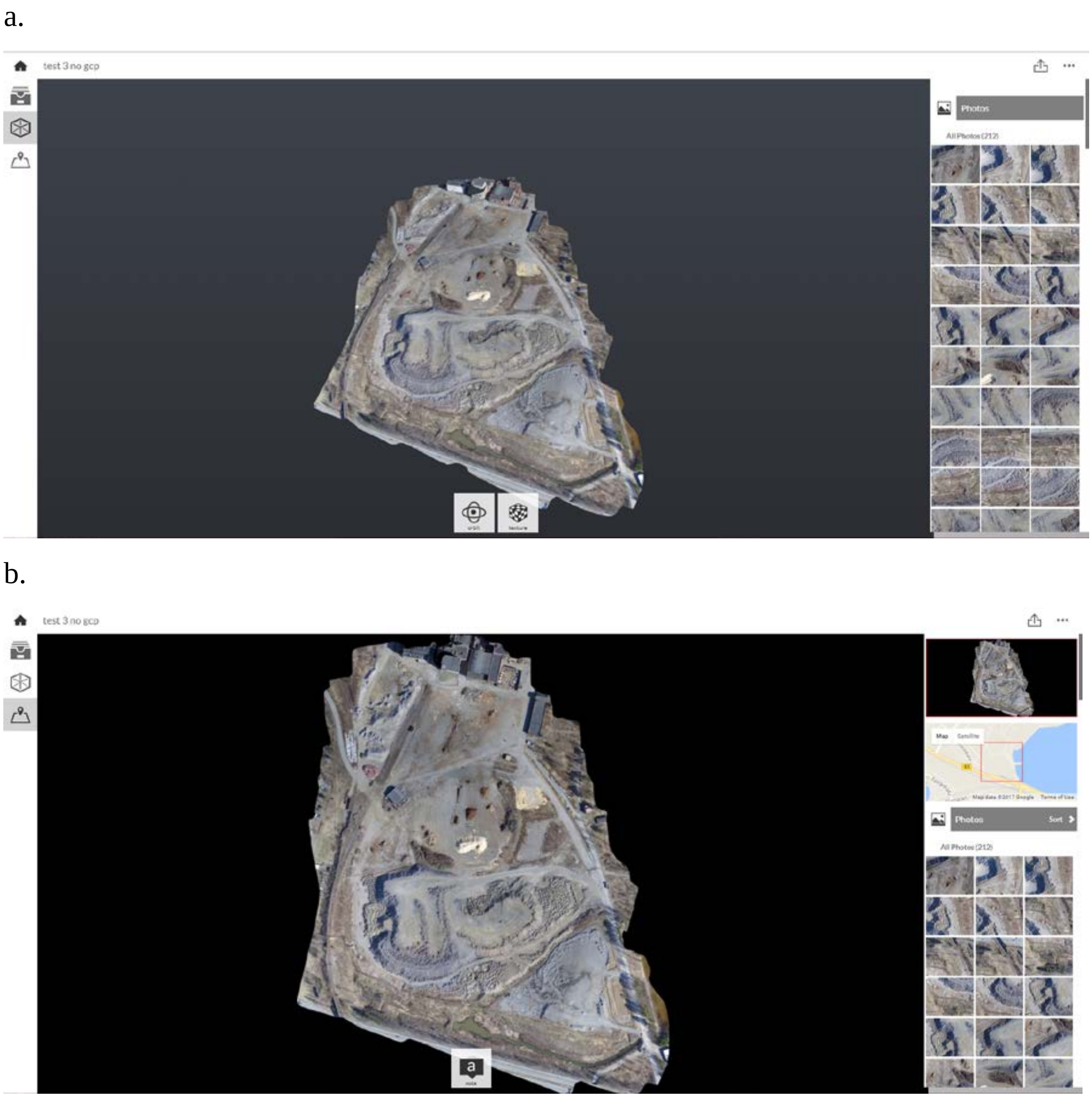


FIGURE 10a. User interface in 3D web viewer and b. User interface in 2D web viewer (Sample)

After viewing, results were downloadable in different formats as pre-defined at quality set-up. They were also available in A360 Drive – an online storage designated for navigating, sharing, and downloading Autodesk projects.

5.1.4 Project resubmission

The trial was resubmitted without recreating project from the scratch to add survey settings. In ReCap web, the GCPs were known as survey points, and these two (02) terms were interchangeable. To add the survey points, the web layout opens up side-by-side photo-viewing panes (figure 11a). One (01) GCP should be marked in three (03) to four (04) different photos based on previously identified photos containing GCPs (Adding Survey Points… 2017). A photo is first selected from either pane; then it is zoomed in to make white cross GCP visible to place a marker (figure 11b). The same procedure was done for the other photo view pane and carried out until all six (06) GCPs were registered with four (04) photos per each. To keep track, a circular icon appeared next to photo viewers whenever a survey point was enabled, the figure in the middle showed the order of GCP and the surrounding color ring indicated number of photos registered for current GCP (red for one photo and green for three or more). Two (02) viewing panes helped speeding up the registering process, and if a photo was selected on one pane, it would be excluded from the other pane to avoid double selections.

In ReCap web, there were only three (03) coordinate systems available which were XYZ, ECEF, and LatLong (Adding Survey Points… 2017); XYZ system was used for this project and the coordinates were the ones recorded using RTK GPS receiver. Geographic data was filled in one (01) time per survey point and was automatically imported to all photos containing the specific GCP markers.

When all survey points were successfully registered, the quality settings were mostly unchanged, except for selection of “Ortho” file format to get orthoimagery as result. The resubmission was also cloud-computed utilizing the pre-uploaded images and required no attention until the project succeeded. The project was resubmitted as a new one. Results were reviewed and downloadable from ReCap web viewer or from A360 Drive.

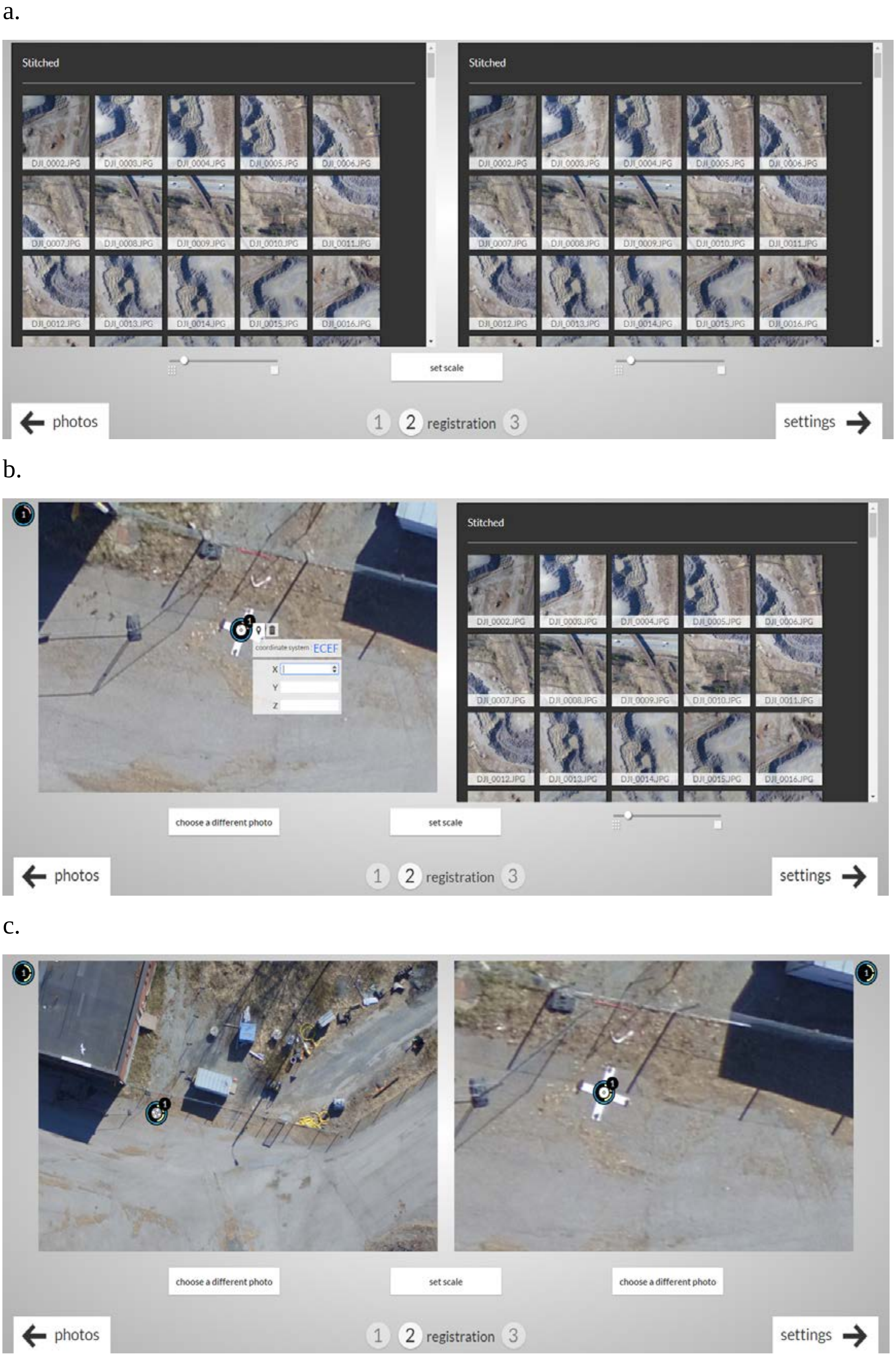


FIGURE 11a. Side-by-side photo viewers; b. Survey point marker in one photo and the input of GPS data; c. Survey point marker placed in the other photo (Sample)

5.2 Agisoft PhotoScan Professional

5.2.1 Preliminary settings

According to System requirements (n.d) of Agisoft, PhotoScan required good local computing power and the processing system of used laptop can be seen in Table 4. Most of the workflow followed tutorials and user manual which were provided by Agisoft team (Agisoft PhotoScan user manual n.d; Tutorial Beginner level n.d).

Table 4. Specifications of project laptop

Laptop: Dell	Processor: Intel®Core™ i5 – 4300U CPU @ 1.90GHz 2.50 GHz
	GPU: GeForce GT 720M (2 cores @ 1550 MHz, 2048 MB)
	OS: Windows 64
	RAM: 8GB

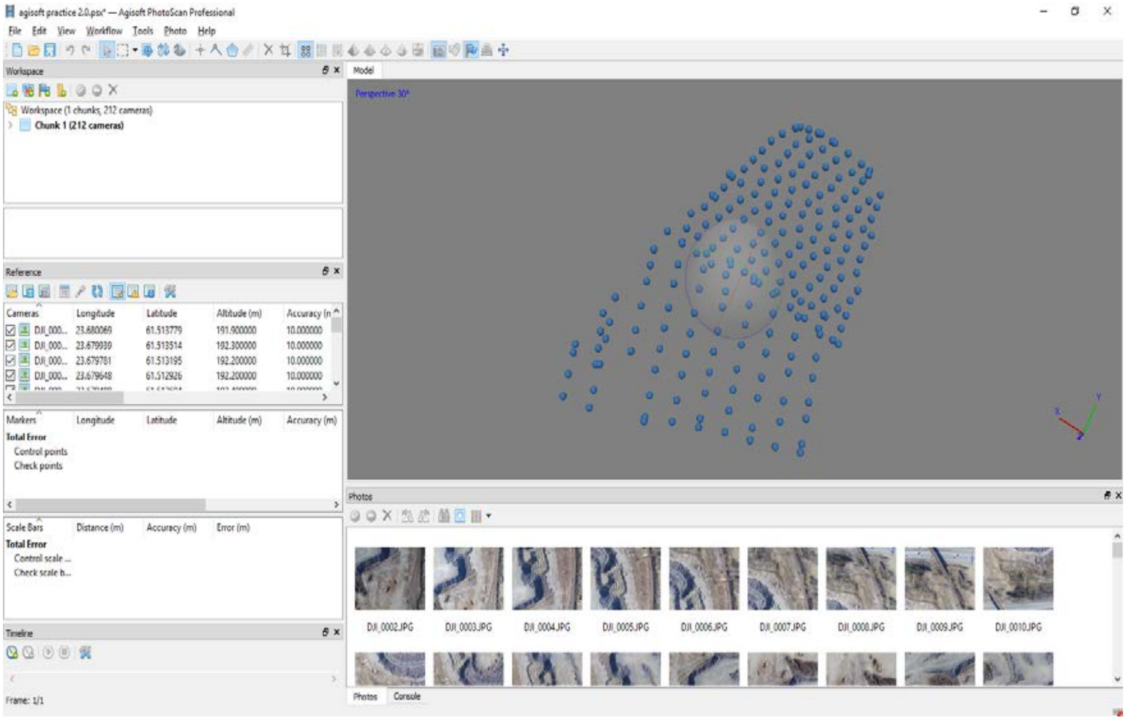
Throughout this workflow, most of the figures presented were only user interface examples (screen captures) taken during the modeling process and were noted with “sample” word. Setting parameters were mainly kept at default. PhotoScan did not have an undo function.

The following outlines workflow with PhotoScan which is presented in this chapter:

- Preferences settings
- Photo upload
- Photo alignment
- Marker registration
- Camera/marker based optimization
- Dense cloud generation and point cloud classification
- Chunk duplication
- Mesh generation
- DEMs & orthomosaic generation
- Result exports
- Batch processing

Figure 12 presents PhotoScan user interface. Most commands is found from the main ribbon on top of the layout. PhotoScan toolbar locates underneath the main ribbon and contains complementary tools for project navigation. There are four main panels in the application window. Workspace displays current project with all its working elements. Under Workspace pane, Reference pane shows information (coordinates and errors) of camera and markers. On the right side of Workspace panel, Model view displays point clouds, mesh model at different processing stages; and Ortho view presents 2D processed data including orthomosaic and DEM. Aerial photographs are reviewed and manipulated in the Photo pane.

Before starting any project, it was necessary to adjust the preferences settings according to the recommendation in Agisoft tutorials (Tutorial Beginner level…n.d, 1). To start modeling, a new project was created and saved under local directory. To visualize a good project flow, a list of steps could be found orderly under Workflow tab, and each step was enabled only upon the completion of preceding ones.



Cameras	Longitude	Latitude	Altitude (m)	Accuracy (m
☑ DJI_000...	23.680069	61.513779	191.900000	10.000000
☑ DJI_000...	23.679939	61.513514	192.300000	10.000000
☑ DJI_000...	23.679781	61.513195	192.200000	10.000000
☑ DJI_000...	23.679648	61.512926	192.200000	10.000000

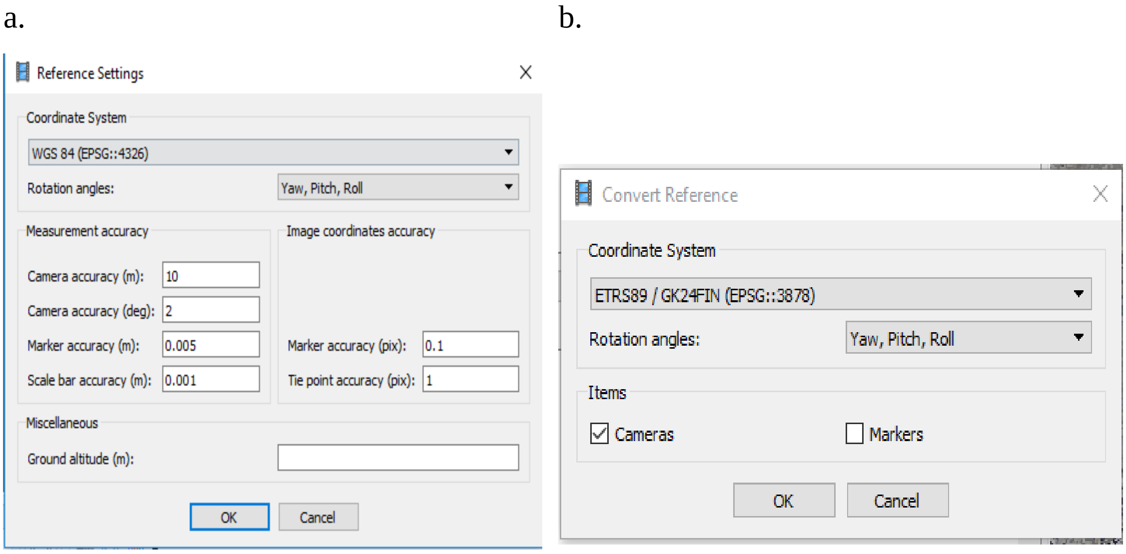
Markers	Longitude	Latitude	Altitude (m)	Accuracy (m)
Total Error				
Control points				
Check points				

Scale Bars	Distance (m)	Accuracy (m)	Error (m)
Total Error			
Control scale ...			
Check scale b...			

FIGURE 12. Graphical user interface of a project after uploading photos, including all work panels (Sample)

5.2.2 Photo upload

The first step was to add photos or folder containing photos, the command could be found either from the dropdown Workflow tab or on Workspace pane. Once the photographs are added, a chunk (with number of photos uploaded) is created in Workspace pane (figure 12). Locating in Reference pane below Workspace are all aerial photos with their geographical data automatically imported. To check the coordinate system of those embedded data, reference settings dialog box could be opened from the toolbar on Reference pane (figure 13a). Since the photos and the GCPs did not share the same coordinate systems, it was necessary to convert the coordinate system of the aerial images' positions (WGS84: EGM96) to ETRS89/GK24FIN (ESPG: 3878), as it was the local (Tampere) coordinate system (EPSG.IO n.d). From Reference toolbar, the Convert tool was opened; and correct coordinate system could be found under Projected Coordinate drop-down. Cameras box was checked for conversion.



a.

