PHOTOGRAMMETRIC 3D-MAPPING USING LOW-COST UNMANNED AERIAL VEHICLE - ANALYSIS OF ACCURACY

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Abstract

The UAV (unmanned aerial vehicle) is a part of the digital transformation in the construction industry. With increased options of low-cost UAVs, more companies will want to integrate UAVs into their business. By capturing a large amount of data in a short time, it could be very useful for several applications within the construction industry. The question is: can the low-cost UAV be an option considering its accuracy and efficiency?

This thesis will investigate how accurate a low-cost UAV can be for 3D modelling. We used a low-cost UAV and a total station in a field study in Malmö, Sweden, to obtain 3D-data from a building for further evaluation and comparison. Moreover, we analyzed the future and evaluation of the implementation of the UAV through a literature study and interviews with professionals working in the construction industry.

The derived results show that it is possible to get a spatially accurate point cloud even without the use of ground control points (GCPs). This point cloud did not give accurate absolute positions to a given reference system without the use of GCPs but as that is not necessary for facade plans and other building plans, it will still be of good use. Our results show an accuracy of about 1-2 cm in a point cloud for an average residential building. Smaller features in darker areas might not be correctly modelled.

It also shows that it is fairly easy to deploy a low-cost drone project for use in the construction industry due to a high level of autonomy during flight.

Keywords: UAV, Drone, Accuracy, photogrammetry, point cloud, 3D modelling

Sammanfattning

Drönare, som också är känt som obemannade luftfartyg, är en del av byggbranschens digitala transformation. Sedan marknaden börjat erbjuda fler alternativ, så som lågkostnadsdrönare har fler företag fått upp ögonen för möjligheterna och är intresserade av att integrera drönare i sin affärsverksamhet.

Genom att samla in mycket data, enkelt och snabbt kan drönare vara användbara inom flera användningsområden för byggbranschen och reducera både tidsåtgång och kostnader. Frågan är om en lågkostnadsdrönare är tillräckligt bra med avseende på noggrannhet och effektivitet?

Denna studie undersöker hur noggrann en lågkostnadsdrönare är för 3D-modellering. I en fältstudie har vi samlat in data från ett hus i Malmö med både en lågkostnadsdrönare och en totalstation för att sedan jämföra och värdera vårt resultat. Vidare har analys av framtiden och implementering av drönare gjorts med hjälp av litteraturstudier och intervjuer med fackmän inom byggnadsindustrin.

Studien visar att det är möjligt att uppnå samma goda noggrannhet, ca. 1-2 cm även utan flygsignalmarkörer (GCP) om tillräckligt antal georefererade bilder används. Dessa ska inte bara vara lodbilder utan även perspektivbilder.

Punktmolnets absoluta koordinater i ett givet referenssystem kommer inte stämma utan GCPer men för framställning av fasadritningar och vissa andra byggnadsritningar är det ändå inte nödvändigt.

Studien visar också att det är relativt enkelt att ta till sig och integrera drönare inom byggindustrin tack vare enkelheten i handhavandet under flygning.

Nyckelord: UAV, drönare, noggrannhet, fotogrammetri, punktmoln

Foreword

This thesis has been conducted at LTH School of Engineering in Helsingborg, part of Lund university, the spring of 2018. We would like to thank our supervisor, Sadegh Jamali, for all his support.

We would also like to thank Mozafar Veysipanah for providing us with LiDAR data and the City of Malmö for sharing geodetic information with us.
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Abbreviations

BIM – Building information modelling

Drone – A system of equipment that can act autonomously on land, at sea or in the air. An aerial drone is also known as UAV.

UAV – Unmanned aerial vehicle

UAS – Unmanned aerial system

TS – Total station

GPS – Global positioning system

TLS – Terrestrial Laser Scanner

RTK – Real time kinematics

PPK – Post processing kinematics

SfM – Structure from motion

GCP – Ground control point

CHP – Check point

GSD – Ground sampling distance

GCS – Ground control station

Exif – Exchangeable image file format

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1. Introduction

In this chapter, the background and aim will be presented as well as a description of the target group and scope. This will be followed by a brief disposition to give the reader an overall view of the study.

1.1 Background

Unmanned aerial vehicles (UAVs), also known as drones, are part of the digitalization of the construction industries. The UAV can be defined as a motorized non-pilot aircraft, which can fly autonomously or be remotely controlled (Transportstyrelsen, 2018). More competitive prices and smarter solutions for the development of data collection makes it likely that the UAV will play an important role in the future. UAV technology can be used for several applications within the construction industry such as inspection, photogrammetry, measuring heights and volumes and generating 3D models. The number of applications is growing and the market is in development and in an expansion phase. At the same time as the development of UAV technology increases, more user-friendly software is being developed and it is becoming easier to integrate the data into different powerful data-analysis tools. The UAV could be an alternative and perhaps a potential solution to handle concerns such as expensive costs and time-consuming equipment.

Since the drone became lower in cost, more companies within the construction industry invest in UAV technology and want to integrate it into their business. Cost, time and quality improvements are some of the benefits and values a drone can create by capturing large amounts of data very quickly. To achieve this with a low-cost UAV, the product must be used appropriately and data must be accurate and reliable. Thus, UAVs could be an excellent choice for data collection and information gathering. This study focuses on how accurate a low-cost UAV can be and shows what value a photogrammetric mission with high accuracy can create.

There are still a lot of questions about the implementation of drones and what opportunities and limitations there are. There are also challenges, such as current regulations that can change fast and integrity issues regarding camera surveillance. Today, the knowledge about drones and their potential is limited, but the interest in UAV technology in the construction industry is growing. Therefore, it is important to show the potential of digitalization and show the noticeable differences that come along with new innovative methods.

1.2 Aim

The purpose of this thesis is to evaluate the UAV technology and the accuracy of our generated 3D–model to provide basis for future research and basis for companies that want to integrate UAVs into their business. It specifically aims to:

- Use a low-cost UAV to create a 3D-model of a building and its surroundings.
- Analyze the accuracy of the created 3D-model.
- Compare accuracy for models created with different capturing modes, including nadir and oblique images.

1.3 Scope and limitations

There is a great number of aspects to take into consideration when generating the 3D-model, and therefore the content needs to be limited due to time restrictions. By using a low-cost UAV, we are entering the airspace which means we need to follow the regulations for aviation. However, we will only mention the regulation system briefly and this thesis will not focus on the legal issues. The geographical scope will be to measure and survey one building located in Malmö.

1.4 Target group

The target group for this study is mainly actors who want our result to evaluate an implementation of UAVs into their business. The main target group will be companies in the architect, engineering and construction industry.

1.5 Status of knowledge

Constructing 3D-models with photogrammetry and structure-from-motion technology is cheaper than using LiDAR. LiDAR is an acronym for "light detection and ranging". However, photogrammetry comes with some drawbacks (Larsson & Tulldahl, 2015). Lidar uses its own light source and is therefore not affected by shadows or low light conditions. In the case of photogrammetry, if leaves on trees are blocking the ground it will be impossible to model it. LiDAR however has some capability to penetrate the foliage.

In a case study conducted in Italy of the Ridracoli dam, a comparison between laser scanned data from a ground based LiDAR scanner and photogrammetric data acquired with a UAV was made. It showed that photogrammetry can rival LiDAR with possible improvements in the placement of ground control points (Buffi, Manciola, Grassi, Barberini, & Gambi, 2017). The post-processing of the data took a considerable amount of time and had to be partitioned into smaller pieces. Processing hardware and software as well as the size of the object to be mapped is essential.

A case study performed in Australia in 2012 of coastal erosion showed that a point cloud from UAV pictures were accurate at a sub decimeter level (Harwin & Lucieer, 2012) .

Low-cost UAVs are often equipped with rolling shutter sensors which could pose a problem. If the objects being depicted are moving fast or the sensor itself is moving too fast, a jello effect will show up and distort the picture and therefore lower the accuracy of the computed points. This effect can be corrected for in the software and if the flying speed is reduced the effect will be negligible (Pix4D; Vautherin, Jonas; et.al, 2018).