Reference Settings

Coordinate System: WGS 84 (EPSG::4326)

Rotation angles: Yaw, Pitch, Roll

Measurement accuracy

Camera accuracy (m): 10

Camera accuracy (deg): 2

Marker accuracy (m): 0.005

Scale bar accuracy (m): 0.001

Image coordinates accuracy

Marker accuracy (pix): 0.1

Tie point accuracy (pix): 1

Miscellaneous

Ground altitude (m):

b.

Convert Reference

Coordinate System: ETRS89 / GK24FIN (EPSG::3878)

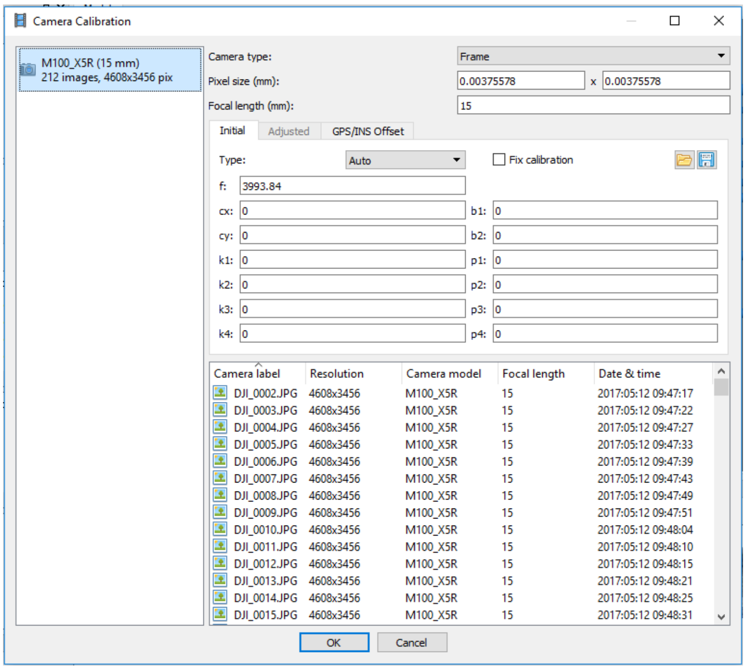
Rotation angles: Yaw, Pitch, Roll

Items

☑ Cameras ☐ Markers

FIGURE 13a. Reference settings for both camera and marker; and b. Convert tool dialog box for cameras and/or markers coordinates conversion (Sample)

Prior to aligning photos, camera parameters derived by PhotoScan should be checked by opening Camera Calibration window from Tool tab. The dialog box is shown as in figure 14. All information within this box was automatically imported, and it was necessary to specify pixel size and focal length of camera lens in case no value was available.



M100_X5R (15 mm)
212 images, 4608x3456 pix

Camera type: Frame
Pixel size (mm): 0.00375578 x 0.00375578
Focal length (mm): 15

Type: Auto
☐ Fix calibration

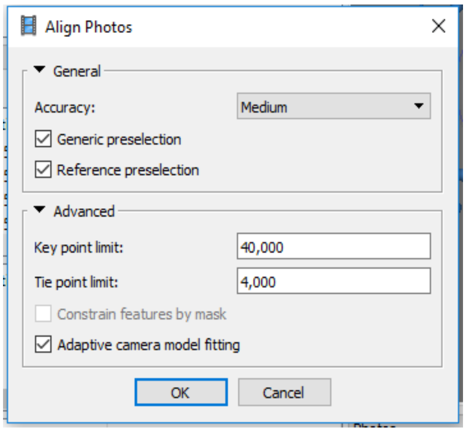
f: 3993.84
cx: 0
b1: 0
cy: 0
b2: 0
k1: 0
p1: 0
k2: 0
p2: 0
k3: 0
p3: 0
k4: 0
p4: 0

Camera label	Resolution	Camera model	Focal length	Date & time
DJI_0002.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:17
DJI_0003.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:22
DJI_0004.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:27
DJI_0005.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:33
DJI_0006.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:39
DJI_0007.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:43
DJI_0008.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:49
DJI_0009.JPG	4608x3456	M100_X5R	15	2017:05:12 09:47:51
DJI_0010.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:04
DJI_0011.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:10
DJI_0012.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:15
DJI_0013.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:21
DJI_0014.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:25
DJI_0015.JPG	4608x3456	M100_X5R	15	2017:05:12 09:48:31

FIGURE 14. Technical information of camera lens

5.2.3 Photo Alignment

Aligning command could be found from the main ribbon under the Workflow tab. Settings were defined (figure 15), with most remained as default.



Accuracy: Medium
☑ Generic preselection
☑ Reference preselection

Key point limit: 40,000
Tie point limit: 4,000
☐ Constrain features by mask
☑ Adaptive camera model fitting

FIGURE 15. Align photo settings dialog box (Sample)

Once the alignment is done, camera positions and orientations are demonstrated by blue rectangles (camera button on main Toolbar to be enabled) (figure 16). Under the camera positions is a sparse point cloud.

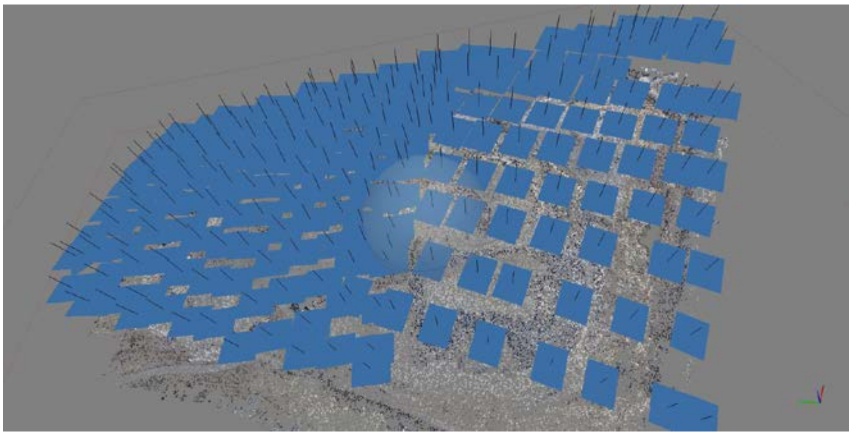
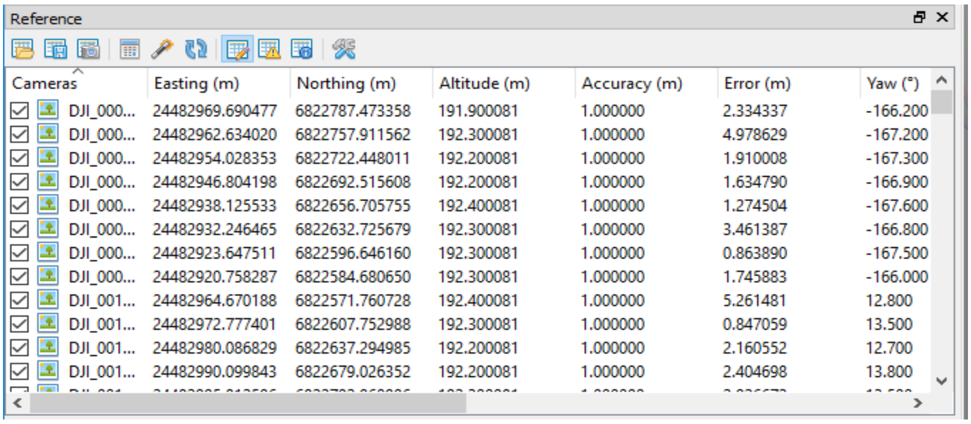


FIGURE 16. Aligned camera positions and reconstructed sparse point cloud underneath (Sample)

5.2.4 Markers registration

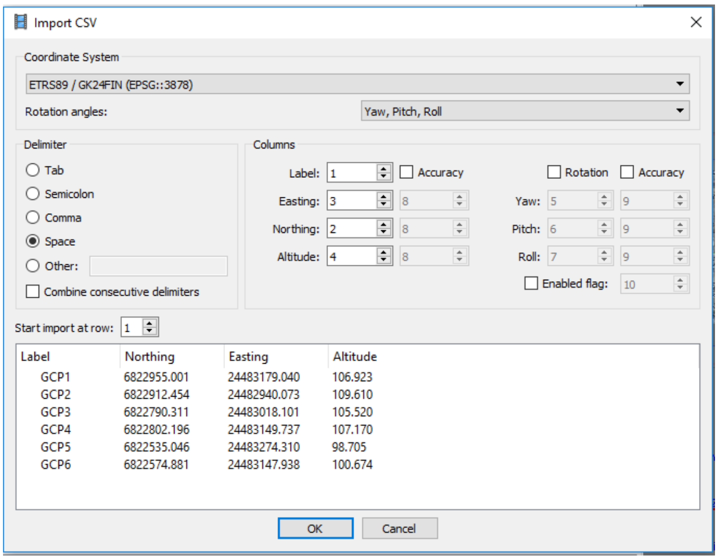
In the previous step (section 5.2.2), coordinates of photographs were converted into those of ETRS89/GK24FIN system and they are illustrated in figure 17.



Cameras	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)	Yaw (°)
☑ DJI_000...	24482969.690477	6822787.473358	191.900081	1.000000	2.334337	-166.200
☑ DJI_000...	24482962.634020	6822757.911562	192.300081	1.000000	4.978629	-167.200
☑ DJI_000...	24482954.028353	6822722.448011	192.200081	1.000000	1.910008	-167.300
☑ DJI_000...	24482946.804198	6822692.515608	192.200081	1.000000	1.634790	-166.900
☑ DJI_000...	24482938.125533	6822656.705755	192.400081	1.000000	1.274504	-167.600
☑ DJI_000...	24482932.246465	6822632.725679	192.300081	1.000000	3.461387	-166.800
☑ DJI_000...	24482923.647511	6822596.646160	192.300081	1.000000	0.863890	-167.500
☑ DJI_000...	24482920.758287	6822584.680650	192.300081	1.000000	1.745883	-166.000
☑ DJI_001...	24482964.670188	6822571.760728	192.400081	1.000000	5.261481	12.800
☑ DJI_001...	24482972.777401	6822607.752988	192.300081	1.000000	0.847059	13.500
☑ DJI_001...	24482980.086829	6822637.294985	192.200081	1.000000	2.160552	12.700
☑ DJI_001...	24482990.099843	6822679.026352	192.200081	1.000000	2.404698	13.800

FIGURE 17. Converted coordinates of aerial images including Easting, Northing, Altitude, and Error

The markers/GCPs coordinates could be imported by using Import button on Reference pane’s toolbar. Character-separated files .txt and .csv were the ones PhotoScan could read when importing local file (Agisoft PhotoScan User Manual 2017, 46 & 47). Figure 18 presents settings available for import file.



Import CSV

Coordinate System

ETRS89 / GK24FIN (EPSG::3878)

Rotation angles: Yaw, Pitch, Roll

Delimiter

○ Tab
○ Semicolon
○ Comma
● Space
○ Other:
☐ Combine consecutive delimiters

Columns

Label: 1 ☐ Accuracy
Easting: 3 8
Northing: 2 8
Altitude: 4 8

☐ Rotation ☐ Accuracy
Yaw: 5 9
Pitch: 6 9
Roll: 7 9
☐ Enabled flag: 10

Start import at row: 1

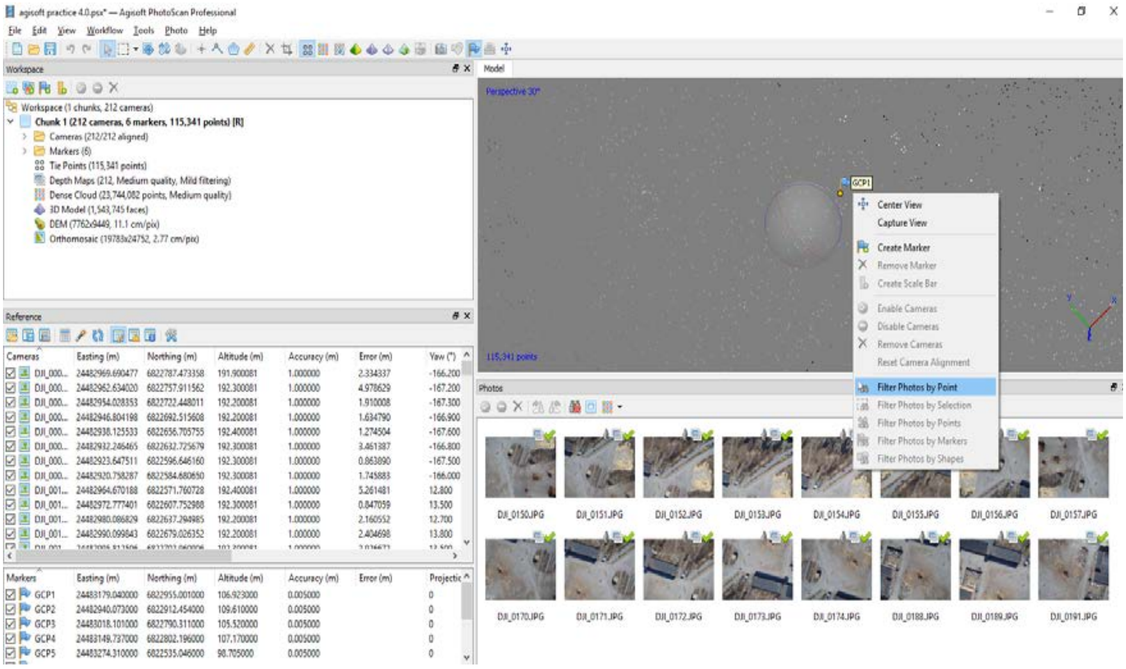
Label	Northing	Easting	Altitude
GCP1	6822955.001	24483179.040	106.923
GCP2	6822912.454	24482940.073	109.610
GCP3	6822790.311	24483018.101	105.520
GCP4	6822802.196	24483149.737	107.170
GCP5	6822535.046	24483274.310	98.705
GCP6	6822574.881	24483147.938	100.674

FIGURE 18. Import settings with coordinate system selections, column order adjustments, list of markers and their corresponding coordinates (Sample)

It was important to pay attention to the order of columns as they could easily be in wrong orders from the original file, in this case the order of Northing and Easting columns were reversed. Coordinate system should be the same as of converted camera coordinates. After the information is defined correctly, the markers are imported and appeared on the sub-pane under Reference pane (figure 19a). In Model view panel, there is number of points of current point cloud presented at bottom left corner, perspective angle at top left corner, and 3-axis rotation indication at bottom right corner.

With the known marker coordinates, PhotoScan automatically suggests their positions by placing blue flags to the assumed positions on the model (figure 19a); however, the accuracy was rather low and therefore, markers were manually placed. To avoid going through all the photos, it was recommended to filter those which included the marker. This could be done in two (02) ways: right clicking on the name of marker on Reference pane to choose Filter photos by markers or right clicking on the blue flag icon in Model view to “Filter photos by points”. Either way, in Photo view pane, PhotoScan provides a series of photos it thinks would contain the chosen marker (figure 19a).

a.



Workspace (1 chunks, 212 cameras)
- Chunk 1 (212 cameras, 6 markers, 115,341 points) [R]
  - Cameras (212/212 aligned)
  - Markers (6)
  - Tie Points (115,341 points)
  - Depth Maps (212, Medium quality, Mild filtering)
  - Dense Cloud (23,744,082 points, Medium quality)
  - 3D Model (1,543,745 faces)
  - DEM (7762x9449, 11.1 cm/pix)
  - Orthomosaic (19783x24752, 2.77 cm/pix)

Cameras	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)	Yaw (°)
☑ DJI_000...	24482969.690477	6822787.473358	191.900081	1.000000	2.334337	-166.200
☑ DJI_000...	24482962.634020	6822757.911562	192.300081	1.000000	4.978629	-167.200
☑ DJI_000...	24482954.028353	6822722.448011	192.200081	1.000000	1.910008	-167.300
☑ DJI_000...	24482946.804198	6822692.515608	192.200081	1.000000	1.634790	-166.900
☑ DJI_000...	24482938.125533	6822656.705755	192.400081	1.000000	1.274504	-167.600
☑ DJI_000...	24482932.246465	6822632.725679	192.300081	1.000000	3.461387	-166.800
☑ DJI_000...	24482923.647511	6822596.646160	192.300081	1.000000	0.863890	-167.500
☑ DJI_000...	24482920.758287	6822584.680650	192.300081	1.000000	1.745883	-166.000
☑ DJI_001...	24482964.670188	6822571.760728	192.400081	1.000000	5.261481	12.800
☑ DJI_001...	24482972.777401	6822607.752988	192.300081	1.000000	0.847059	13.500
☑ DJI_001...	24482980.086829	6822637.294985	192.200081	1.000000	2.160552	12.700
☑ DJI_001...	24482990.099843	6822679.026352	192.200081	1.000000	2.404698	13.800

Markers	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)	Projectic
☑ GCP1	24483179.040000	6822955.001000	106.923000	0.005000		0
☑ GCP2	24482940.073000	6822912.454000	109.610000	0.005000		0
☑ GCP3	24483018.101000	6822790.311000	105.520000	0.005000		0
☑ GCP4	24483149.737000	6822802.196000	107.170000	0.005000		0
☑ GCP5	24483274.310000	6822535.046000	98.705000	0.005000		0

b.