1.6 Research approach

The UAV and its accompanying technology is going through an expansion phase with constant and ongoing development. This made the research more complex and it was important to stay updated with the latest news and technology to keep this thesis relevant. Therefore, we made the decision that interviews and former reports should comprise a substantial part of the information gathering. This thesis was initiated to examine if a low-cost UAV could be an alternative to more expensive UAVs or LiDAR. Thus, it would give the thesis more depth and it would become more relevant to companies and engineers within the construction industry. The methods of data collection and information gathering has been varying to achieve a more substansive study. The first part, the theoretical framework, is based on literature, former reports and information from different kinds of Swedish departments that regulate the UAV and its applications. This provides a basis for the case study that was performed.

1.6.1 Literature studies

The primary aim of the literature study is to give the reader an overall view of the subject and UAV technology, which provides a context for the case study and its results. The UAV technology is under constant and quick development which makes new studies and reports more relevant.
The literature study contains several reports and articles, both in English and Swedish and the keywords have been UAV, accuracy and drone.

Furthermore, we have also investigated the requirements for flying drones and our main source of information was the department of transportation (Transportstyrelsen, 2018). A summary of the legislation is presented to illustrate how the regulations are applied on a national and European level. Because of the Swedish membership in the European Union both levels always need to be considered.

1.6.2 Interviews

To gather information about essential and potential applications for drones within the construction industry we conducted interviews with experts within this field. To get a better picture, interviews were conducted with an architect and a contractor. The focus has been to see what kind of possibilities and limitations there are for a low-cost UAV. The interviews were so called semi-structured interviews which means that the main questions are predetermined, but can be supplemented by additional questions.

1.6.3 Method criticism

We chose a method that would enable us to reach our aim and goal with this thesis. Like all methods, the case study method has some shortcomings. Firstly, it can be very much information for the reader to take in because our case study has a quite long process. The case study itself, where we choose a total station to measure the building, could have got even more accurate and precise results with TLS (Terrestrial Laser Scanner). Unfortunately, we did not have access to that type of equipment. Furthermore, only conducting two interviews can be considered too few and it can be difficult to get a general picture of the UAV in the construction industry from these. The main purpose of the interviews is to get increased understanding about the UAV and try to show the opinion of two big companies about UAV- technology and the future. Finally, our building is small and has a simple geometry and the case study could have investigated a more complex building.

1.7 Outline

Chapter 1 – Introduction
This chapter gives the reader an overview of the subject and contains background theory. It also contains a short summary of what questions and problems the study will answer. It describes choice of method for the study and provides a more detailed explanation of the study arrangement.

Chapter 2 – Theory
In this chapter, theory regarding the basis of UAV, essential parts for the flight, current regulations, computer software and other background information will be presented.

Chapter 3 – Materials

This chapter gives a short introduction to the case study and the equipment needed for its execution.

Chapter 4 – Method
Chapter 4 presents the method of the case study, from setup to finished model.

Chapter 5 – Result

In chapter 5 the results are summarized.

Chapter 6 – *Analysis and discussion*

This chapter contains a wider discussion and deeper analysis, and the results of the accuracy and interviews will be presented and discussed.

Chapter 7 – Conclusion

Chapter 7 presents the conclusion of the study and further research and development is discussed.

Chapter 8 – References

All references are presented in chapter 8.

2.0 Theory

This chapter gives a theoretical background about the UAV and basis to the aim of this study. It is divided into three parts: UAV, UAV technology and software.

2.1 UAV (Unmanned aerial vehicles)

The first part of this chapter gives an introduction to the UAV and the drone. It also contains the essential applications and areas that the UAV can operate in. It is followed by a short summary of the regulations and laws about UAVs.

2.1.1 UAV

Unmanned aerial vehicles are also known as drones are defined as motorized non-pilot aircrafts which can fly autonomously or remotely controlled (Transportstyrelsen, 2018). The term UAS (Unmanned aerial system) refers to the entire package needed to operate the system which means that the UAV, ground control system (GCS), camera and GPS are all included in this term (Jurovich surveying, 2018). There is a large number of different types of drones, from small ones that weigh only a hundred grams to big drones that weigh over several hundred kilograms and work exactly as a real plane. The price ranges from approximately 3000 SEK for a small consumer drone with a decent camera up to 200 000 SEK and above for enterprise UAVs. A low-cost UAV in this thesis is in the price range of up to 10 000 SEK. Prices continues to fall as technology advances.

2.1.2 Applications

The main purpose of UAVs has been military use, but they have become more common for private and commercial use in recent years (NE, 2016). This depends on the cost of equipment falling and new areas of use being discovered. There are applications for drones in almost every sector and the market is undergoing constant development. The main technical feature is the ability to obtain data and this is possible with the on-board camera and the advanced sensors. The number of applications is growing but in this thesis we focus on the introduction of UAVs to the construction industry.

The construction company Skanska AB has developed and integrated UAV technology into their business and uses the drone in a wide range of applications. Inspection and monitoring, 360-degree panorama photos, land surveying, mapping, calculations and generating 3D-models are just some of the powerful applications that a drone can achieve (Sandén, 2018). In many of the major projects frequent surveys are conducted to investigate how the project is progressing, and UAVs are used for documenting the construction site. There are many ways to utilize the UAV and it has added value to Skanska by reducing both time consumption and costs.

Another area where UAV technology can create value is within BIM (Building Information Modelling), which is a work method where information about a construction project is created and handled throughout the life cycle of the project (M. A Mortenson, 2008). Today, a growing number of players within the construction industry are using BIM and this work method has affected the whole industry. Some of the most common applications are 3D–modelling, visualization, planning, coordination and property management. This is possible because the model is built up with different objects that contain information and data. Thus, an overall picture of all components included in the model and digital representation of data are easily available.
BIM, which is becoming increasingly more common within the construction industry, demands a large amount of accurate and precise data. By integrating the UAV with BIM, the BIM becomes more efficient, since the UAV offers fast and cost efficient data and information

The UAV can be of great help in the creation of 3D-models of objects or areas. A large amount of data is captured when the UAV is flying, and this data is subsequently fed into software, where a point cloud is generated. This point cloud can be integrated with BIM and by manually importing the point cloud into different software applications such as Autodesk Revit and AutoCAD, it may become an even more useful tool to different players within the construction industry. The generated point cloud is compared with the existing BIM-model to check for deviations. Often, the point cloud must be adjusted

manually but some companies are trying to find solutions for automatic interpretation and classification of objects in the point cloud.
Another possibility of integrating BIM and the UAV is when illustrating, over a certain period, how a project or construction progresses and reporting it digitally. This will give the company a more comprehensive view and it would make it easier to keep track of costs in the project.

2.1.4 Current regulations

The laws and regulations about drones are complex and undergoing development. In the last three years (2015-2018) the legislation has changed several times, both on the national and the EU-national level. Drone flying is regulated by the rules for aviation. The EU has common laws and regulations for drones which weigh over 150 kilos, and for drones under 150 kilos you are obliged to follow regulations at national level which means that each member of the EU specify their own regulations.

From February 1 2018, new regulations have been issued by the department of transportation (TSFS 2017:110) for Unmanned Aerial vehicles (drones). The reason for the new regulations is the increasing use of UAVs in the airspace and the department of transportation wanted to make it easier and clearer which guidelines and rules regulate drones.
The new regulations specify that you no longer need to apply for permission to fly drones weighing less than 7 kilos, provided that the drone is within sight through the whole flight. Furthermore, the same regulations apply to both private and commercial flights. The new regulations also state that you can fly as high as 120 m over land and the regulations no longer applies when you fly indoors.

Below are the most significant laws and regulations for this thesis:

Filming and photographing with drones

Since August 1, 2017, drones are no longer restricted by the camera surveillance law (2013:460) which means that permission is no longer required for private persons and companies for filming and photographing. Instead, the personal data act comes into play and this means that you have to show respect and regard to other people and try to avoid integrity issues. This means that if the material does not offend a person who is captured on film or photo you are allowed to use the drone for filming and photography.

Film and photograph distribution

Public distribution of film, photos or any other data revealing geographic information is prohibited in Sweden. It is possible to apply for permission for distribution from the Swedish maritime administration or the National Survey of Sweden (Lantmäteriet) depending on the type of area covered.
Exceptions from the regulation exists and some of those are essential:
Public places as defined in 1 Ch. 2 § ordningslagen (1993:1617).
Private homes.
Construction sites.
The above is just some of the exceptions where no permission is needed and all are defined by SFS (2016:319) and (2016:320).

Flying close to airports

Since the February 1 2018, drones weighing less than 7 kilos with a maximum speed of 90 km/h are allowed to fly in a control zone without permission from the air traffic control provided that the UAV flies lower than 50 meters from the ground and not closer than 5 km from the runway. In case of a military airport the maximum altitude is 10 meters.
Permission from air traffic control is needed to fly at any altitude closer than 1 km from a heliport.

Protected and restricted areas

National parks, prisons and military areas all fall under protected and restricted areas, which means that you are not allowed to fly drones nearby or over such areas.

2.2 Photogrammetry

This section gives a more thorough explanation of UAV technology, how the UAV collects data and how it generates the 3D-model.

2.2.1 Photogrammetry

Photogrammetry means measuring with photographs, and this method was developed as early as the middle of the 19th century. The first photographic pictures were captured from a balloon and were then available for measures (NE , 2017). The method is validated and it can be used for several applications such as to calculate distances, volumes and heights. To make calculations, photographs of the same area or object but with different camera locations are needed. With at least two overlapping images you create an overlay. Two photographs with overlay are also known as an image pair, and this makes it possible to create three dimensional measures. One of the most common applications within photogrammetry is producing different kinds of topographic maps of and this is done by aerial photogrammetry.

2.2.2 Structure-from-motion

With the emergence of computer vision, photogrammetry has evolved into a powerful and widely used tool for three-dimensional geodesy applications (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). Structure-from-motion is an example of this and because of its low cost it is also ideally suited for high quality topographic reconstruction. The ease of use and low-cost approach is due to its ability to reconstruct a scene without the need for known camera positions and deployment of fixed markings. Instead, the positions can be calculated in post processing with a series of overlapping images and an iterative process called bundle adjustment. This procedure involves algorithms that find matches across related images, so called key points. Those matches are then refined iteratively using least-square minimization as more and more solutions are becoming available from the bundle adjustment database of the set. The software creates three dimensional automatic tie points from the 2D key points.

The reconstructed scene, in this phase, lacks scale and geographic constraints, but with a set of 3D-ground control points with known coordinates visible in the scene, or coordinates of the acquired images, the scene can be aligned to a real world coordinate system using 3D-similarity transformation (Pix4D - Olivier Küng, 2018).

The ground control points (GCPs) should be clearly visible in the field with high contrast shape and color compared to the surrounding. The points can be natural features of the scene but in practice it is often easier to deploy man-made physical objects with high contrast and a clearly defined centroid. The position of the centroid or feature should then be surveyed using traditional geodetic techniques such as a theodolite, total station or Real time kinematics-GPS receiver.

To be able to solve the locations of camera position, structure-from-motion (SfM) uses many different algorithms, and among those is SIFT - Scale Invariant Feature Transform object recognition system. The procedure automatically finds key points of interest in the images. Those are stored as feature descriptors which are largely invariant to changes in scale, position, rotation and partially invariant to illumination. (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012)

The number of key points per image is dependent on the sharpness and resolution of the images as well as the actual complexity, contrast and illumination of the scene to be captured. This dependency on the motif therefore affects the accuracy of the reconstructed model. Variations in individual scenes make a generic guidance on sufficient number of images and overlap virtually impossible (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012) but as a minimum, 3 images per key point should be used, and it is highly recommended to acquire as many images as logistically feasible. However, processing time will increase with increasing number of images.

Accuracy is also dependent on the ground sampling distance (GSD). A GSD of 1cm will render an accuracy of about 2-3cm in the project regardless of accuracy of GCPs. (Pix4D - Olivier Küng, 2018)

2.2.3 Scene reconstruction

When the key points and descriptors are finished the next step in the process is the creation of the sparse point cloud. With the help of key points trackable in multiple images the so called RANSAC algorithm (Random Sample Consensus) builds the sparse point cloud, discarding features not meeting all the criteria. That way, moving objects in the scene like people or cars are inherently removed from the dataset. Static noise like smudges on the lens or landing gears that exist in every image are also discarded since it is not consistent with the model seen from every angle (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). Further algorithms like Clustering View for Multi-view Stereo (CVMS) and Patch-based Multi-view stereo (PMVS2) can be employed to form a densified point cloud filling out the sparse point cloud up to or in excess of two orders of magnitude, typically >4000 points to >400 000 points from the sparse- to the densified point cloud. (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012). Agisoft Photoscan and Pix4D are proprietary commercial software and therefore the exact use of algorithms are not disclosed but both use combinations of the aforementioned technologies.

2.2.4 Georeferencing

To be able to take measurements in our generated 3D-model georeferencing is needed, which means a transformation of the point cloud to external coordinate system (Boberg A. , 2013). Traditionally, indirect georeferencing for UAV images are used to coordinate points on the ground, so called Ground control points (GCPs) (Fig. 2.1). These markers help us scale the model and are best placed in each corner of the scanned area. This demands a measurement of new points or points that are known since earlier.

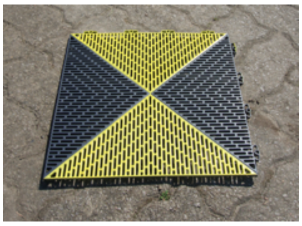


Fig. 2.1. *GCP - Ground control point used in this project*

2.3 Software

The last part of the chapter contains a short introduction to the software and applications that were used during this thesis.

2.3.1 Pix4D – Professional drone mapping and photogrammetry software

The software used for generating our point cloud was Pix4Dmapper, which is suitable for different kinds of drone mapping and photogrammetry missions. Pix4D offers specialized software packages aimed at different businesses like agriculture, mining, mapping and construction industry with both cloud computing and local desktop applications for use with workstations. The software has community and online support. The program was developed in Switzerland starting in 2011 and has become one of the most useful programs for professional drone mapping. The version used for this thesis was Pix4D mapper pro. The post processing process will be explained in chapter 4.

2.3.2 Agisoft Photoscan

Photoscan is a stand-alone software for Mac, Linux and Windows for photogrammetric processing of 2D images into 3D-models and 2D mapping. It is comparable with Pix4D in features and they both use the same underlying algorithms together with their own proprietary additions explained in chapter 3.2.

2.3.3 Cloud compare

Cloud Compare was used for the comparison of the generated point clouds. The program is an open source software, developed in 2003 and its main feature is the comparison of different point clouds (CloudCompare, 2017). We are using Cloud Compare to compare our different point clouds made from the UAV and Laser scanner.

3.0 Materials

This chapter covers how, when and what equipment was used in this thesis.

3.1 Case study

This thesis is based on a case study, which means that the study investigates a contemporary phenomenon within its real-life context (Yin 2009). As previously stated, the aim was to find what level of accuracy is achievable with a point cloud made from images captured with a UAV. The captured images were transferred to a computer and processed with a commercial photogrammetry software, Pix4D, to create a point cloud or 3D-model. Evaluation of accuracy was done by comparison to reference measurements from a Total station and laser scanner. This made it possible to compare the model with reference data to see how accurate the model is.

3.2 Site survey

The object to be surveyed is a 1½- storey private home at Nypongatan, Malmö, Sweden, and was built approximately in 1920 (Fig. 3.1).

The owners intend to apply for a building permit to restore the facade to its original shape with lime plaster and to replace some of the windows.