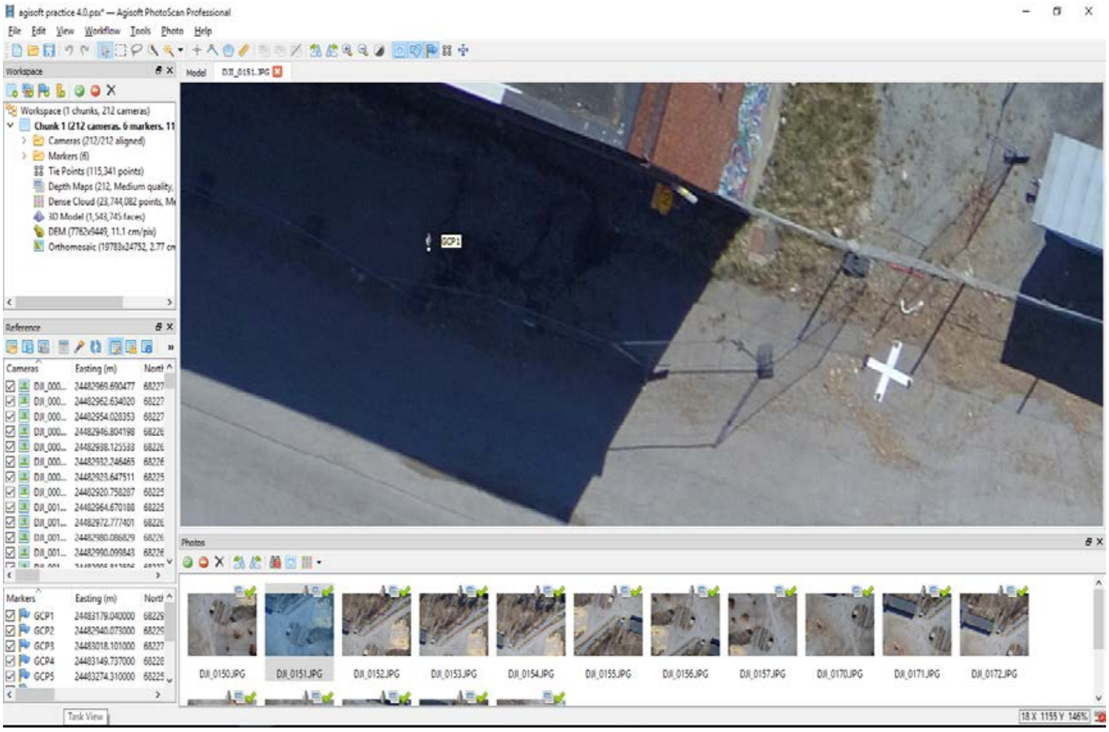
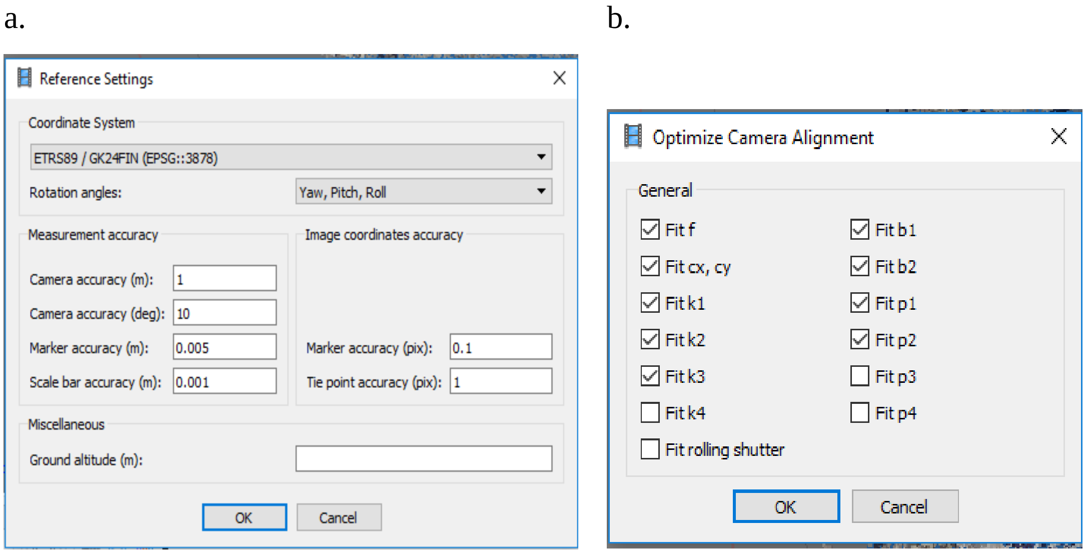


FIGURE 19a. User interface with camera and marker coordinates imported and synchronized; suggested blue flag marker position by PhotoScan, and filtered photos by point were available in Photo viewer and b. User interface during manual marker registration to a photo; the grey icon was an inaccurately placed marker suggested by PhotoScan; and the visible white cross marked the correct position of marker (Sample)

By double clicking on the photo in Photo view pane, the photo was opened in another tab next to Model view. From figure 19b, white cross marker is visibly seen after zooming in; PhotoScan suggests the marker as a grey icon named GCP1 but it is in a wrong position. Therefore, the icon was manually moved to the white cross location to register a correct marker position. After that was done, a small green flag icon appeared on top right corner of the photo thumbnail in Photo view pane. For all suggested images, this step was repeated until grey icons were correctly positioned. For the remaining five (05) markers, the procedures of filtering photos and hand-placing marker were repeated until all were registered.

5.2.5 Camera optimization

For this step, due to the higher accuracy of marker's coordinates, a marker-based optimization was done instead of camera-based (Agisoft PhotoScan User manual 2017, 49). First, all cameras were unchecked in Reference pane. Then, Reference Settings box (Reference pane toolbar) was opened to set marker accuracy to 0.005 as recommended by PhotoScan (Tutorial Beginner level n.d, 9).



Coordinate System
ETRS89 / GK24FIN (EPSG::3878)
Rotation angles: Yaw, Pitch, Roll

Measurement accuracy
Camera accuracy (m): 1
Camera accuracy (deg): 10
Marker accuracy (m): 0.005
Scale bar accuracy (m): 0.001

Image coordinates accuracy
Marker accuracy (pix): 0.1
Tie point accuracy (pix): 1

Miscellaneous
Ground altitude (m):

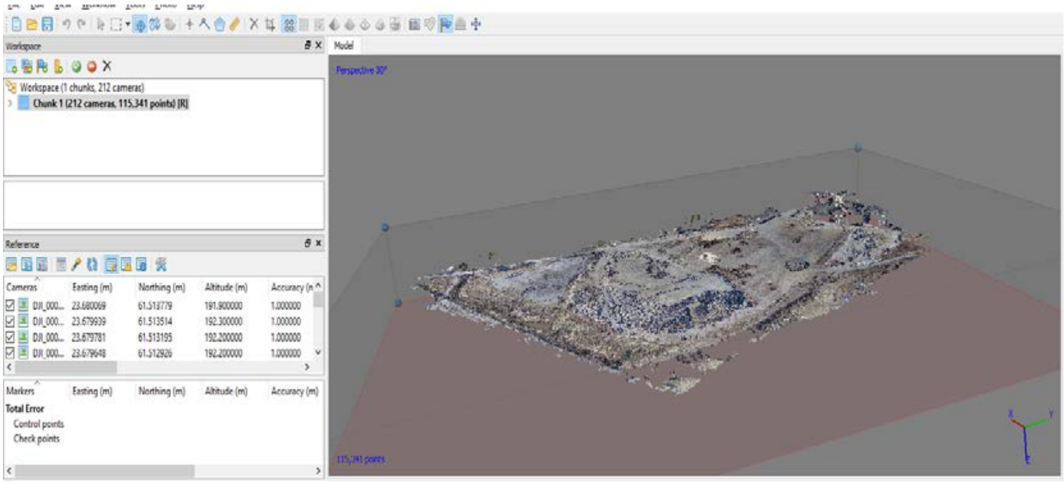
General
☑ Fit f
☑ Fit cx, cy
☑ Fit k1
☑ Fit k2
☑ Fit k3
☐ Fit k4
☐ Fit rolling shutter
☑ Fit b1
☑ Fit b2
☑ Fit p1
☑ Fit p2
☐ Fit p3
☐ Fit p4

FIGURE 20a. Reference setting dialog box with coordinate system and marker accuracy defined; and b. checked camera parameters as per Agisoft suggestion

Finally, optimization tool was found in the toolbar of Reference pane. Camera parameters (figure 20b) are checked according to suggestion of Agisoft (Tutorial Beginner level n.d, 9). Optimization was done based on markers, therefore, the accuracy of camera was not considered and would not affect the process.

5.2.6 Dense cloud generation

Prior to dense cloud generation, a bounding box should be created to define the area for reconstruction. The box could be enabled by pressing either “Resize region” or “Rotate region” buttons on main Toolbar. The colored surface of bounding box is treated as ground plane; therefore, it should be rotated when necessary to correspond with the designated ground surface of point cloud (figure 21). Size of bounding area could be adjusted to process a certain part of the area or to filter out unnecessary noise. Another way to avoid processing unwanted noise points was to manually select and delete them using selection tools from main Toolbar.



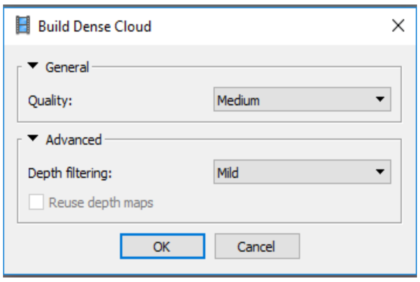
Workspace (1 chunks, 212 cameras)
Chunk 1 (212 cameras, 115,341 points) [R]

Cameras	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m
☑ DJI_000...	23.680069	61.513779	191.900000	1.000000
☑ DJI_000...	23.679939	61.513514	192.300000	1.000000
☑ DJI_000...	23.679781	61.513195	192.200000	1.000000
☑ DJI_000...	23.679648	61.512926	192.200000	1.000000

Markers	Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)
Total Error				
Control points				
Check points				

FIGURE 21. Sparse point cloud inside a bounding box (Sample)

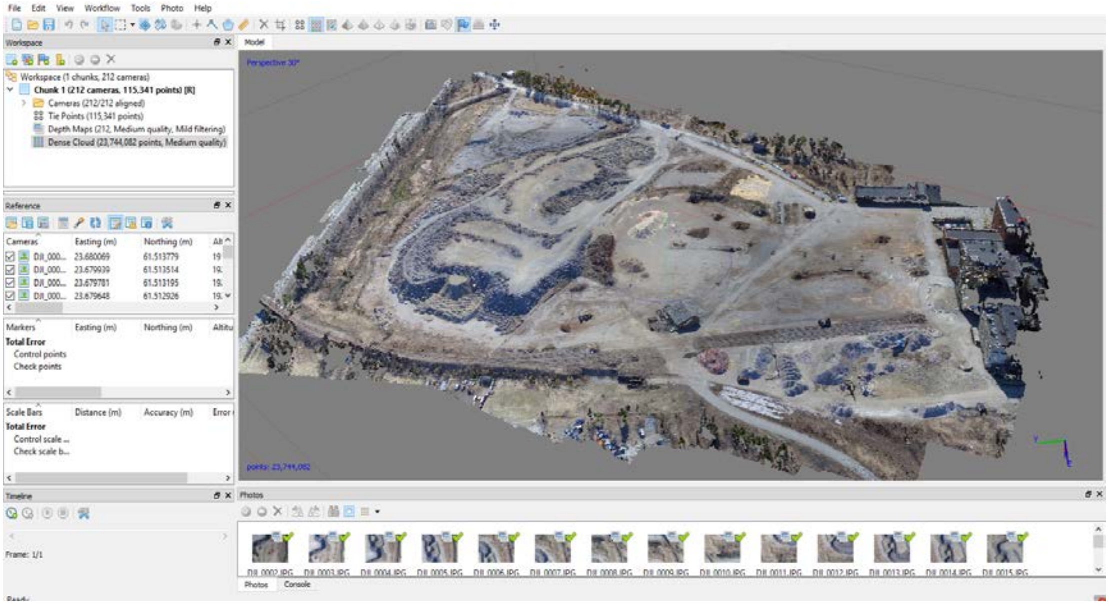
From Workflow tab, “Build dense cloud” command was found, and settings could be adjusted in the dialog box. Depth filtering was set to be Mild to avoid filtering out details such as buildings and vegetation (Tutorial Beginner level n.d, 10). The quality of dense cloud could be set from “lowest” to “ultra-high”, depending on the need of user.



General
Quality: Medium
Advanced
Depth filtering: Mild
☐ Reuse depth maps

FIGURE 22. Dense cloud generation settings (Sample)

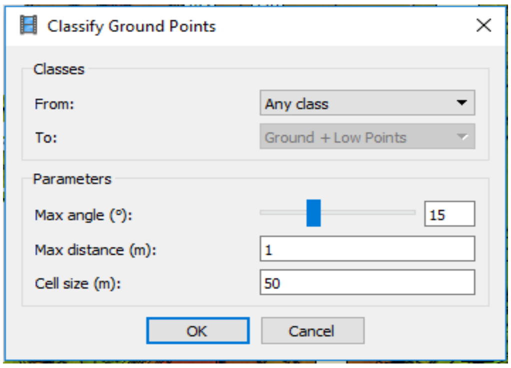
Once the dense cloud is built, Workspace pane shows successful generations of Depth Maps and Dense Cloud as seen from figure 23, along with some basic information of the component. Dense cloud model is previewed on Model view pane. On main Toolbar, there are three (03) options to view the point cloud: Sparse Point Cloud, Dense Cloud, and Dense Cloud Classes. Number of points in the dense cloud is presented at bottom left corner of Model view.



Workspace (1 chunks, 212 cameras)
Chunk 1 (212 cameras, 115,341 points) [R]
Cameras (212/212 aligned)
Tie Points (115,341 points)
Depth Maps (212, Medium quality, Mild filtering)
Dense Cloud (23,744,082 points, Medium quality)

FIGURE 23. User interface when dense cloud was successfully generated (Sample)

At this stage, it was possible to assign point cloud classes manually or automatically. To assign automatically, the command Classify Ground Points was found under Tools, Dense Cloud expansion. With this tool, only ground and low points classes would be created.

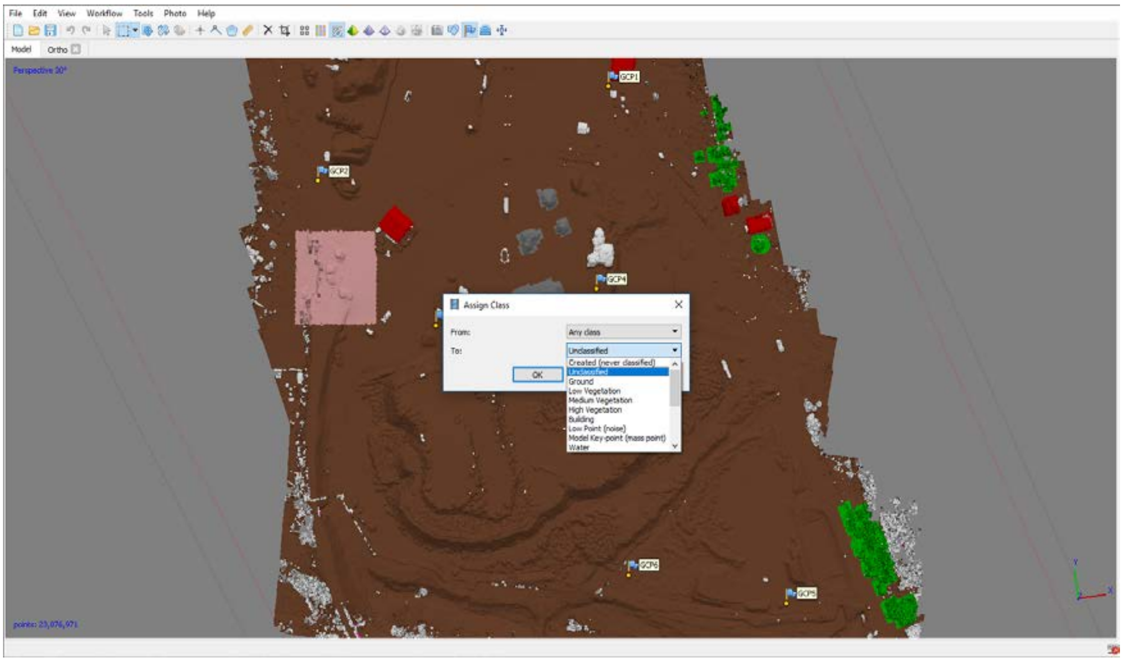


Classes
From: Any class
To: Ground + Low Points

Parameters
Max angle (°): 15
Max distance (m): 1
Cell size (m): 50

FIGURE 24. Setting parameters for automatic ground point classification (sample)

For manual classification of point cloud, the model was viewed under Dense Cloud Classes mode (from main Toolbar). Rectangle/Free Form Selection tool is chosen from main toolbar to select objects from the model. The selected part is enabled in light pink as shown in figure 25. A combination of "Ctrl+Shift+C" is performed, and a dialog box is available showing different classes to assign the chosen area to. After classification, each class is demonstrated on the view panel in distinct color code.



From: Any class
To: Unclassified

FIGURE 25. Manual classification of point cloud with selected part (pink highlight) and a range of classes to assign the selection to (sample)

5.2.7 New chunk

Agisoft provided the possibility to work with different chunks in the same project and this was mainly recommended for projects with large number of photographs/scans. By splitting the photos, parts of project could be processed and combined in the final stage. A new chunk was created from "Add chunk" button from the Workspace pane toolbar;

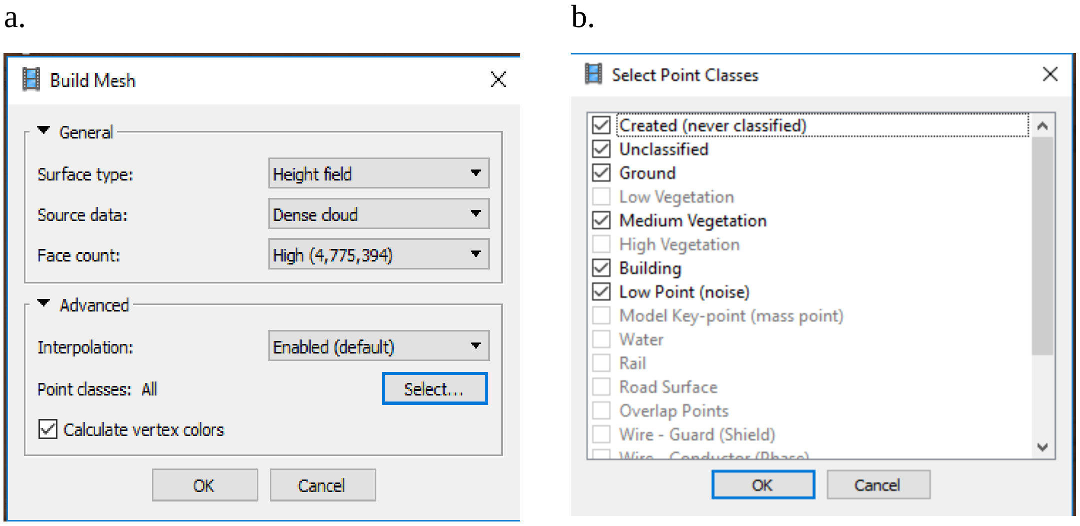
This project, however, did not work with an entirely new chunk but with a duplicated one, given that there was a need to create different results for experimental purposes and PhotoScan could only produce one output at each stage of the process. Thus, this section listed out some essential notes while working with multiple chunks.

The chunks should be named to distinguish between one and another. While there could be many chunks, only one would be activated at a time and commands could only be performed on active chunk. To activate one, user could double click on the chunk name or find the “enable chunk” command from right-click menu of the chunk. Each chunk worked independently.

In this project, one was named “DTM” and the other was “DSM”. As the duplication produced a copy of the original chunk, two (02) chunks shared the same procedure and results up to dense point cloud classification stage.

5.2.8 Mesh generation and texture mapping

Mesh building was carried out twice due to the presence of two (02) separate chunks. Build Mesh command was found from Workflow tab expansion. Settings were as followed:



Build Mesh

General

Surface type: Height field

Source data: Dense cloud

Face count: High (4,775,394)

Advanced

Interpolation: Enabled (default)

Point classes: All

☑ Calculate vertex colors

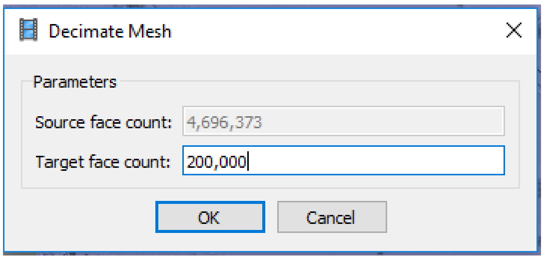
Select Point Classes

☑ Created (never classified)
☑ Unclassified
☑ Ground
☐ Low Vegetation
☑ Medium Vegetation
☐ High Vegetation
☑ Building
☑ Low Point (noise)
☐ Model Key-point (mass point)
☐ Water
☐ Rail
☐ Road Surface
☐ Overlap Points
☐ Wire - Guard (Shield)
☐ Wire - Conductor (Phase)

FIGURE 26a. Setting parameters for mesh generation; and b. Available point classes which contained assigned objects

Dense cloud was taken as source data and the Face count was set to be high. As the points in dense cloud were classified, the mesh could be built based on the class choices. For DTM chunk, only Ground class was enabled for mesh construction. For DSM chunk, the mesh model was built using all point classes.

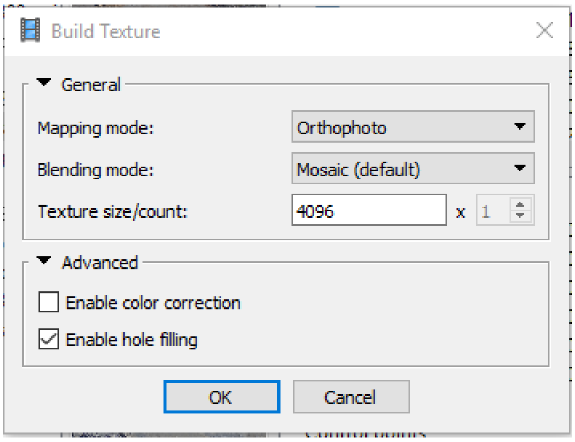
According to Agisoft PhotoScan User Manual (2017, 68 & 69), the models which the software produced could be in “excessively high geometry resolution” and cause troubled when being read in other application; hence, a tool called Decimation was available to decrease the model resolution while maintaining high object accuracy. Decimate Mesh command is found under Tools tab with the settings as in figure presented below. User could specify desired number of faces for the decimation.



Source face count: 4,696,373
Target face count: 200,000

FIGURE 27. Mesh decimation dialog box (Sample)

Once the mesh was completely generated, texture mapping could be done to make the mesh more realistic. The command was accessible from Workflow drop-down. Settings were kept at default.



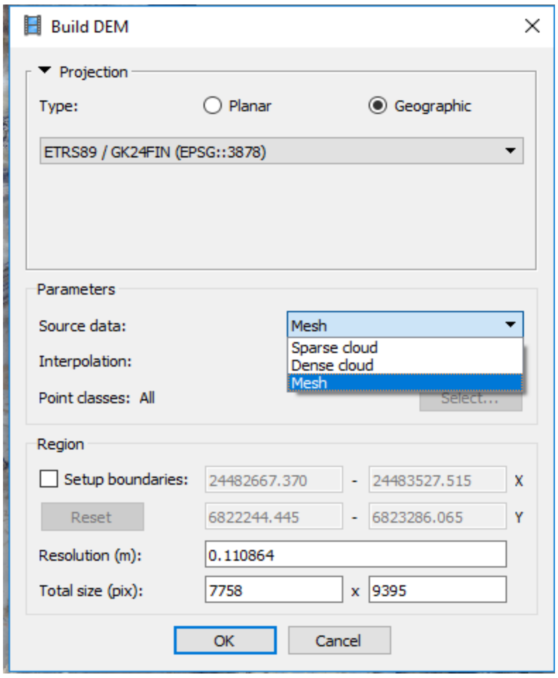
Mapping mode: Orthophoto
Blending mode: Mosaic (default)
Texture size/count: 4096 x 1
☐ Enable color correction
☑ Enable hole filling

FIGURE 28. Build texture dialog box (sample)

5.2.9 DEMs and Orthomosaic generation

DEM could be generated using sparse cloud, dense cloud, or mesh as source data and the step was performed twice for two (02) chunks. It was necessary to specify the coordinate system for the DEM. All settings were kept at default including boundary, resolution, and total size (in pixel) of the DEM. When necessary, boundaries for particular part of the project would be defined either by adjusting the bounding box or entering two (02) sets of (x,y) coordinates of bottom left and top right corners of that area.

Since mesh was generated based on classes selection, the DEM generation could utilize corresponding built meshes as source data to construct DTM and DSM. However, general, it was recommended that dense cloud was chosen as source data (Agisoft PhotoScan User Manual n.d, 24). With dense point cloud as source data, “Point classes” parameter in setting box would be enabled for selection. To rasterize a DTM, only “Ground points” class should be chosen for generation. As for DSM, it could be made including one to a few/all other point classes, depending on the need of the project.



Type: ○ Planar ● Geographic

ETRS89 / GK24FIN (EPSG::3878)

Source data: Mesh

Interpolation:

Point classes: All

☐ Setup boundaries: 24482667.370 - 24483527.515 X

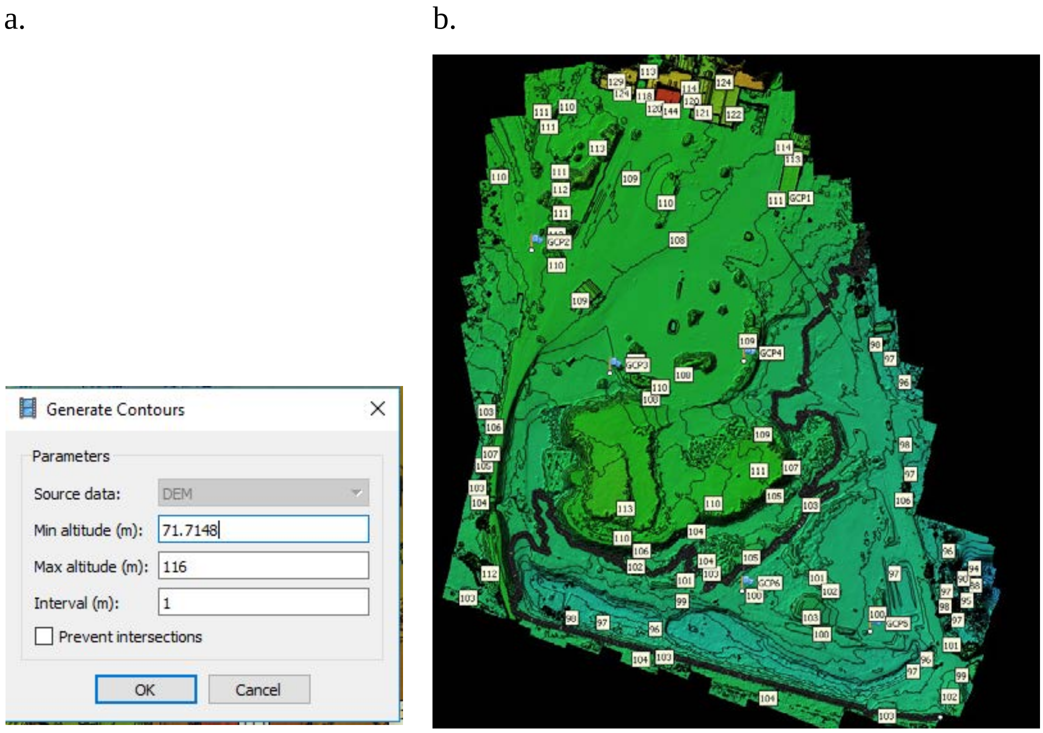
6822244.445 - 6823286.065 Y

Resolution (m): 0.110864

Total size (pix): 7758 x 9395

FIGURE 29. Settings for DEM building (sample)

Contour lines were generated to provide complementary information for DEMs and orthomosaic. The command could be found from Tools tab or by right click on DEM name on Workspace pane. Within the setting dialog box, minimum and maximum altitude of contour lines could be specified, and interval between contour lines was set to be one (01) meter.


a.

b.

Generate Contours

Parameters

Source data: DEM

Min altitude (m): 71.7148

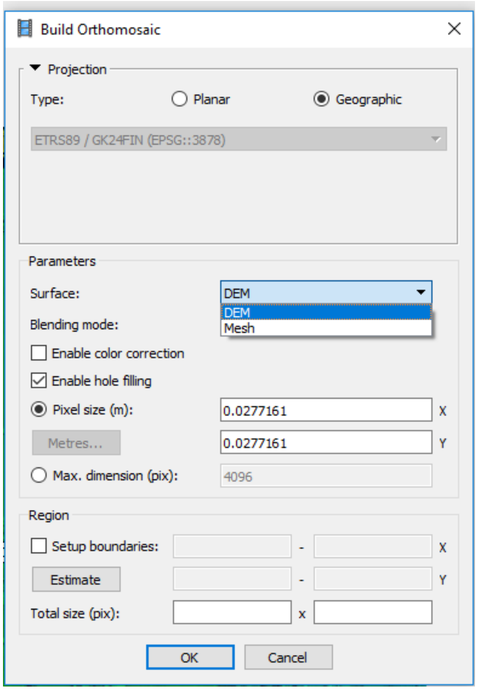
Max altitude (m): 116

Interval (m): 1

☐ Prevent intersections

FIGURE 30a. Contour lines settings and b. Contour lines on DEM (sample)

For orthomosaic generation, the command could be found from Workflow tab and the settings were kept at default. In this project case, the coordinate system onto which orthomosaic was projected was automatically defined.


Build Orthomosaic

Projection

Type: ○ Planar ● Geographic

ETRS89 / GK24FIN (EPSG::3878)

Parameters

Surface: DEM

Blending mode:

☐ Enable color correction

☑ Enable hole filling

● Pixel size (m): 0.0277161 X

0.0277161 Y

○ Max. dimension (pix): 4096

Region

☐ Setup boundaries:

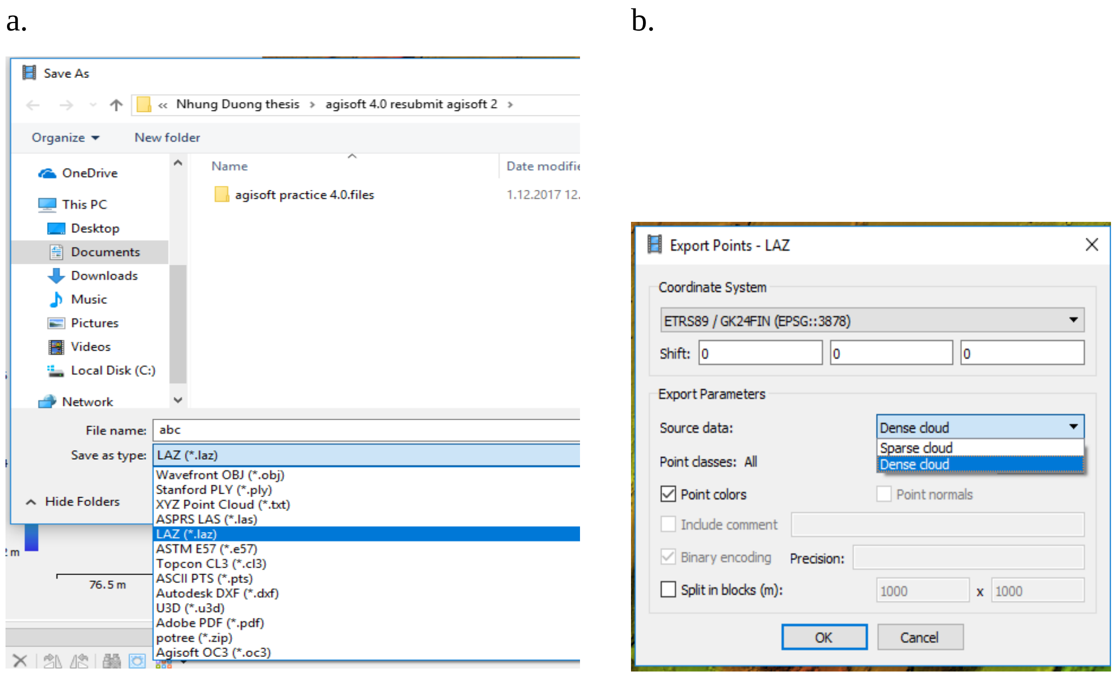
Total size (pix):

FIGURE 31. Setting dialog box for orthomosaic generation (sample)

According to Agisoft User Manual (n.d, 25 & 26), Using DEM as surface data saved time comparing to the other option. Color correction was disabled because it would take longer processing time and it was used only in cases of poor quality photos. Automatically, PhotoScan generated orthomosaic for the area with surface data. However, if needed, the software allowed for selection of interest area by defining “region” or using selection tool on main Toolbar.

5.2.10 Exporting results

Export commands could be found from File tab on the main ribbon or by right click on the current chunk in Workspace pane. PhotoScan allowed the export of results in many file extensions which could be opened in different 3D data processing applications. For example, figure 32 presents the export settings and file formats available when exporting sparse/dense point cloud.



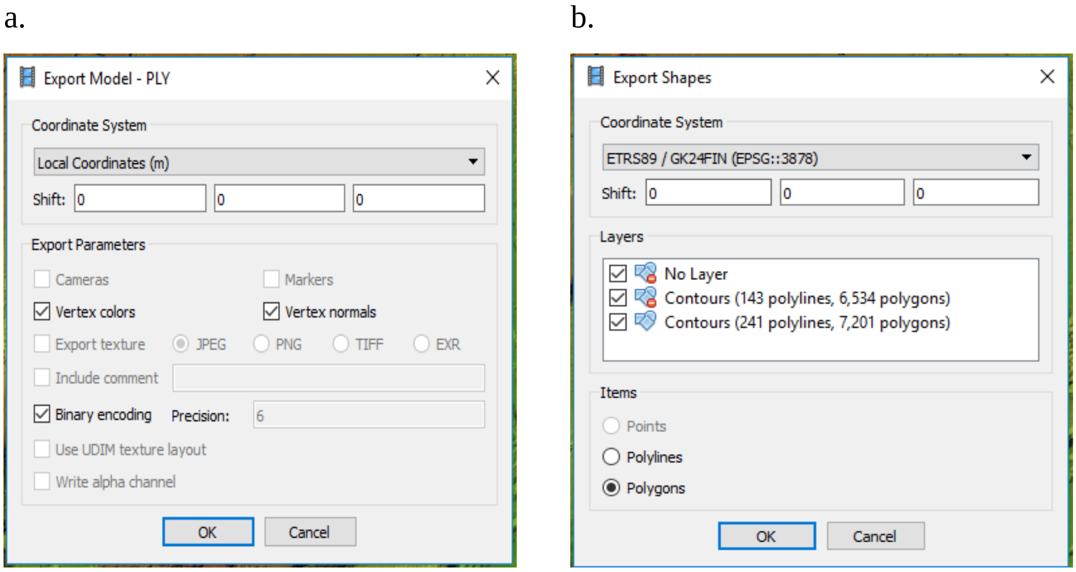
File name: abc
Save as type: LAZ (*.laz)

Coordinate System: ETRS89 / GK24FIN (EPSG::3878)
Shift: 0 0 0
Source data: Dense cloud
Point classes: All
☑ Point colors
☐ Point normals
☐ Include comment
☑ Binary encoding
☐ Split in blocks (m): 1000 x 1000

FIGURE 32a. File extensions for point cloud export; and b. setting dialog box for exporting .laz file (sample)

Figure 33 illustrates the settings for export of models and shapes. The same coordinate system ETRS89/GK24FIN was chosen for exporting results to create uniform results collection. For models to be edited in other 3D data processing software, it might be useful to use “Shift” to translate/shorten the whole coordinate system of the model. However, in this project, there was no shifting applied.