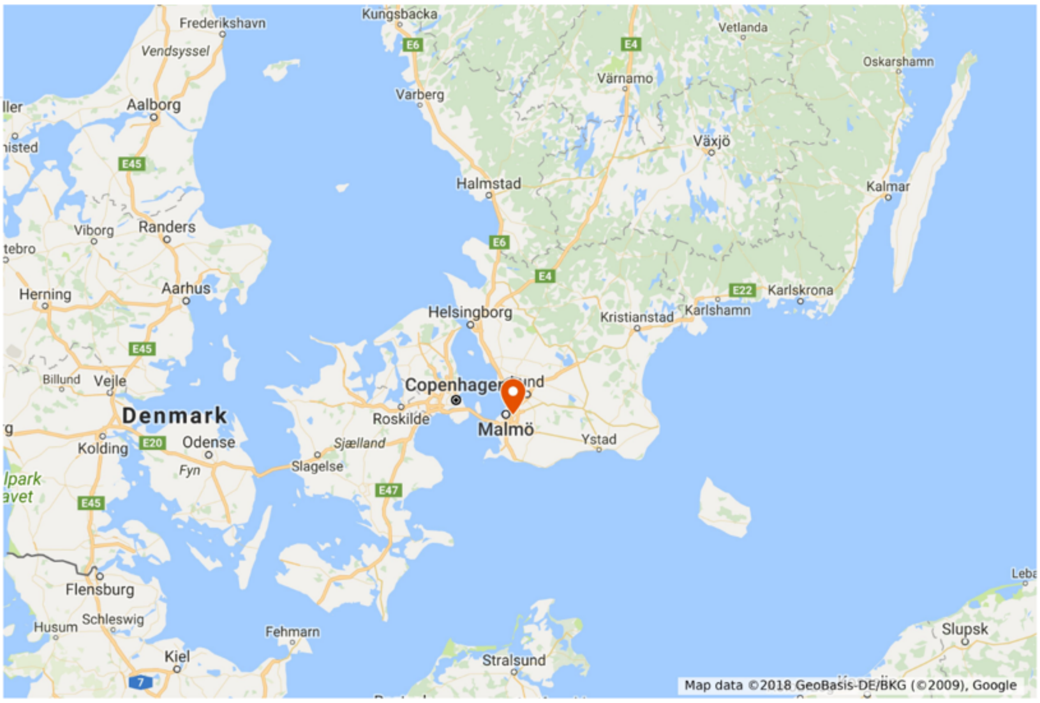


Fig. 3.1. *Location for the case study, Nypongatan, Malmö, Sweden. A more detailed view of the location can be found in chapter 4, Fig. 4.2*

3.3 Equipment

3.3.1 UAV

The UAV used for this thesis was DJI Mavic pro (Fig. 3.2). The drone is produced by the Chinese company Dà-Jiāng Innovations doing business internationally as DJI, offering drones from hobby level to enterprise. With camera and the battery, The DJI Mavic pro weighs 734 grams and has a fly time around 20 – 27 minutes depending on wind conditions (DJI, 2018). Its compact size make this drone easier to fly and since it is lightweight, no permission is needed according to the new regulations. Furthermore, it is equipped with a 4K camera and 3-axis gimbal which allows the drone to capture stabilized photographs and films. The DJI Mavic pro costs around 10,000 SEK in stores (2018).

Fig. 3.2. *The drone used in this thesis with its remote controller connected via USB cable to an iPad for telemetry data, flight planning and live video feed.*

3.3.2 Total station

A total station is a combined optical and electronic instrument that can measure and record angles and distances. The instrument is very useful for different kinds of surveying missions within the construction industry. The total station is an electronic theodolite integrated with an EDM (electronic distance meter) to measure both angles and distances (Andersson, 2013). The total station used for this thesis was the Leica TS06 plus 2” (Fig 3.3) which has an angular measurement accuracy of 0.6 mgon and a distance measuring accuracy between 1.5mm + 2.0 ppm with reflector and 2.0 mm + 2 ppm without reflector at best according to Leica geosystems specifications.

Fig. 3.3. *Leica TS06 plus 2"*

3.3.3 LiDAR

For comparison, data from a Leica ALS80-HP Aerial LiDAR scanner was used. The Leica ALS80-HP is suited for general purpose mapping over wide areas. It can be mounted on smaller aircrafts such as those used for conventional photogrammetric flight missions. LiDAR is an acronym for light detection and ranging, similar to RADAR but using laser pulses instead of radio waves. LiDAR scanners use moving mirrors to cover a full swath. A laser pulse is sent and the time it takes for the pulse to return (times the speed of light) gives the distance. The scanner can detect several returns at different wavelengths caused by pulses that for example partially penetrate foliage.

4.0 Methods

The following chapter describes how the data was collected. The field work is divided into three parts, where each part corresponds to one measurement technique.

4.1 Fieldwork

A field survey at the Malmö site was made on April 20, 2018 with the intention to do two flights and to take measurements of the object to be able to verify the point clouds' spatial accuracy after processing. After processing and initial evaluation, a decision was made to extend the survey and conduct new flights. This was done on May 25, 2018. The fieldwork is divided into three parts where each part corresponds to one measuring technique.

4.1.1 Reference measurements

In the first survey on April 20 and for validation of the finished model, we used a tape measure EU class 1, to measure key lengths and distances of the building. Those measurements were recorded directly on photos taken of the facades (Fig. 4.1).

Fig. 4.1. *Measurements written directly on pictures in the field*

4.1.2 Station setup

For the second survey on May 25, we used a total station together with polygon points, which were obtained from the city of Malmö (Fig. 4.2).

The polygon points had no height information so an arbitrary height of 100m was given to the starting point (PP2366).

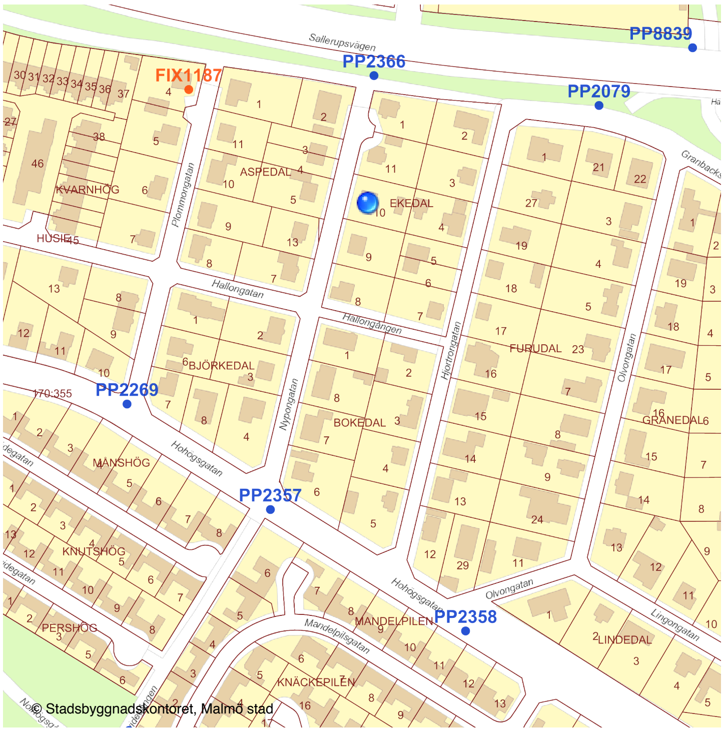


Fig. 4.2. *Map of polygon points near the site. © City planning authority, City of Malmö.*

The first station setup was established on PP2366 with the setup method "Orientation with coordinates" which can be used when station and target coordinates are known. PP2079 was used as back sight to orient the station. A new polygon point closer to the target building was created and given the name PP2400. This point was used to setup a new station and was oriented with PP2366 as back sight. Target measurement was performed by using a Leica round prism on a measuring rod in vertical position with the help of a tripod. The tripod helps to minimize the error sources (Fig. 4.4).

4.1.3 GCPs and Check points

When station setup at PP2400 was completed, we proceeded with establishment of coordinates of GCPs and Check Points. The GCPs were placed around the building and each GCP had to be visible from the total station, or at least the prism on the rod had to be visible.

Check points were divided into two groups: reflector-less measurements and measurements to reflective targets (Fig. 4.3).