When extracting contours (or possibly other shapes), from “Layers”, all the shapes created during the process can be found and it is possible to export only needed files (figure 33b). Depending on the purpose, contours can be exported under either polylines or polygons.



a.

Export Model - PLY

Coordinate System
Local Coordinates (m)
Shift: 0 0 0

Export Parameters
☐ Cameras ☐ Markers
☑ Vertex colors ☑ Vertex normals
☐ Export texture ● JPEG ○ PNG ○ TIFF ○ EXR
☐ Include comment
☑ Binary encoding Precision: 6
☐ Use UDIM texture layout
☐ Write alpha channel

OK Cancel

b.

Export Shapes

Coordinate System
ETRS89 / GK24FIN (EPSG::3878)
Shift: 0 0 0

Layers
☑ No Layer
☑ Contours (143 polylines, 6,534 polygons)
☑ Contours (241 polylines, 7,201 polygons)

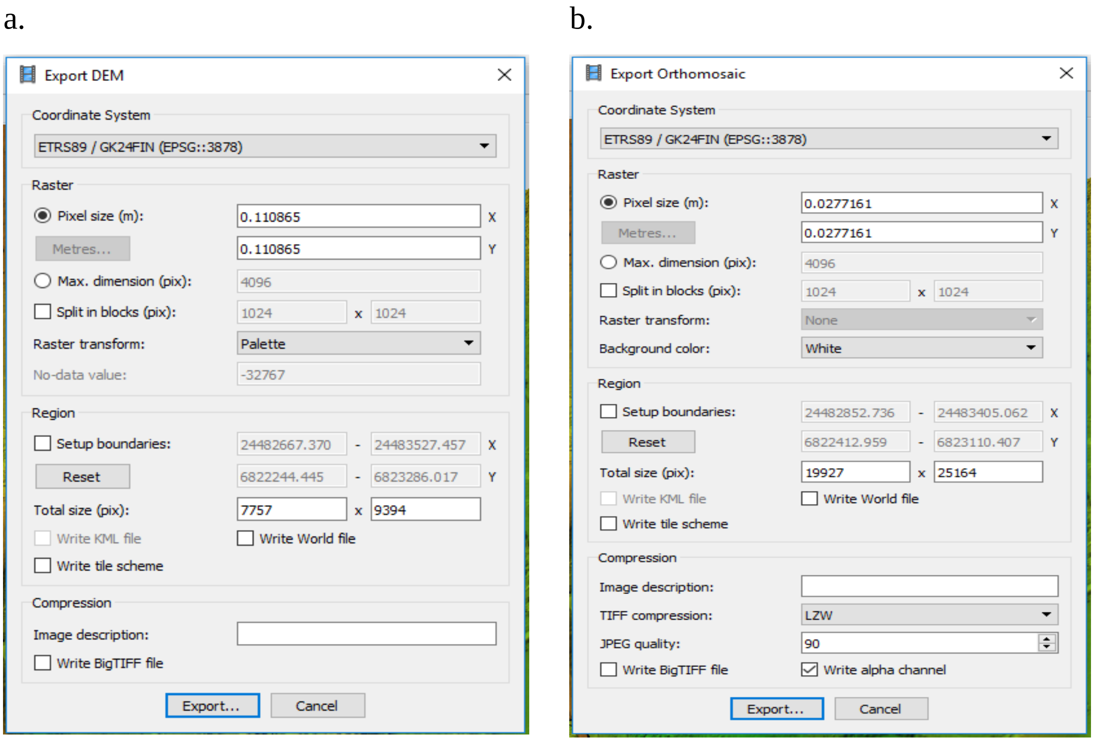
Items
○ Points
○ Polylines
● Polygons

OK Cancel

FIGURE 33 Setting dialog box for a. exporting .ply file model; and b. exporting contours (sample)

Figure 34 demonstrates the settings for DEM (DSM/DTM) and orthomosaic export. Coordinate system is specified for both. In Export DEM settings, Raster transform should be Palette for the color to be exported in the result. Other parameters are at default.

For larger projects, it was possible to split the rectified images into smaller blocks. Also, there was option to compress file or create a file larger than the standard size from “Compression” section in setting box (Agisoft PhotoScan user manual n.d, 32 & 33). In region section, boundaries could be specified to export a particular part of the project.



a.

Export DEM

Coordinate System
ETRS89 / GK24FIN (EPSG::3878)

Raster
● Pixel size (m): 0.110865 X
Metres... 0.110865 Y
○ Max. dimension (pix): 4096
☐ Split in blocks (pix): 1024 x 1024
Raster transform: Palette
No-data value: -32767

Region
☐ Setup boundaries: 24482667.370 - 24483527.457 X
Reset 6822244.445 - 6823286.017 Y
Total size (pix): 7757 x 9394
☐ Write KML file ☐ Write World file
☐ Write tile scheme

Compression
Image description:
☐ Write BigTIFF file

Export... Cancel

b.

Export Orthomosaic

Coordinate System
ETRS89 / GK24FIN (EPSG::3878)

Raster
● Pixel size (m): 0.0277161 X
Metres... 0.0277161 Y
○ Max. dimension (pix): 4096
☐ Split in blocks (pix): 1024 x 1024
Raster transform: None
Background color: White

Region
☐ Setup boundaries: 24482852.736 - 24483405.062 X
Reset 6822412.959 - 6823110.407 Y
Total size (pix): 19927 x 25164
☐ Write KML file ☐ Write World file
☐ Write tile scheme

Compression
Image description:
TIFF compression: LZW
JPEG quality: 90
☐ Write BigTIFF file ☑ Write alpha channel

Export... Cancel

FIGURE 34 Setting dialog box for a. DEM export; and b. orthomosaic (sample)

With this program, in addition to exporting orthomosaic, individual orthophotos were also available to be exported upon user’s need, using the command from Tool menu drop down.

5.2.11 Batch processing

With batch process command, PhotoScan let user define a chain of steps along with their settings, then it would automatically process the predefined request in order and require no additional input until the calculations finished. All settings were final and once the operation started, it would be impossible to revert or change them without restarting the procedure.

Batch process was a command which Agisoft recommended to use when working with many chunks in the same project (Agisoft PhotoScan User Manual n.d, 78). While individually, only one activated chunk could be processed at a time; this tool allowed for automatic processing of many chunks.

“Batch process” was used in this study for trial resubmission of the project. After each step was done individually with relatively time-efficient settings (i.e. medium quality settings and accuracy), the command was used to redo the project from the scratch with settings set up to high level accuracy. Once the new adjustments had been set, resubmission happened automatically and there was attention required until the process was done.

6 RESULTS AND DISCUSSION

The computing process by ReCap web took approximately 7 – 8 hours, disregard of time in a day and quality settings. With PhotoScan, at each phase of the project, elapsed and remaining time was estimated to users; total duration took 5 hours using the settings as presented in this section and the same processing laptop (refer to Table 4).

Viewing of results within this section was done by CloudCompare unless stated otherwise. Results are georeferenced.

6.1 Point cloud

ReCap web did not support the export of point cloud alone, thus, .rcs file was downloaded and converted to .e57 (a point cloud file format) by ReCap desktop. Two (02) point clouds generated by the software are presented in figure 35.

It could be seen from Table 5 and the figure that both point clouds are dense enough to clearly present the terrain and its features. The coloring and edges of elements on PhotoScan dense cloud are slightly sharper; also, holes are visible on ReCap web dense cloud and not on the one of PhotoScan.

Table 5. Point clouds and their corresponding number of points, processing time and setting

Cloud	No. of points	Time	Setting	File size
Sparse cloud - PhotoScan	119 820	1 – 2 minutes	High	1.33 MB
Dense cloud - PhotoScan	23 699 376	2 hours and 16 minutes	Medium & Mild filtering	231 MB
Dense cloud - ReCap web	11 807 624	n/a	Ultra	169 MB

PhotoScan clearly was capable of generating significantly denser point cloud, especially when the presented PhotoScan result was at medium setting and the one of ReCap was the only result.

While ReCap web only supported the extraction of dense cloud, PhotoScan allowed the export of sparse point cloud (appendix 2). By having this feature, modification (point removal) could be made at the earliest stage of the project creation, thus, saving later computing time.

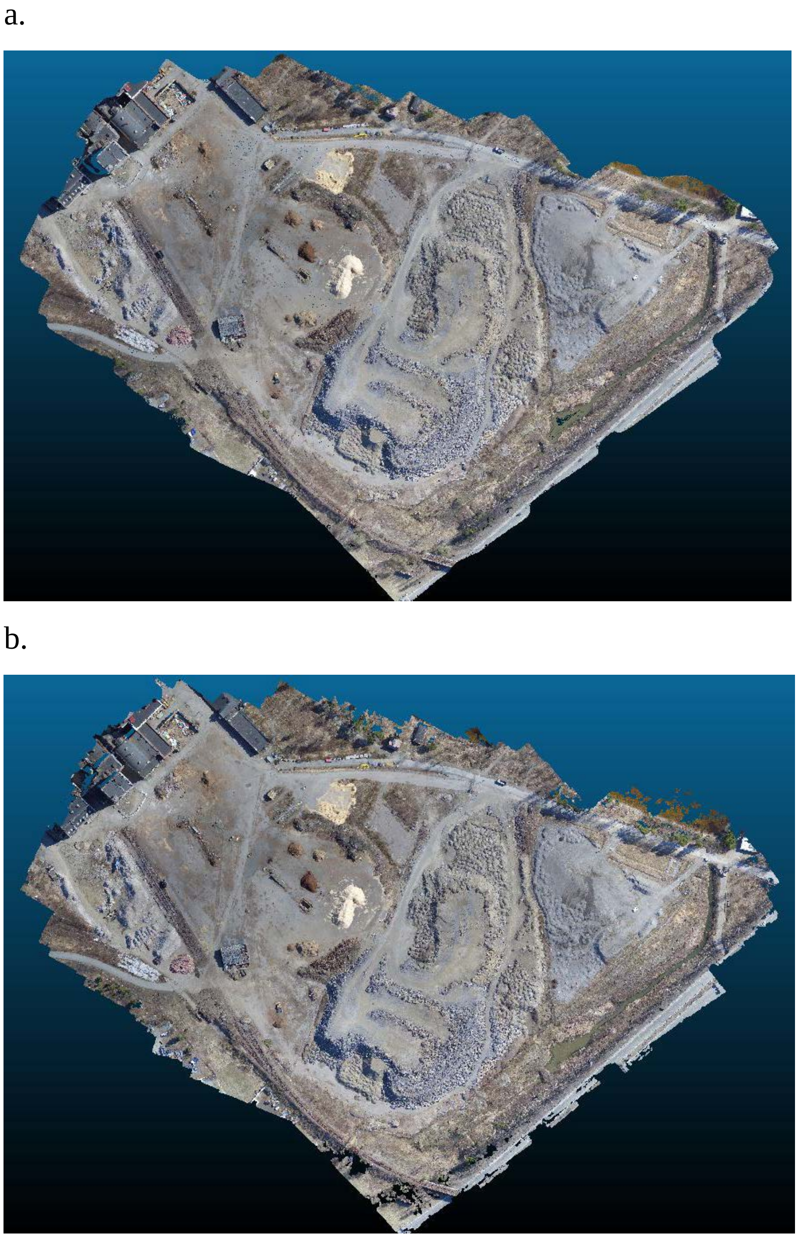


FIGURE 35 Dense point cloud generated by a. ReCap web and b. PhotoScan

6.2 Mesh models

6.2.1 Models viewing

While PhotoScan allowed the generation of a much denser point cloud than ReCap, polygon count of PhotoScan mesh is remarkably smaller than that of ReCap web as can be seen from Table 6. Interestingly, with over 23.5 million points in dense cloud, PhotoScan constructs only 1.5 million faces with 770 thousands vertices (default suggestion) at Medium mode. On the other hand, by default and as the only option, ReCap builds 13 times more compact mesh model.

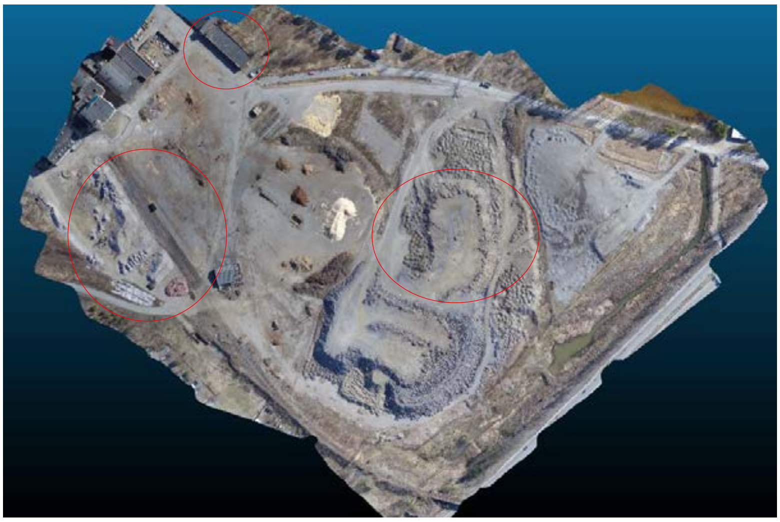
Table 6. Models and their corresponding number of faces, processing time and setting

Model	No. of faces	No. of vertices	Time	Setting	Size
Decimated mesh - PhotoScan	800 000	403 002	< 1 minute	n/a	20.2 MB
Full mesh-PhotoScan	1 579 958	773 791	1 minute & 14 seconds	Medium with interpolation	75.7 MB
Full mesh - ReCap web	14 103 129	7 053 411	n/a	Ultra	1.04 GB

The number of faces and vertices could be accountable for the quality of meshes which both software produced. Visually, from the screen captures in figure 36a, b, PhotoScan mesh is clearly rougher and noisier than the one generated by its opponent. ReCap mesh also has sharper details and less distortions, for example, by comparing the red circled elements. Decimated mesh by PhotoScan has lighter color tone and blurry feature details.

However, there was a possibility to change/improve the quality of PhotoScan mesh by specifying the desired face count, and expectedly, a mesh with similar quality to the one of ReCap could be produced. Self-evidently, PhotoScan offered users more room to control their desirable outputs.

a.



b.

FIGURE 36 Mesh model generated by a. ReCap web and b. PhotoScan, c. decimated mesh by PhotoScan

From side views, there are holes on the building façade in ReCap mesh but not in PhotoScan mesh, instead, their surfaces are covered by geometric figures. This applies to all the objects (buildings, vegetation near shore) of which side surface information was missing due to vertically taken aerial photographs. Perhaps, the fill-up was done by interpolation function as PhotoScan suggested and computed the missing information based on the limitedly available data (Agiosft PhotoScan user manual n.d, 23).

The small details such as tree tops are filtered out by ReCap web but are kept by PhotoScan since the “mild” filtering mode was applied while generating dense cloud. According to Agisoft, this mode was useful for aerial projects which contained small size features (Agiosft PhotoScan user manual n.d, 21).

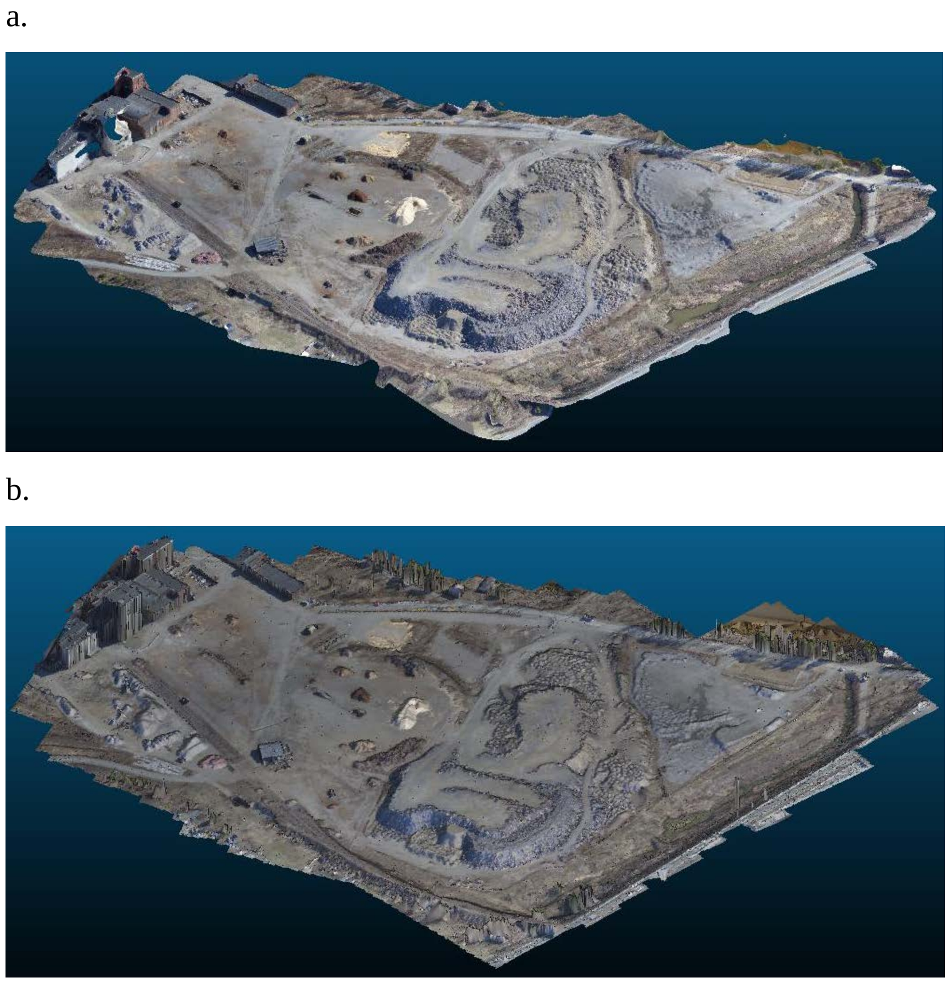


FIGURE 37 Side views of mesh models by a. ReCap web and b. PhotoScan

6.2.2 Distance computation

For this comparison, PhotoScan dense cloud was used as the reference cloud and the figure showed the distance (in meter) of ReCap cloud in comparison with the reference cloud. 1 million points were randomly sampled from both of the meshes to create similar point clouds for comparison.