Fig. 4.3. *Reflective target for total station measuring. The contrasting plastic sheet helps with later identification in the point cloud reconstruction phase.*

Fig. 4.4. *Precise measuring of the position of a GCP.*

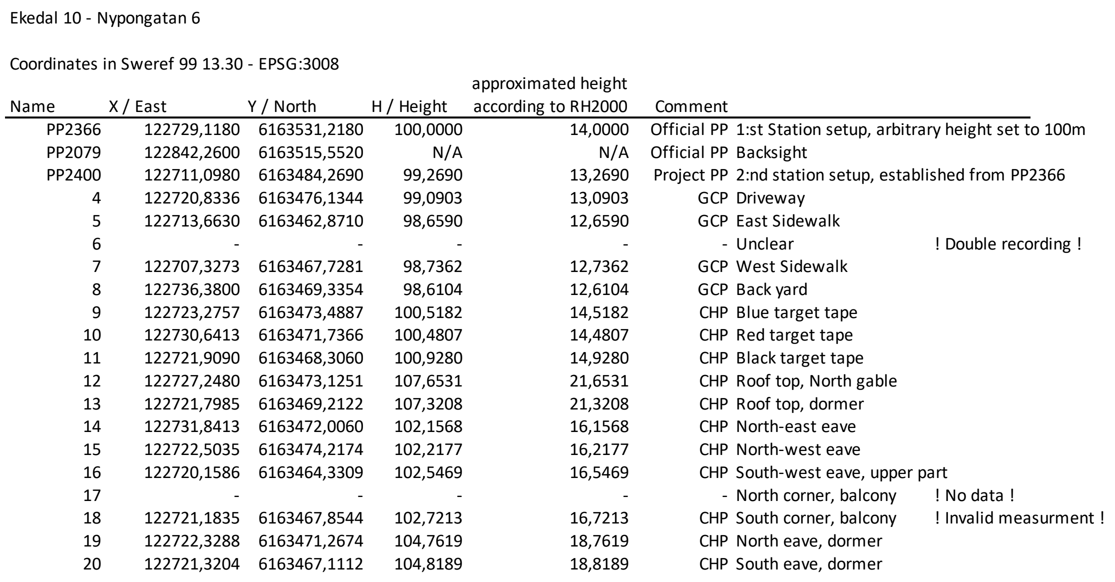
Reflectorless targets were features of the building with high contrast and clearly defined locations like roof tops on dormer and gable. Those locations are not easily accessible but significant to the survey.

Three check point targets were placed on the facades that were visible from the total station. Those targets were self-adhesive reflective tape targets placed on plastic sheets that was taped to the building. This made it easier to aim the total station to the so called check points, and those points would also be visible in the generated model which makes it easier to do the comparison.

4.1.4 Coordinates

The City of Malmö uses SWEREF 99 13 30 (EPSG:3008) which is a local projection of Sweden’s official reference system SWEREF 99, a realization of the European reference system ETRS89. The GPS system instead uses a global reference system called WGS 84 (EPSG:4326). Uncertainty of basic GPS positioning are typically in the order of 10 meters. Lower uncertainty is possible with the help of RTK or PPK GNSS techniques together with network reference stations. Both SWEREF 99 and WGS 84 are three-dimensional reference systems (Lantmäteriet, 2018). Pix4D and Agisoft Photoscan can handle both systems and can also transform coordinates between them. GCP and Check Point coordinates (Table 4.1) resulting from total station measurements are also presented visually (Fig. 4.5).

Table 4.1. *Coordinates of GCPs and CHPs*



Ekedal 10 - Nypongatan 6

Coordinates in Sweref 99 13.30 - EPSG:3008

Name	X / East	Y / North	H / Height	approximated height according to RH2000	Comment		
PP2366	122729,1180	6163531,2180	100,0000	14,0000	Official PP	1:st Station setup, arbitrary height set to 100m	
PP2079	122842,2600	6163515,5520	N/A	N/A	Official PP	Backsight	
PP2400	122711,0980	6163484,2690	99,2690	13,2690	Project PP	2:nd station setup, established from PP2366	
4	122720,8336	6163476,1344	99,0903	13,0903	GCP	Driveway	
5	122713,6630	6163462,8710	98,6590	12,6590	GCP	East Sidewalk	
6	-	-	-	-	-	Unclear	! Double recording !
7	122707,3273	6163467,7281	98,7362	12,7362	GCP	West Sidewalk	
8	122736,3800	6163469,3354	98,6104	12,6104	GCP	Back yard	
9	122723,2757	6163473,4887	100,5182	14,5182	CHP	Blue target tape	
10	122730,6413	6163471,7366	100,4807	14,4807	CHP	Red target tape	
11	122721,9090	6163468,3060	100,9280	14,9280	CHP	Black target tape	
12	122727,2480	6163473,1251	107,6531	21,6531	CHP	Roof top, North gable	
13	122721,7985	6163469,2122	107,3208	21,3208	CHP	Roof top, dormer	
14	122731,8413	6163472,0060	102,1568	16,1568	CHP	North-east eave	
15	122722,5035	6163474,2174	102,2177	16,2177	CHP	North-west eave	
16	122720,1586	6163464,3309	102,5469	16,5469	CHP	South-west eave, upper part	
17	-	-	-	-	-	North corner, balcony	! No data !
18	122721,1835	6163467,8544	102,7213	16,7213	CHP	South corner, balcony	! Invalid measurment !
19	122722,3288	6163471,2674	104,7619	18,7619	CHP	North eave, dormer	
20	122721,3204	6163467,1112	104,8189	18,8189	CHP	South eave, dormer	