Distance between two (02) point clouds is represented into three different dimensions x,y,z in figure 38, and among all, distance along the z axis is the most representative. Visibly, the distance ranges from -7.5 to 3.7 m. It can be seen that ReCap cloud is slightly curvy. From figure 38c, anything which falls below 0 indicates the position of particular part of compared model being under its corresponding part in reference model, around 0 means the areas are in coincidental position, and above 0 suggests area being above. It seems that ReCap model is curved in inverted-u shape. While the border area seems to be sunken (figure 38c. – blue and darker green color), the bright orange/red-marked region in the middle demonstrates outcurve. The distances between points along x and y-axis are rather insignificant as seen from figure 38a and b.

Reasonable explanation for deep concavity could be the lack of data (i.e. overlapped photographs or inaccurate built-in GPS data of the photos) which resulted in poorly constructed area and features such as building roofs, as well as inaccurate elevation.

Even though, there was an intermediate steps to make two (02) models comparable by rasterizing the point clouds, it should be noted that the distance calculated could only be regarded as relatively true distance.

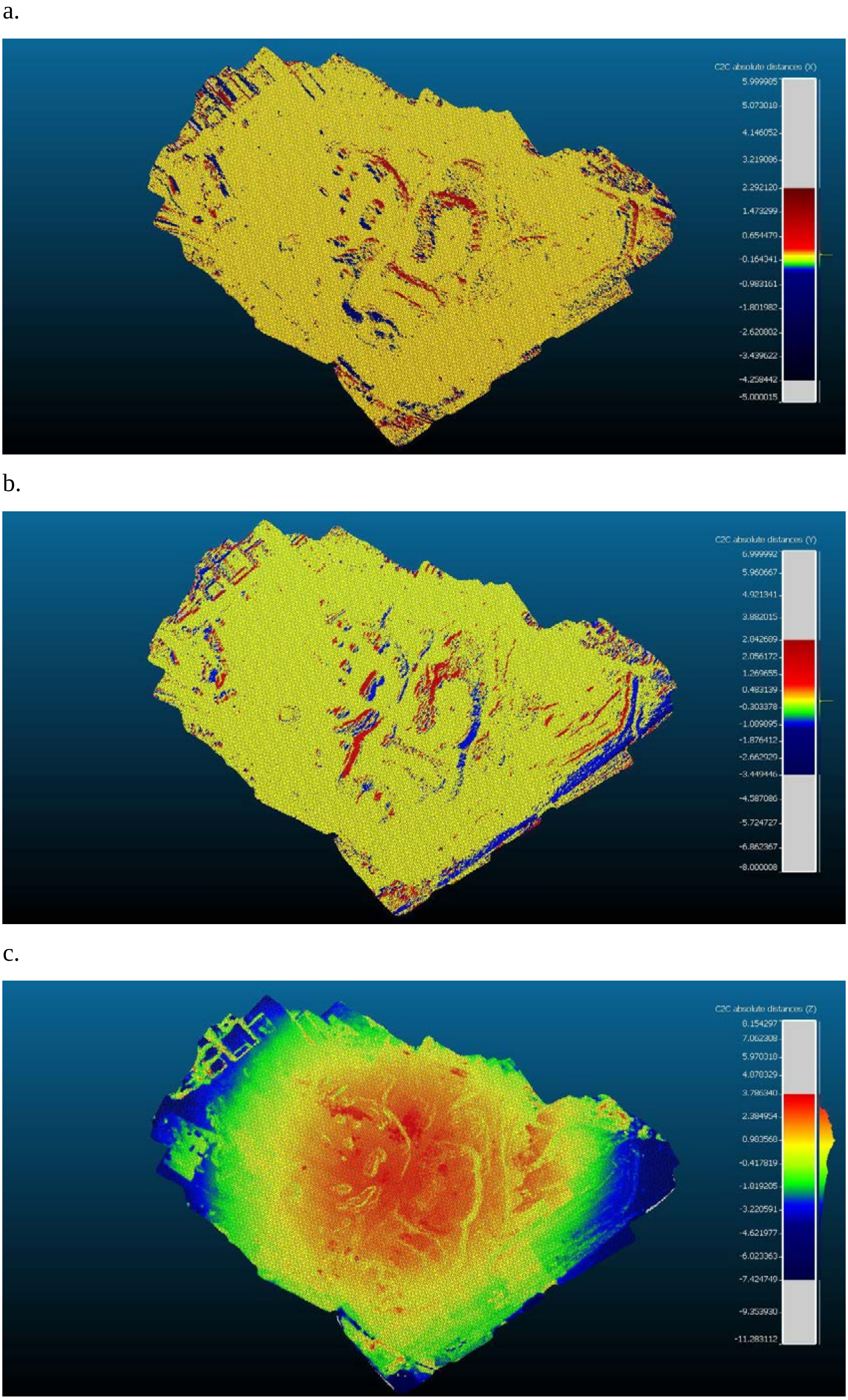


FIGURE 38. Distance comparisons along a. x-axis b. y-axis, and c. z-axis

From figure 39, the trend in distances distribution is illustrated through the Gauss distribution fitting. The dominant distance difference falls between 0 and 1.5 m, indicating that despite all differences, result generated by ReCap web is quite comparable to that of PhotoScan.

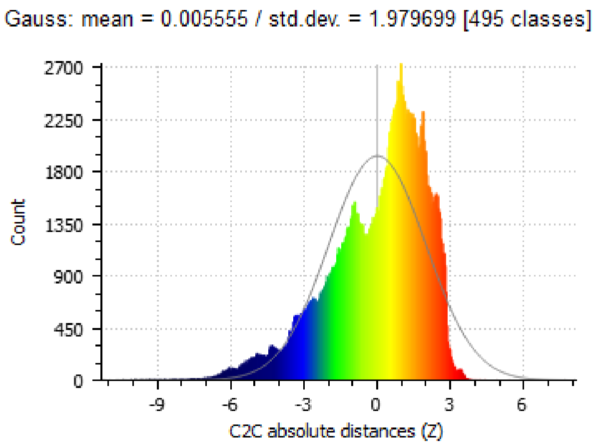


FIGURE 39. Statistical distribution of point distances – z axis

6.3 Orthoimagery & DEM

With ReCap web, only one (01) DEM was produced, but with PhotoScan, both DSM and DTM were generated. However, the rasterized results could be view in appendix 4 and 5, and new DEMs are generated using CloudCompare to create a common ground for data comparison (figure 40).

Table 7. Orthoimagery and DEM and their corresponding source data, processing time, and setting

	Source data	Time	Setting	File size	Image size (pixel)
DEM (DSM & DTM) - PhotoScan	Dense cloud	3 minutes/ each	Interpolation	DTM: 59.7 MB DSM: 58.4 MB	
DEM – ReCap web	-	-	-	14.3 MB	
Orthomosaic - PhotoScan	DEM as surface data	1 hour 6 minutes	Mosaic blending mode Hole filling	1.25 GB	W x H: 19830 x 24783
Orthoimagery - ReCap web	-	-	-	143 MB	W x H: 8191 x 10556

The DEMs were rasterized using the previous sample point clouds. White lines were contours with 6 meters difference. As discussed, PhotoScan point cloud had more detail features than that of ReCap web, and it is clearly visible in the border areas in figure 40a and b.

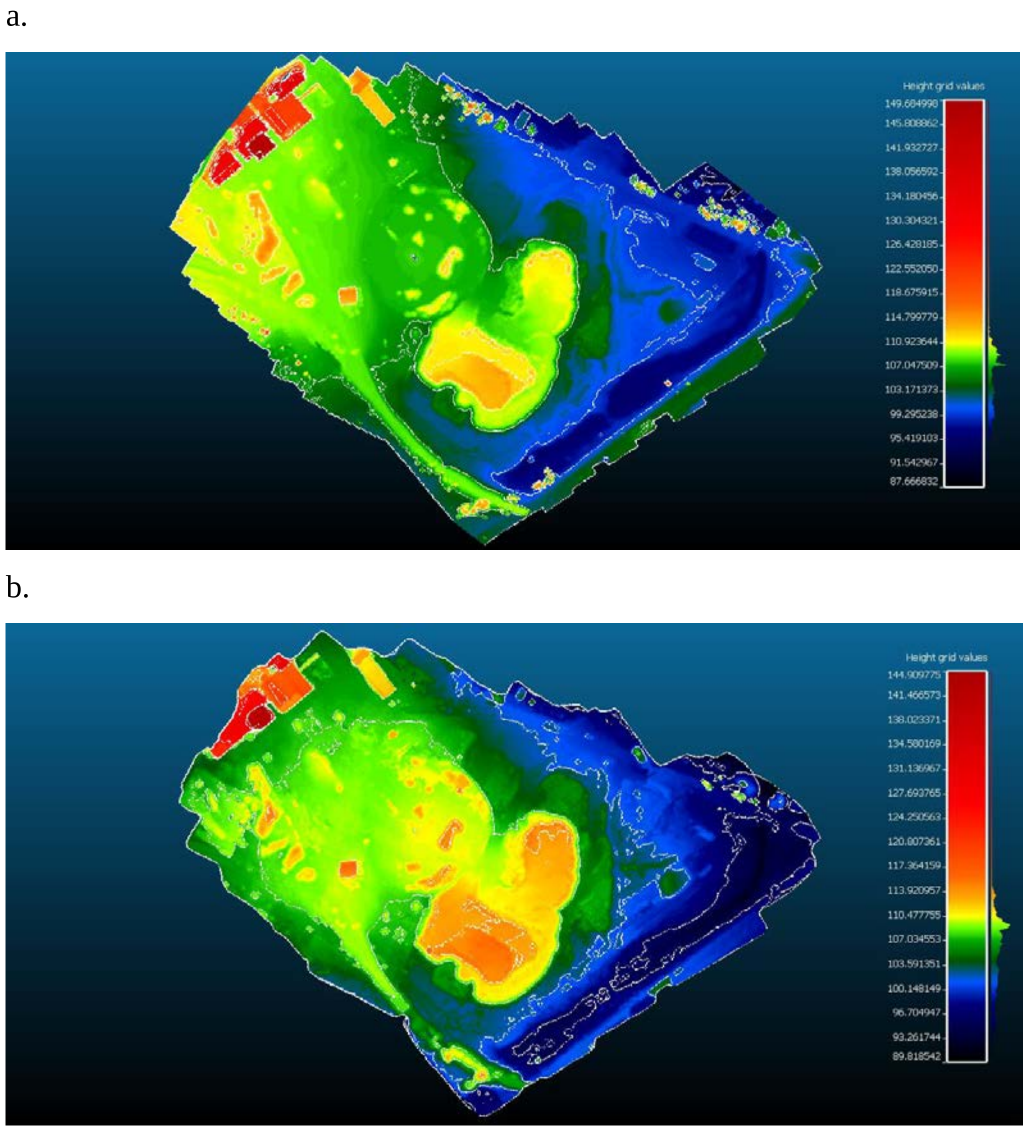


FIGURE 40 DEM of a. ReCap cloud and b. PhotoScan cloud

Figure 41 gives a closer view to the color scales of two (02) DEMs. ReCap web records highest elements at the altitude of 145 m and the lowest at approximately 90 m. PhotoScan, however, assigns different value with highest points at 149.7 m and lowest at 88 m. Elevation of PhotoScan model seems to vary more than that of ReCap model. Despite the limit differences, these rasterized images agree on main height distribution among classes (buildings, vegetation, other man-made elements, ground, and water bodies). Elevation level of each class in two (02) DEMs fall within relatively similar range, even though color scales are slightly different.

Realistically, Lake Näsijärvi is at 95 m above sea level (Waymarking 2012), making the lowest altitude recorded in both DEM to be inaccurate. This could be explained by the fact that near shore area was reconstructed mainly based on built-in GPS data derived from the drone camera, and the data was not sufficiently reliable.

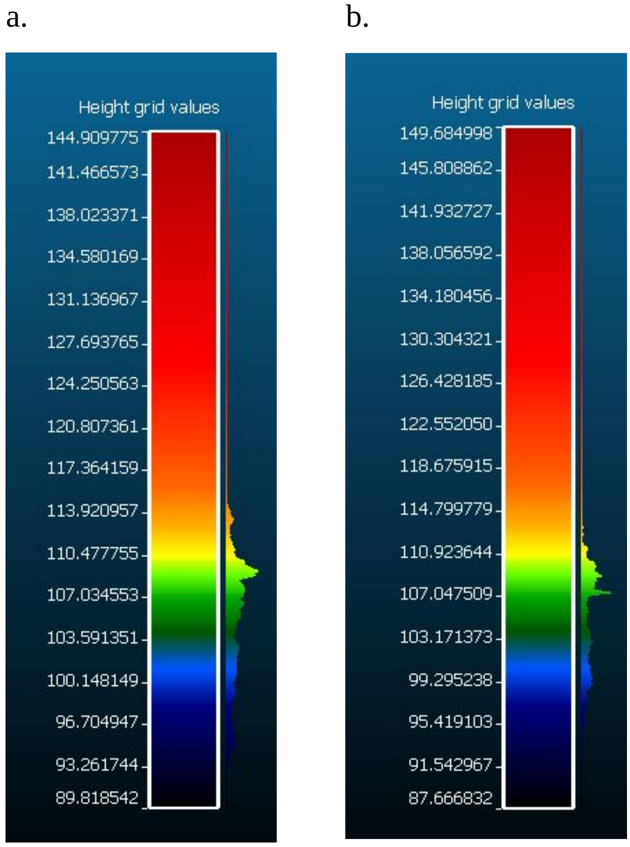
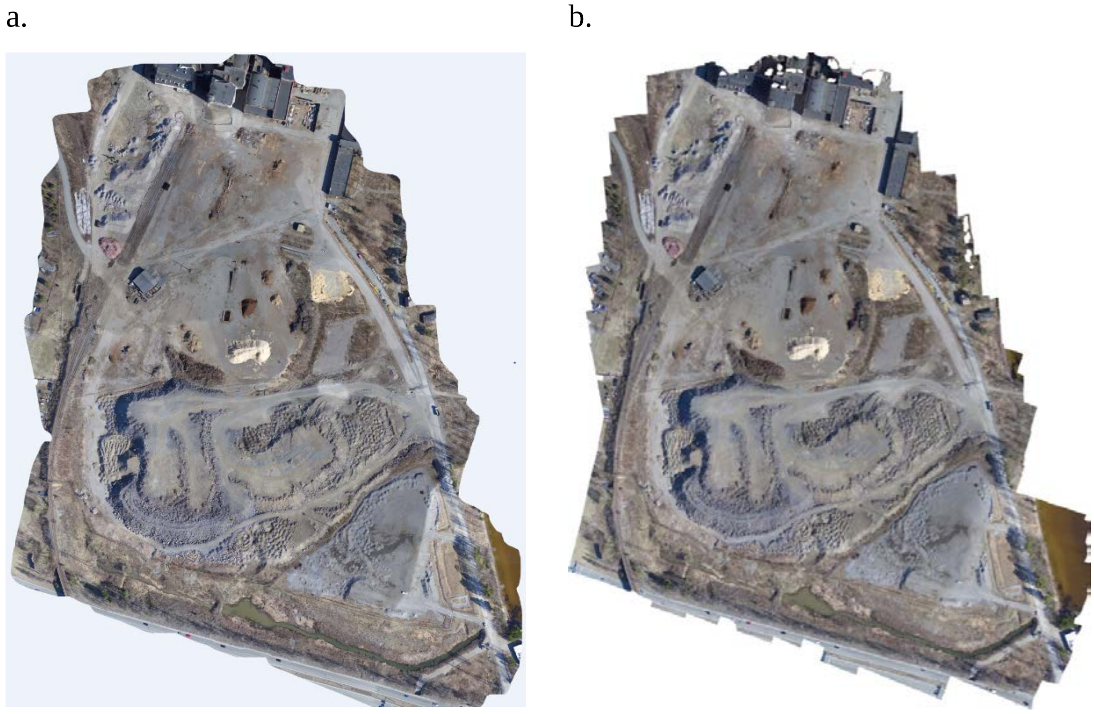


FIGURE 41 Close-up scalar fields of a. ReCap DEM and b. PhotoScan DEM

Figure 42b shows the orthomosaic of PhotoScan having holes in the building area and on the right border, even though the hole filling function was enabled. The image and file sizes from table 7 indicate the image generated by PhotoScan has higher resolution, and this might suggest that it has more details and is sharper than the one produced by ReCap web. This assumption is based on the fact that both files were created from the same set of aerial photographs with the same individual photo quality, resolution, texture. High resolution imagery is certainly favorable for area survey, mapping, and GIS application.

Theoretically, an orthoimagery should be correctly georeferenced and contain the same lack of distortion as a map (explained in section 2.4), especially with the assistance of highly accurate GCPs. However, the accuracy in scaling and georeferencing of these images were not tested due to limited scope of the study.



a.

b.

FIGURE 42 Orthomosaic generated by a. ReCap and b. PhotoScan – viewed by Window Photo Viewer

6.4 User experiences

This section briefly discussed details of user experiences throughout the study and finished with a compiled table comparing two (02) software by relevant criteria to software selection decision making.

6.4.1 ReCap web

ReCap web had a straightforward user interface which offered step-by-step guide to a successful project. The workflow (as can be seen from section 5.1) was a one-direction approach consisting of three (03) steps to keep user from falling off the project track. The commands and functions were limited, thus, causing less confusion in tool selections. ReCap web was a cloud-based application which diminished the importance of strong computing power. By being a product of a well-known CAD software producer Autodesk, ReCap web was supported by a large community including Autodesk staff, professionals, and other users globally. Users could seek for help from the resourceful forum at any time.

However, the maximized simplicity was the first drawback to this application as it allowed extremely limited control over the project as well as the quality of the products. A few project components which users could control were input materials (or photograph quality), markers registration or object scaling, and mesh basic quality settings. The coordinate systems ReCap web provided were rather simplified comparing to a wide range of currently available systems, resulting in errors in georeferencing/scaling of subject. A second drawback would be heavy dependence of project creation on stable and relatively strong internet connection. As it was cloud-based, confidentiality of a project might be compromised to a certain level, therefore, could be a potential disadvantage to intellectual property issues. ReCap web was suitable for small to medium sized projects due to its limitation of 250 photographs per project (Lievendag 2016).

6.4.2 PhotoScan

PhotoScan of Agisoft was a desktop application with more complex workflow. For (new) users, Agisoft offered an extensive user manual and several basic tutorials for common projects. In addition to that, it also had a huge supportive community and discussion forum which provided assistance to project creations. Regarding tool set, PhotoScan had a fair amount of tools and commands with different setting modes (from low to high) for project modification. More importantly, there were a selection of coordinate systems to register corresponding GCPs and camera geographical data to. Unlike ReCap web, PhotoScan had the ability to process thousands of images with a capable processing computer and memory (Memory Requirements Tips n.d). The privacy of project created by PhotoScan would be more secured than by ReCap, given that the processing was done locally.

With PhotoScan, there was a huge trade-off between processing time and resources. Higher quality products would require more time and resources. A powerful computer could help with the burden; but self-evidently, a strong computer can be costly. Also, time investment is absolutely necessary to perform tests and trials on different functions of the software.

Table 8 formulates a comparison of relevant factors when considering two software. Some criteria is subjectively based on user experiences.

Table 8. Comparison between ReCap Photo-to-3D web services and Agisoft PhotoScan

		ReCap photo -to – 3D	**PhotoScan**
Purpose		Close-range UAV Aerial (Lievendag 2016)	Close-range UAV Aerial (PhotoScan Presentation n.d)
Cost ($)	**Education**	0	549/professional edition 59/standard edition (Educational Edition n.d)
	Stand-alone	40/month 300/year 900/3 years (The package included ReCap desktop application for laser scans) (ReCap Pro subscribe n.d)	3499/professional edition 179/standard edition (Professional Edition n.d)
User interface		Simple	Simple
Functionality		Basic	Moderately complex
Photo capacity		250 (Lievendag 2016)	10000 (PhotoScan Presentation n.d)
User		Beginner	Intermediate & proficient
Outputs		.obj, .rcm, .rcp/rcs, GeoTIFF	.obj, .ply, .laz, geoTIFF, .jpeg, .png, etc. (full listing could be found from PhotoScan user manual)
Modeling approach		n/a	Parametric Design
Community size and supports		Excellent	Excellent
Platform		Web (Chrome)	Windows Linux Mac OS (PhotoScan Presentation n.d)

Licenses	Time limited - Stand-alone - Educational	Not time-limited - Stand-alone - Floating - Educational
Developer friendly	No	Yes
Hardware requirements	n/a	- Windows XP or later (32 or 64 bit), Mac OS X Mountain Lion or later, Debian/Ubuntu with GLIBC 2.13+ (64 bit) - Intel Core 2 Duo processor or equivalent - 4 GB of RAM (System Requirements n.d)
Processing time	Moderate	Moderate

6.5 Limitations

For many studies, limitations had significant impact on the results. This section briefly discussed a few key factors which affected the study.

As mentioned in the introduction, the scope limitation did not allow further investigation into the accuracy of the results, for example, the scaling and geometry of model components, as well as the georeferencing of model, DEM, and orthomosaic.

Time was a big factor to be considered. The total allocated time for the study including modeling was roughly three (03) months. For ReCap web, the amount of time was sufficient; however, PhotoScan would require more trials and testing time to explore different functions and settings available. Tools and featured used during the study were not utilized up to their full potential as most of the setting parameters were kept at default value. In addition to that, there were functions yet to be used due to the limited scope of the study.

Another factor was human error. This included the extremely limited field knowledge and practical operation on photogrammetric software of the student. These led to a longer process in self-education and planning along the project. In addition to that, during project trials, operating errors were unavoidable.

Software and hardware played a huge role in the success of a project. For ReCap web, since it was undergoing a structural change at the time of this study, there were problems in creation, preview, and download of projects. The IT support provided by Autodesk staff was limited because ReCap web was being discontinued and moved permanently to a desktop application called ReCap Photo. With PhotoScan, there was no major drawback concerning the hardware and software.

7 CONCLUSIONS

This study documented two (02) detail modeling processes of the same subject using two (02) SfM photogrammetric application: ReCap Photo-to-3D web service and Agisoft PhotoScan Professional. Chosen subject was an area by the shore of Lake Näsijärvi, in the future district Hiedanranta, Tampere; and the materials were acquired through an independent aerial survey project. The study also conducted results and user experience comparisons.

The workflows indicated a rather effortless, cloud-based modeling process done with ReCap web and slightly more complicated work with desktop-based PhotoScan. Autodesk provided full assistance in project creation by offering a thorough step-by-step guide with only a few options of changing project settings, thus, giving almost no room for project failure. Also, no subscription is needed to create a model using ReCap web at a certain limit; and this is sufficient for small and simple projects. By delivering this type of services, any user, regardless of their photogrammetry knowledge and skill, can easily produce 3D models with a set of rightly-captured photographs over the subject of interest. However, there are always two (02) sides of a coin as hardly any project manipulation or quality control could be made with ReCap web. Furthermore, the fully automated operation prevented users (especially photogrammetry beginners) from understanding the basic data processing and model reconstruction procedures. Unlike ReCap, PhotoScan provided sufficient guidance to a certain degree and enabled users to freely modify their projects. The workflow in PhotoScan was informative and self-explanatory comparing to that of ReCap web. As a result, not only could users control projects and outputs, but they also could learn the basic procedures of 3D modeling. Additionally, Photo upload capacity in PhotoScan was more generous, though there were trade-offs between large amount of high-resolution photographs and computer power, processing time, and RAM. Services PhotoScan provides, in general, are subscription only which might be costly for those who are new to photogrammetry.

Results produced by ReCap web suggested that the engine was capable of generating quite dense cloud and mesh model, as well as a good-quality textured 3D model. Despite that, DEM and orthomosaic might not be suitable to use for highly accurate precision mapping and global survey, mainly due to a limited available coordinate system options for GCPs registration and unknown approach which the program used to handle the difference between drone-derived and GCPs coordinates. Also, it might be an inconvenience as an intermediate software for file conversion/decimation was needed prior to external post-processing. On the other hand, PhotoScan also produced quality outputs, but it did not limit users by fixed file sizes nor non-versatile file formats. In addition to that, the software offered a comprehensive list of currently available coordinate system to enable accurately georeferenced results.

There are different ways to approach a project, especially using PhotoScan; therefore, the walk-throughs documented in this study cannot be considered as the only approach. Considering all limitations which were previously discussed, this study narrowly analyzed the applicability of both photogrammetric software through a case study and mainly visual inspection; thus, would not be sufficient to either evaluate technical accuracy of the outputs or determine which software was better. It served solely as a reference material to decision making process and other educational purposes. Furthermore, despite vast differences throughout the comparison, it could be suggested that both software are useful for photogrammetric project, and whether to choose one over another depends heavily on many aspects of the users, including purpose, budget, requirements, etc.

REFERENCES

About Scan and Photogrammetry Files and Projects. 2018. Autodesk Help. ReCap. Read 2.12.2017.https://knowledge.autodesk.com/support/recap/learn-explore/caas/CloudHelp/cloudhelp/2017/ENU/Reality-Capture/files/GUID-9B5661B9-4B67-4574-93F6-A850892FA075-htm.html

Adding Survey Points to Photo Projects. n.d. Autodesk Help. ReCap. Read 2.12.2017. https://knowledge.autodesk.com/support/recap/learn-explore/caas/CloudHelp/cloudhelp/2018/ENU/Reality-Capture/files/GUID-BE7A4E6A-F73A-4A44-842A-3AC1511670F8-htm.html

Aerial Triangulation. n.d. GISbox Maps and beyond. Read 15.1.2018. http://www.gisbox.ro/index.php?p=22

Agisoft PhotoScan User Manual Professional Edition version 1.4. n.d. Agisoft PhotoScan. Read 15.11.2017. http://www.agisoft.com/pdf/photoscan-pro_1_4_en.pdf

Agisoft Processing Report. 2018. Read 4.1.2018. file:///C:/Users/tunnus.KK606807LS/OneDrive%20-%20Tampereen%20ammattikorkeakoulu/Thesis/redo%20files/processing%20report.pdf

Autodesk Help. 2016. Re Cap Glossary. Read 15.12.2017. https://knowledge.autodesk.com/support/recap/learn-explore/caas/CloudHelp/cloudhelp/2017/ENU/Reality-Capture/files/GUID-2EFB413E-C65E-41D9-984D-F5816B644A48-htm.html

Autodesk ReCap. n.d. Product Overview. Read 3.12.2017. http://help.autodesk.com/view/RECAP/2018/ENU/?guid=GUID-91810DA7-71F5-4C6C-989C-790455B7C847

Autodesk. n.d. ReCap subscribe. Read 3.12.2017. https://www.autodesk.com/products/recap/subscribe?geoNavigationPreferredSite=US&plc=RECAP&term=1-YEAR&support=ADVANCED&quantity=1

Benli, G. 2015. The Advantages of Using Laser Scanners in Surveying in Protected Sites: A Case Study in Historical Peninsula in Istanbul. Handbook of Research on Emerging Digital Tools for Architectural Surveying, Modeling, and Representation. IGI Global Disseminator of Knowledge. Read 3.1.2018. https://www.igi-global.com/chapter/the-advantages-of-using-laser-scanners-in-surveying-in-protected-sites/133421

Blender 3D: Beginner Tutorials/Print version. n.d. Wikibooks. Read 3.1.2018. http://petitdragon999.free.fr/Document/3D/Blender_Noob1.pdf

Broomhall, C. 2016. 3-D (three dimensions or three-dimensional). Essential Guide: Enterprise 3D printing tutorial: CIO challenges and advice. Read 3.1.2018. http://whatis.techtarget.com/definition/3-D-three-dimensions-or-three-dimensionalv

City of Tampere. 2016. The idea competition for the Hiedanranta area in Tampere attracted 39 contestants. Read 2.12.2017. https://www.tampere.fi/en/city-of-tampere/info/current-issues/2016/10/18102016_1.html

CloudCompare. n.d. Introduction. Read 2.12.2017. http://www.cloudcompare.org/

CloudCompare. n.d. User Manual version 2.6.1. Read 15.12.2017. http://www.danielgm.net/cc/doc/qCC/CloudCompare%20v2.6.1%20-%20User%20manual.pdf

Coordinate systems, map projections, and geographic (datum) transformations. n.d. ESRI. Read 10.1.2018. http://resources.esri.com/help/9.3/ArcGISEngine/dotnet/89b720a5-7339-44b0-8b58-0f5bf2843393.htm

Difference between WGS84 and ETRS89. Geography. Read 4.1.2018. http://www.differencebetween.net/miscellaneous/geography-miscellaneous/difference-between-wgs84-and-etrs89/

Digital Elevation Models. n.d. Learn ArcGIS. Read 3.1.2018. https://learn.arcgis.com/en/related-concepts/digital-elevation-models.htm

Educational Edition. n.d. Online store. Agisoft PhotoScan. Read 15.12.2017. http://www.agisoft.com/buy/online-store/educational-license/

EPSG. n.d. EPSG:3878. ETRS89/GKFIN24. Read 15.12.2017. https://epsg.io/3878

GIS geography. 2016. DEM, DSM & DTM Differences – A Look at Elevation Models in GIS. GIS Analysis. Read 4.1.2018. http://gisgeography.com/dem-dsm-dtm-differences/

Granshaw, S. 2016. Photogrammetric terminology: Third edition. The photogrammetric record. P 221. Read 15.1.2018. http://onlinelibrary.wiley.com/doi/10.1111/phor.12146/epdf

Granshaw, S. 2016. Photogrammetric terminology: Third edition. The photogrammetric record. P 238. Read 15.1.2018. http://onlinelibrary.wiley.com/doi/10.1111/phor.12146/epdf

Heidemann, H, K. 2014. Lidar Base Specification. Collection and Delineation Book 11. Section B, US Geological Survey Standards. Chapter 4. P 18-20. Read 4.1.2018. https://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf

HiPer SR. n.d. HiPer SR Specifications. Read 3.12.2017. https://www.topconpositioning.com/gnss/integrated-gnss-receivers/hiper-sr#panel-product-specifications

Introduction to ortho mapping. n.d. ArcGIS Desktop. Ortho Mapping. Read 4.1.2018. https://pro.arcgis.com/en/pro-app/help/data/imagery/introduction-to-ortho-mapping.htm

Kar, B. 2014. Aerial Photogrammetry vs. Terrestrial Photogrammetry. Read 15.1.2018. https://www.linkedin.com/pulse/20141204183829-28931042-aerial-photogrammetry-vs-terrestrial-photogrammetry/

Karppi.2017. Hiedanranta –smart and sustainable city district of the future. Väliaikainen Hiedanranta blog. Read 2.12.2017. http://valiaikainenhiedanranta.fi/in-english/hiedanranta-smart-and-sustainable-city-district-of-the-future

King, R. 2010. 3D modeling: Straight or curved lines? Surfaces or solids?. Read 3.1.2018. http://itknowledgeexchange.techtarget.com/semantic-web/3d-modeling-straight-or-curved-lines-surfaces-or-solids/

Klinkenberg, B. n.d. Unit 38 – Digital Elevation Models. Read 3.1.2018. http://ibis.geog.ubc.ca/courses/klink/gis.notes/ncgia/u38.html

Lievendag, N. 2016. Autodesk Recap 360 review. Read 15.12.2017. https://3dscanexpert.com/autodesk-photogrammetry-review-recap-360/

Matthews, N. A. 2008. Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation. Technical Note 428. U.S. Department of the Interior. P 3. Read 4.1.2018. https://www.blm.gov/nstc/library/pdf/TN428.pdf

McCarty, B. 2014. G-FAQ – What is Ground Control? Part 1. Apollo Mapping – The Image hunters. Read 4.1.2018. https://apollomapping.com/blog/g-faq-ground-control-part

McGlone, C. 2016. How does photogrammetry work?. Quora. Read 20.1.2018. https://www.quora.com/How-does-photogrammetry-work

Memory Requirements Tips. n.d.. Agiosft PhotoScan. Read 4.12.2017. http://www.agisoft.com/pdf/tips_and_tricks/PhotoScan_Memory_Requirements.pdf

PhotoScan Presentation. n.d. PhotoScan – Fully automated professional photogrammetric kit. Read 15.12.2017. http://www.agisoft.com/pdf/photoscan_presentation.pdf

Professional Edition. n.d. Online store. Agisoft PhotoScan. Read 15.12.2017. http://www.agisoft.com/buy/online-store/

Schain, S. 2017. ReCap for Animation. CAD Learning. Read 2.12.2017. http://blog.cadlearning.com/3ds-max/recap-for-animation/

Schuckman, K, n.d. Geometry of the Aerial Photograph. The Single Vertical Aerial Photograph. PennState College of Earth and Mineral Sciences. Department of Geography. Read 15.1.2018. https://www.e-education.psu.edu/geog480/node/452

Schwind, M & Starek, M. 2017. Producing High-quality 3D Point Clouds from Structure-from-Motion Photogrammetry. How to produce high-quality 3D point clouds. Read

3.1.2018. https://www.gim-international.com/content/article/structure-from-motion-photogrammetry

Singh, S. 2016. Confused between DEM, DTM, and DSM. GIS resrouces. Read 4.1.2018. http://www.gisresources.com/confused-dem-dtm-dsm/

Slick, J. 2017. 3D defined – What is 3D?. 3D Computer Graphics, Film, and All important Z-axis. Read 3.1.2018. https://www.lifewire.com/what-is-3d-1951

Slick, J. 2018. 3D Model Components - Vertices, Edges, Polygons & More. Read 3.1.2018. https://www.lifewire.com/3d-model-components-1952

System Requirements. n.d. Agisoft. Read 2.12.2017. http://www.agisoft.com/downloads/system-requirements/

Tutorial (Beginner Level): Orthomosaic and DEM Generation with Agisoft PhotoScan Pro 1.3 (with Ground Control Points). n.d. Agiosft. http://www.agisoft.com/pdf/PS_1.3%20-Tutorial%20(BL)%20-%20Orthophoto,%20DEM%20(GCPs).pdf

Waymarking. 2012. Näsijärvi. Read 15.1.2018. http://www.waymarking.com/waymarks/WMEDZ9_Nsijrvi_Tampere_Finland

What is raster data?. n.d. ArcMap. ESRI. Read 3.1.2018. http://desktop.arcgis.com/en/arcmap/10.3/manage-data/raster-and-images/what-is-raster-data.htm#GUID-40BD8AAA-E6A8-4263-9086-20647BDDC00F