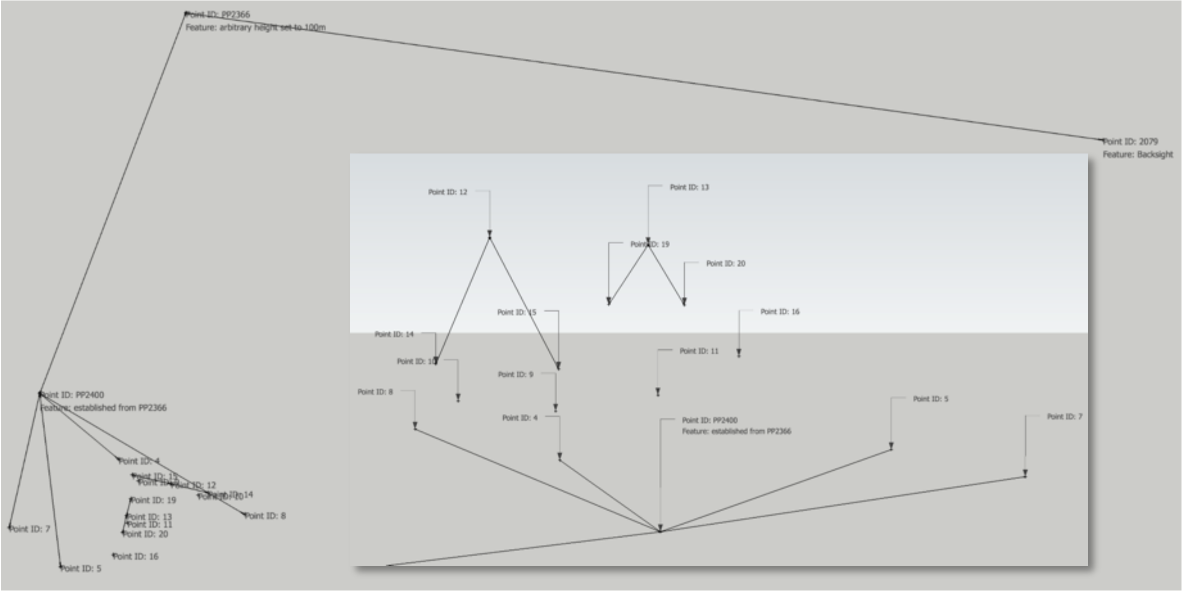
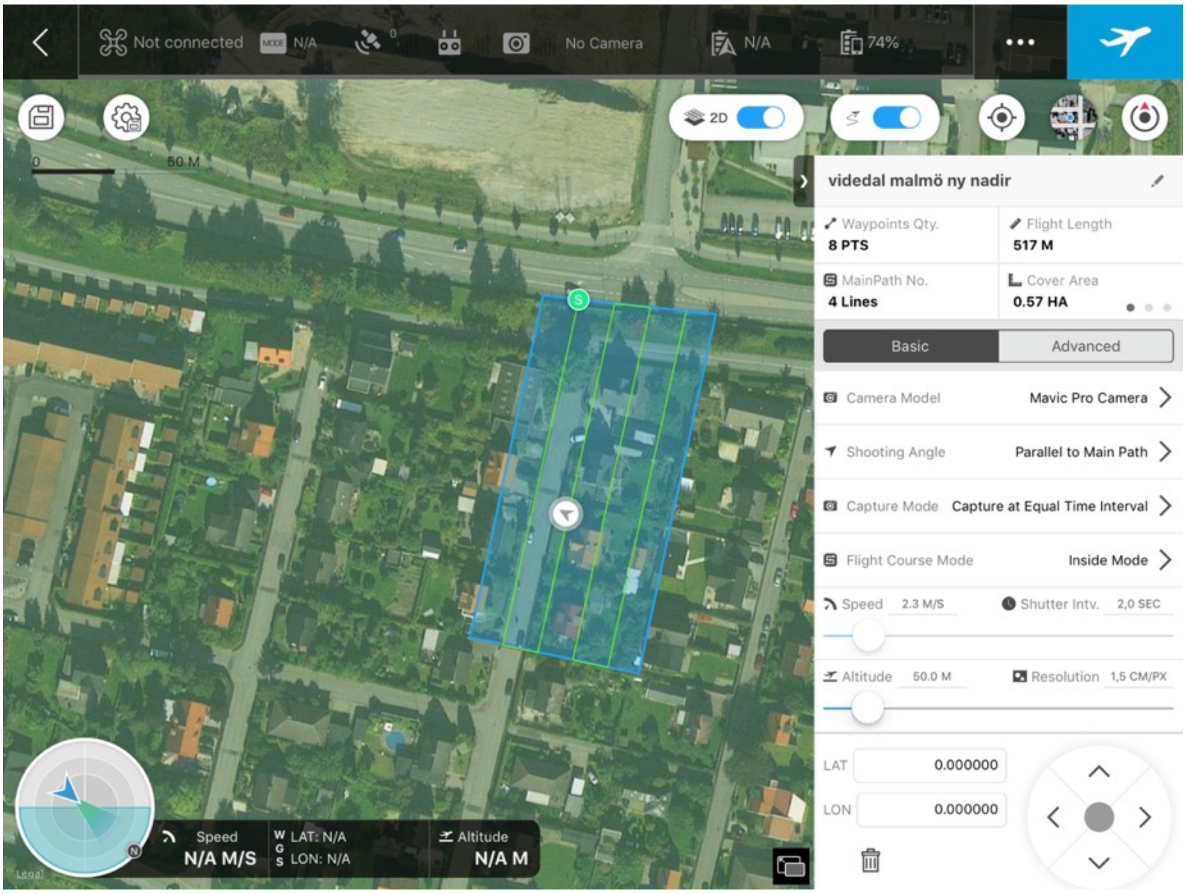


Fig. 4.5. *Visual representation of GCPs and CHPs. Larger figure shows points from top view. Embedded figure shows points as seen from total station.*

4.1.5 Flights

The DJI Mavic pro supports many different applications for flying, both for free-flights and automated flying. Via software API (Application Programming Interface) anyone can build an app to control the drone and to be able to use the camera's video feed and telemetry data. We used an iPad 10,5" connected to the remote controller via a USB-A to lightning cable. The app DJI Ground station PRO was used to plan the flights and then the UAV is able to fly the missions autonomously with GPS waypoints.

Weather conditions on the day of the flight were sunny with a cloudless sky and wind speed of approximately 2-5 m/s with some occasional gusts. The flights were planned to take place around noon to avoid long shadows which can introduce errors in the point cloud and orthophoto. Two different flight missions were conducted at the site. First flight was planned and executed with DJI Ground Station PRO. Parallel flight paths and camera shooting angle in nadir (vertical down) direction (Fig. 4.6**Fig**) covering the building and all GCPs as well as a margin of a couple of meters.



videdal malmö ny nadir

Waypoints Qty. 8 PTS	Flight Length 517 M
MainPath No. 4 Lines	Cover Area 0.57 HA

Camera Model: Mavic Pro Camera
Shooting Angle: Parallel to Main Path
Capture Mode: Capture at Equal Time Interval
Flight Course Mode: Inside Mode
Speed: 2.3 M/S
Shutter Intv.: 2,0 SEC
Altitude: 50.0 M
Resolution: 1,5 CM/PX
LAT 0.000000
LON 0.000000

Fig. 4.6. Flight path and settings in DJI Ground Station Pro.

Flight altitude was set to 50 m which, when used together with the Mavic pro camera, roughly translates to a GSD of 1,5 cm/pixel. Other settings not visible in Fig. 4.6 was a front overlap ratio of 90% and a side overlap ratio of 82%. The importance of overlap will be discussed further in chapter 6.1.

Second flight was planned and executed in the Litchi app and was set up in orbit mode (Fig 4.7) with oblique camera angle. Oblique angle are defined here as any angle except nadir. Two orbits around the building were conducted. The first orbit flight was at 12 m and the second flight at 18 m above ground. The camera gimbal was programmed to aim at the same height above ground in both orbits giving slightly different perspectives for the two flights. Flight radius for both orbits were 25 m.

Image coverage is given by the drone’s air speed and the camera shooting interval. There is no fully automatic setting for this and different objects need different radiuses and therefore varying settings. We used 2.0 degrees/s and a 2 second interval between exposures.

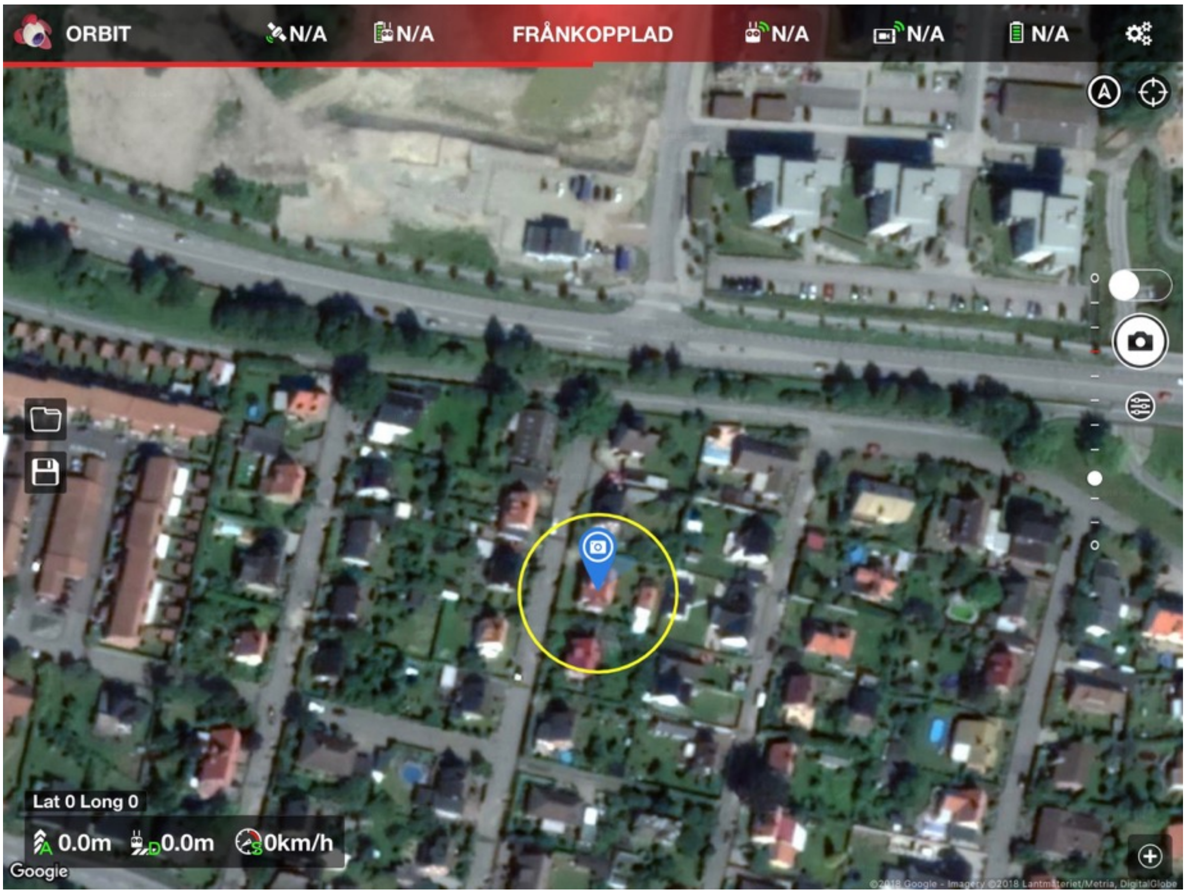


Fig. 4.7. Litchi app for flight planning and execution.

We also executed free flights and manual photography in DJI go 4 for the first survey. For the free flights, we used two different take off points. One in the back yard and one in the front driveway. Both are indicated with a black and yellow GCP (Fig. 4.8).

Fig. 4.8. *One of the GCPs placed around the building.*

4.1.6 LiDAR scan

LiDAR scans were performed with a Leica ALS80-HP (Table 4.2) from an aircraft over Malmö in 2017 on behalf of the City of Malmö. LiDAR scans were not included in our field work but has kindly been shared with us as reference, mainly to compare geometry and location of our survey object.

Table 4.2 *Parameter settings used in LiDAR scan of Malmö in 2017.*

Leica ALS80-HP parameters	
Aircraft speed	115 kn
Flight altitude	782-1000 m
Side overlap	20 %
Point density (on last and only return pulse)	>20 points/m^2
Field of view	7.5 – 11.5 deg.
Measurement rate	560 – 682 kHz
Scan rate	62 – 68 Hz

4.2 Post processing

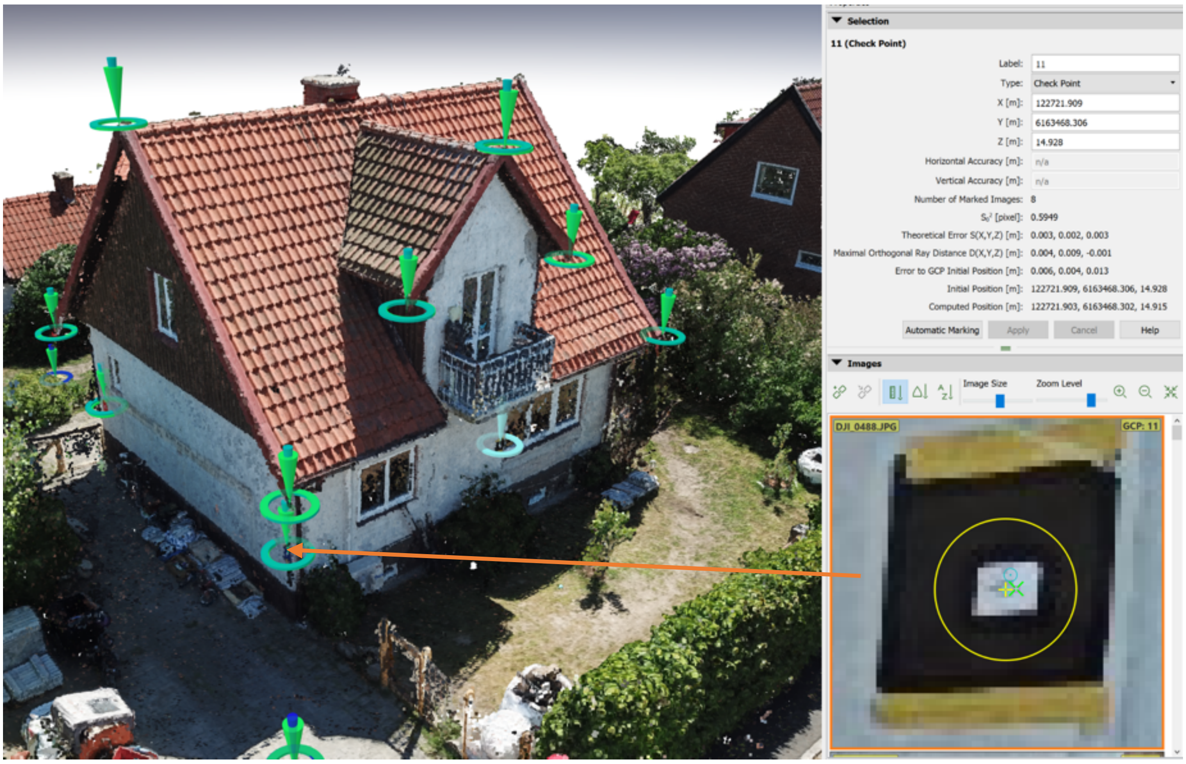
4.2.1 Photogrammetry software processing

All photos were transferred to the workstation for post processing in Pix4Dmapper pro. Photos taken with the DJI Mavic Pro drone contains meta data in the Exif format of camera settings, geo information and position of the camera gimbal.

4.3 Comparison

Comparisons are made with the generated point clouds from Pix4D and the georeferenced point cloud is used as a reference in Cloud Compare. We compare the geometry of the building, not its absolute position. Because of the consumer grade GPS in the drone, the point clouds without GCP correction are shifted in both X, Y and Z axes. To be able to compare the geometry, the point clouds are aligned by marking at least four common point pairs in both clouds. The GCP markers are used as common attributes in Nadir- and Oblique data sets respectively. When the point clouds are aligned, further comparison are made with the command “cloud to cloud distance” which measures absolute distances between the nearest neighbors. A colored point cloud displays the results ranging from blue (closest match) to red (largest difference). A maximum distance threshold can be set to avoid lengthy processing time and also to eliminate outliers. Point clouds from Nadir, Oblique and Oblique & LiDAR are all evaluated and compared in the Cloud Compare software. Oblique and total station comparison were made in Pix4D.

A close comparison of certain check points were done in Pix4D (Fig. 4.9). The yellow cross symbolizes the user marked intended position while the green x shows the computed position. The larger yellow circle indicates the confidence level given to a certain user marked point and depends on how zoomed in the image was when the point was marked. The blue dot in the blue circle shows the true coordinate as given from the total station.
Check Point No. 11 is a reflective self-adhesive target tape sticker on a black plastic sheet taped to the facade with yellow tape as seen in Fig. 4.3. The total station measurement is made to the center of the target. Check points do not influence the shape of the model but are used specifically to assess the quality of the model.



11 (Check Point)

Label: 11
Type: Check Point
X [m]: 122721.909
Y [m]: 6163468.306
Z [m]: 14.928
Horizontal Accuracy [m]: n/a
Vertical Accuracy [m]: n/a
Number of Marked Images: 8
S_0^2 [pixel]: 0.5949
Theoretical Error S(X,Y,Z) [m]: 0.003, 0.002, 0.003
Maximal Orthogonal Ray Distance D(X,Y,Z) [m]: 0.004, 0.009, -0.001
Error to GCP Initial Position [m]: 0.006, 0.004, 0.013
Initial Position [m]: 122721.909, 6163468.306, 14.928
Computed Position [m]: 122721.903, 6163468.302, 14.915

Fig. 4.9. *Check Points on facades and clearly distinguishable features. All Check Points are marked with a light blue cone in a light blue ring and the corresponding point marked and verified by the user are shown as a green cone in a green ring. GCPs are marked in darker blue cone in ring.*

5 Results

In this chapter, the result will be presented and summarized. The results are divided into four different sections and each part will be evaluated separately.