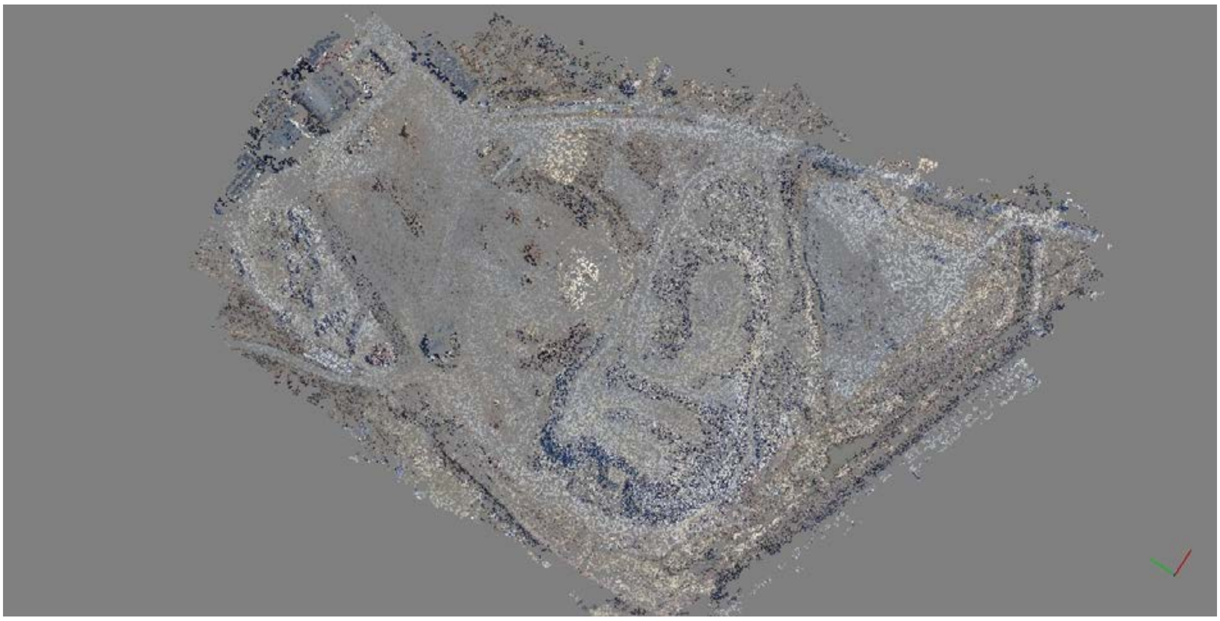
Zapata, M. 2015. What are GCPs or Ground Control Points?. Compass Data. Read 4.1.2018. http://compassdatainc.com/what-are-ground-control-points/

APPENDICES

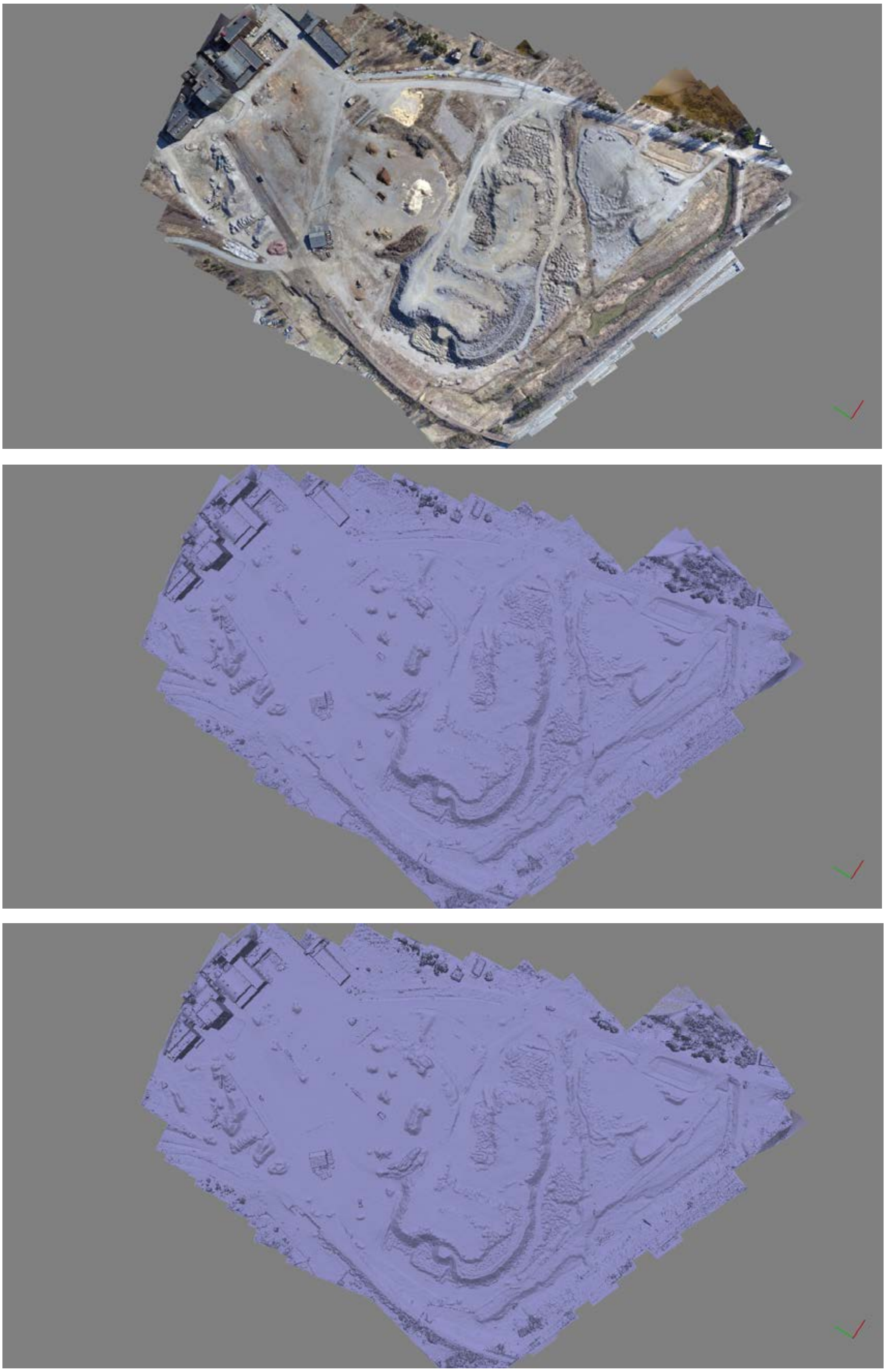
Appendix 1. GCP GPS Coordinates

	y	**x**	**z**
GCP1	6822955.001	24483179.040	106.923
GCP2	6822912.454	24482940.073	109.610
GCP3	6822790.311	24483018.101	105.520
GCP4	6822802.196	24483149.737	107.170
GCP5	6822535.046	24483274.310	98.705
GCP6	6822574.881	4483147.938	100.674

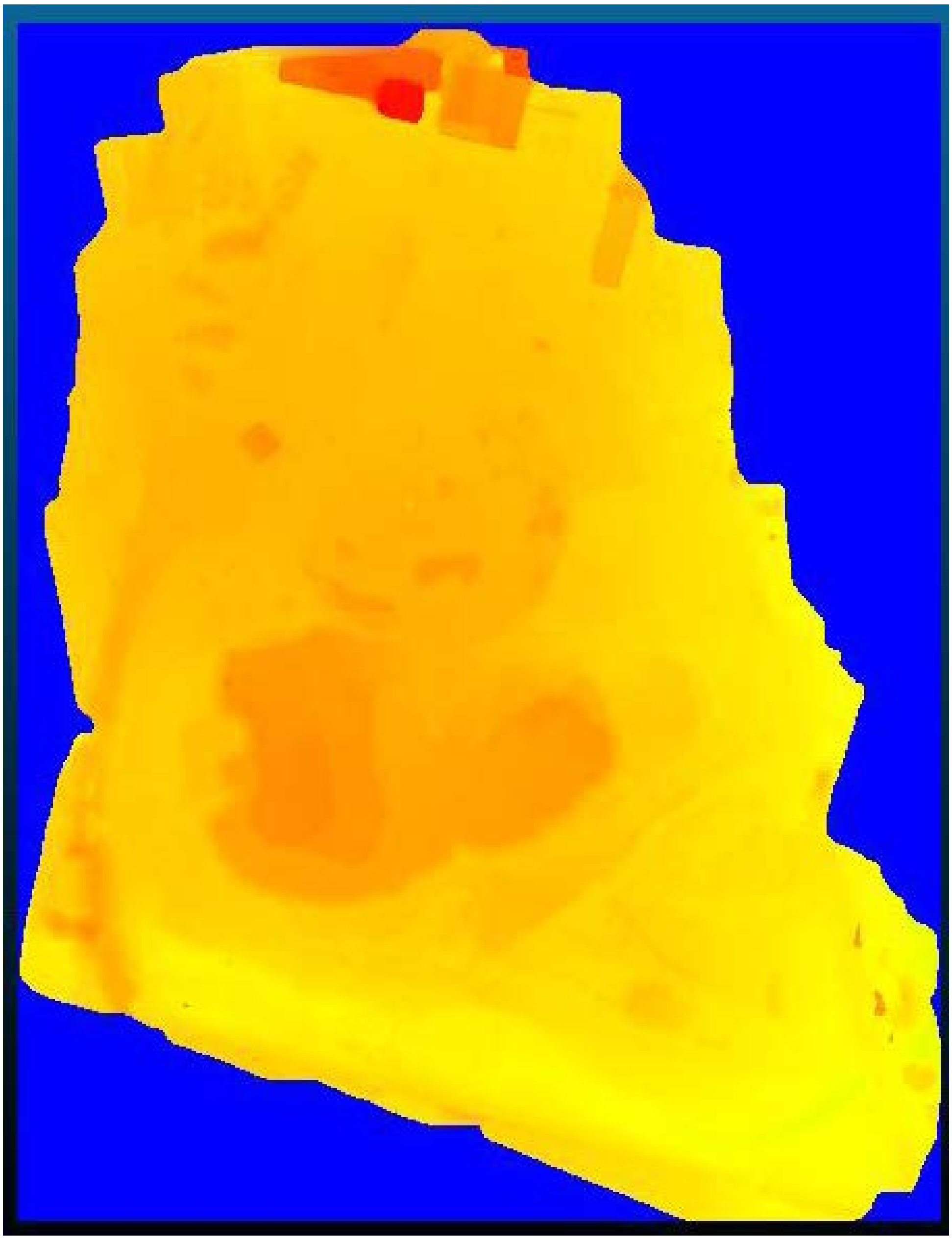
Appendix 2. PhotoScan sparse cloud top view – a screen capture from PhotoScan viewer



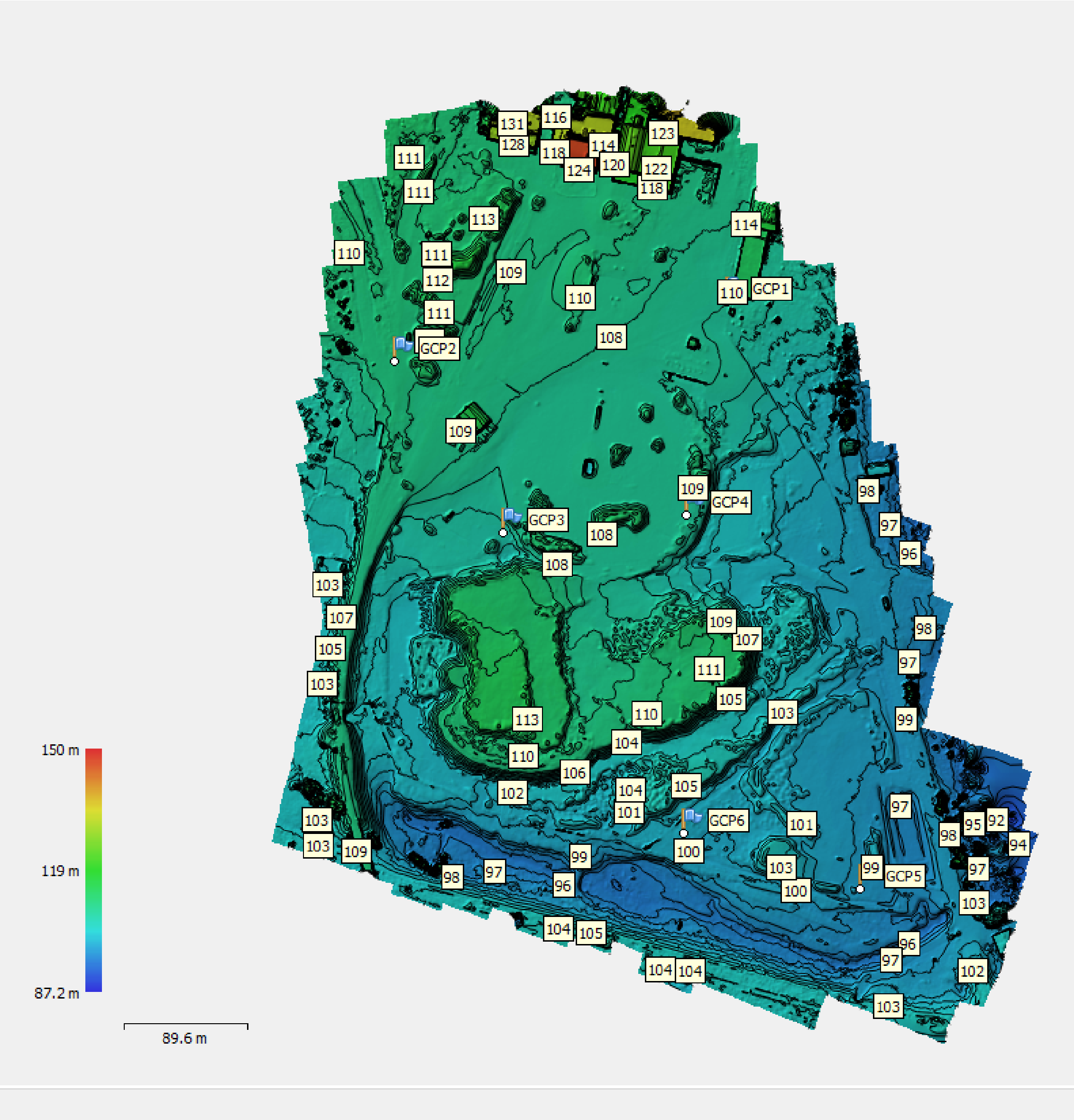
Appendix 3. PhotoScan mesh model - top views in order of shaded, solid, wireframe - a screen capture from PhotoScan viewer

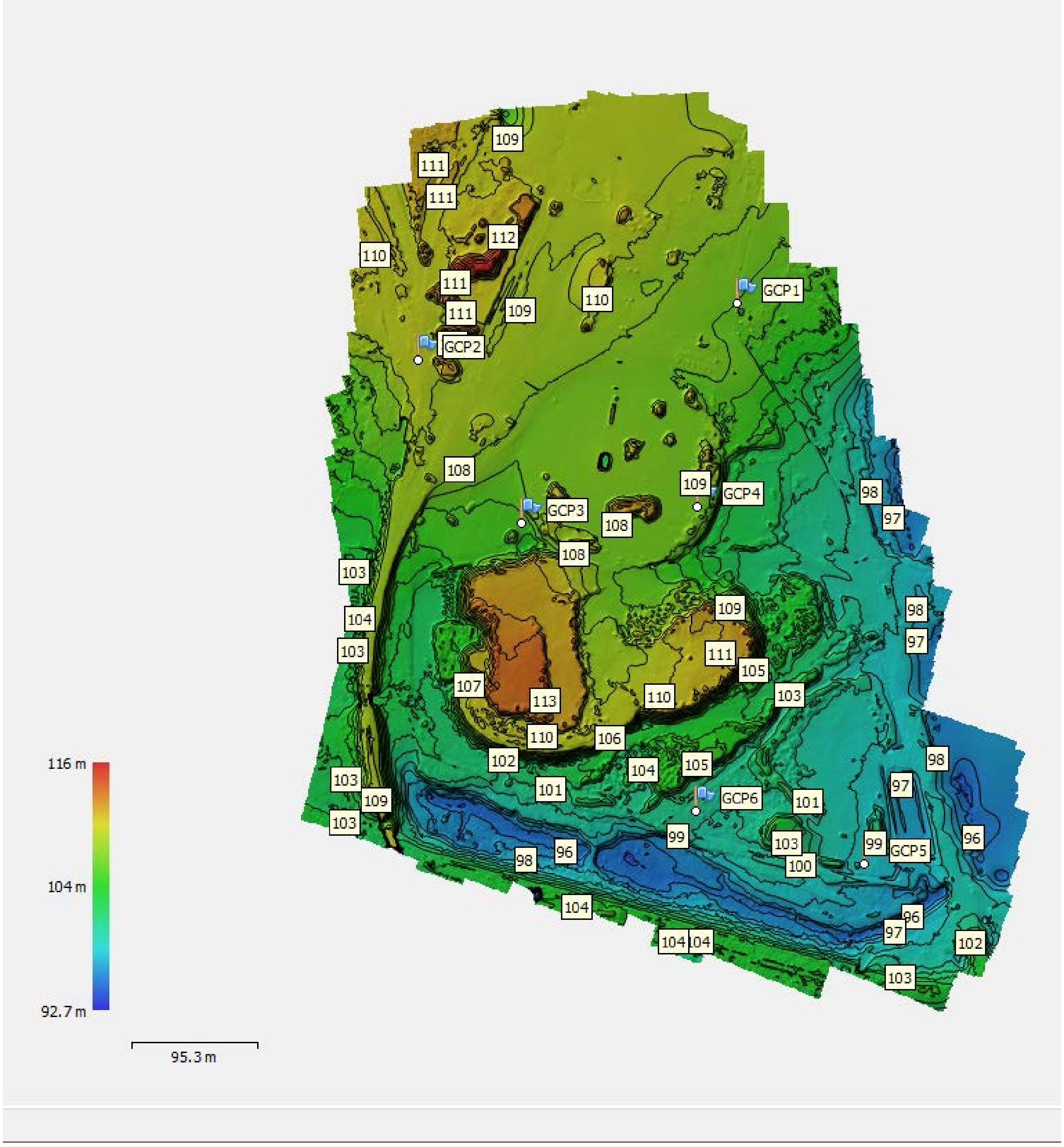


Appendix 4. ReCap web-built DEM and viewed by CloudCompare



Appendix 5. Photoscan-built DSM and DTM with contours – viewed by PhotoScan

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