5.1 Point cloud from nadir images

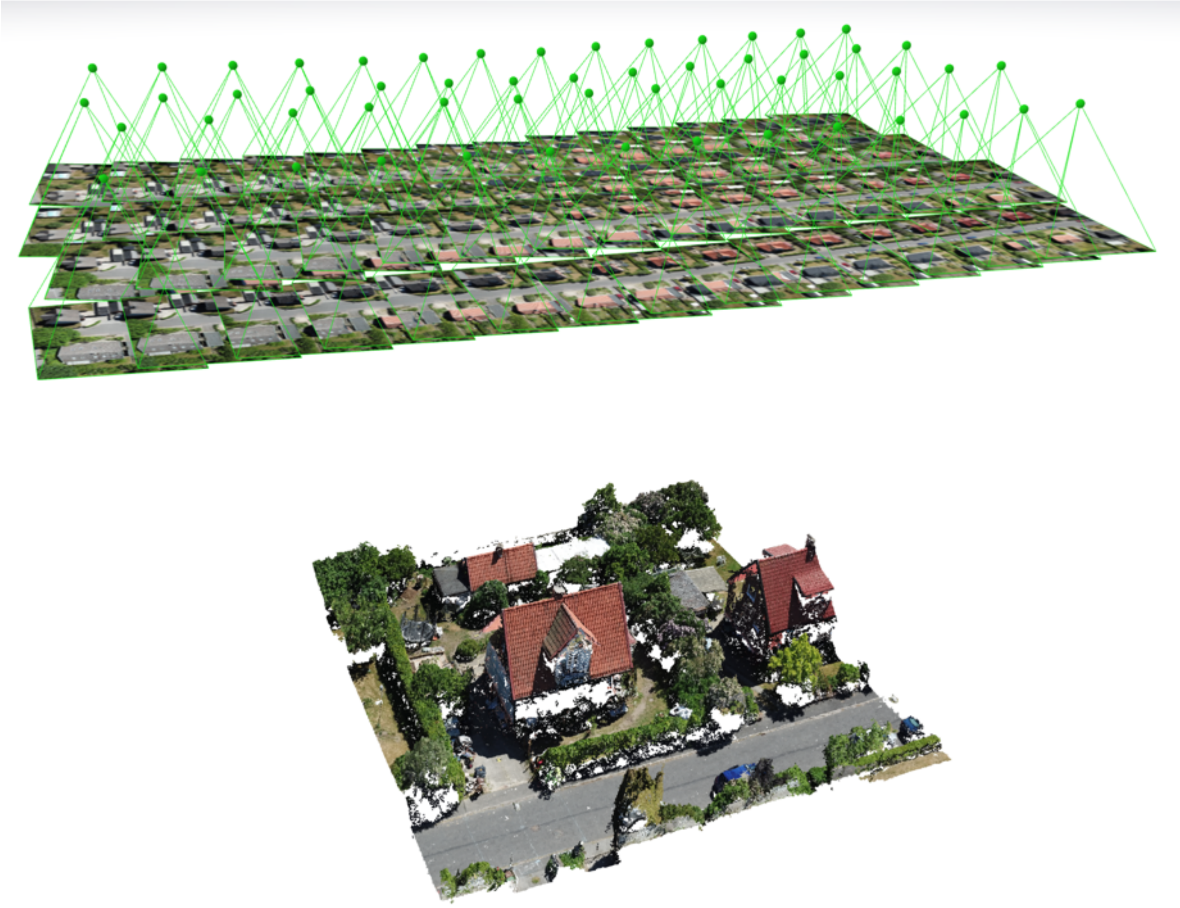


Fig. 5.1. *Densified point cloud made with Pix4D from georeferenced images. The upper green pyramids show the position and the angle from where the images were captured. The white gaps in the model indicate missing points in the cloud due to obscuring elements like roof footings and vegetation etc.*

A coloured point cloud were reconstructed from nadir images from the second survey (Fig. 5.1). White gaps in the point cloud are the result of obscuring objects like dense foliage and eaves. To be able to estimate errors in the point cloud, a set of check points were used (Table 5.1). The point cloud were georeferenced and scaled with GCPs. A root mean square error in the worst dimension (Y) was 0.83m. The error increases with height (Table 5.1).

Table 5.1. *Errors in check points (CHP) related to total station measurements. Nadir model with GCPs.*

Check point #	*Error X [m]*	*Error Y [m]*	*Error Z [m]*	*Projection error [pixel]*
9	0.0768	0.1893	-0.0032	0.8462
10	0.1062	0.2618	-0.2210	0.6686
12	0.4124	1.2701	-0.2890	1.3579
13	0.3449	1.2171	-0.2863	1.5803
16	0.1225	0.5084	-0.3017	1.2171
Mean [m]	0.212570	0.689363	-0.220225	
Sigma [m]	0.138080	0.465051	0.112117	
RMS error [m]	0.253480	0.831561	0.247123	

5.1.1 Comparison of Nadir models

The point cloud made from images taken in nadir direction (Fig. 5.1) are compared in Cloud Compare (Fig. 5.2-3) with a point cloud made from the same images but without GCPs. Image acquisition positions were instead taken from the onboard GPS recorded in Exif information. The coloring in cloud compare ranges from blue to green to red. Blue represents the smallest difference between neighboring points and red the largest difference. A perfect match between two clouds would be all blue. Mean value of distance between two neighboring points, which is presumed to be equal, is 16 cm with a standard deviation of 14 cm.

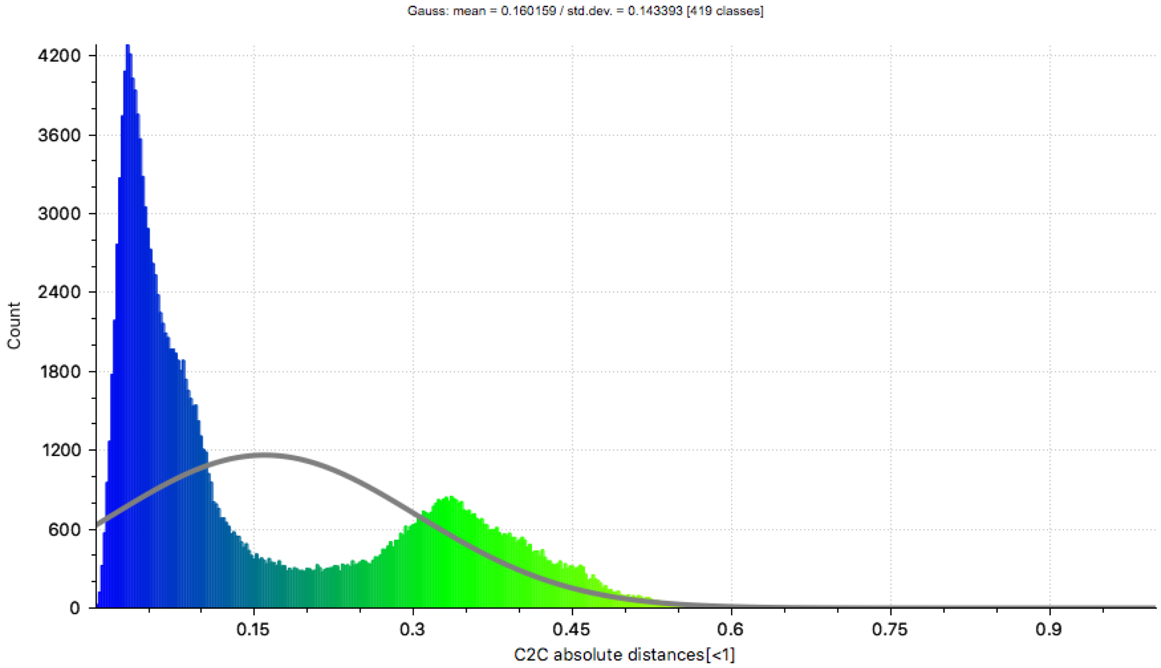


Fig. 5.2. *Comparison of distance to nearest neighbouring point in two point clouds. Absolute distance in meters.*

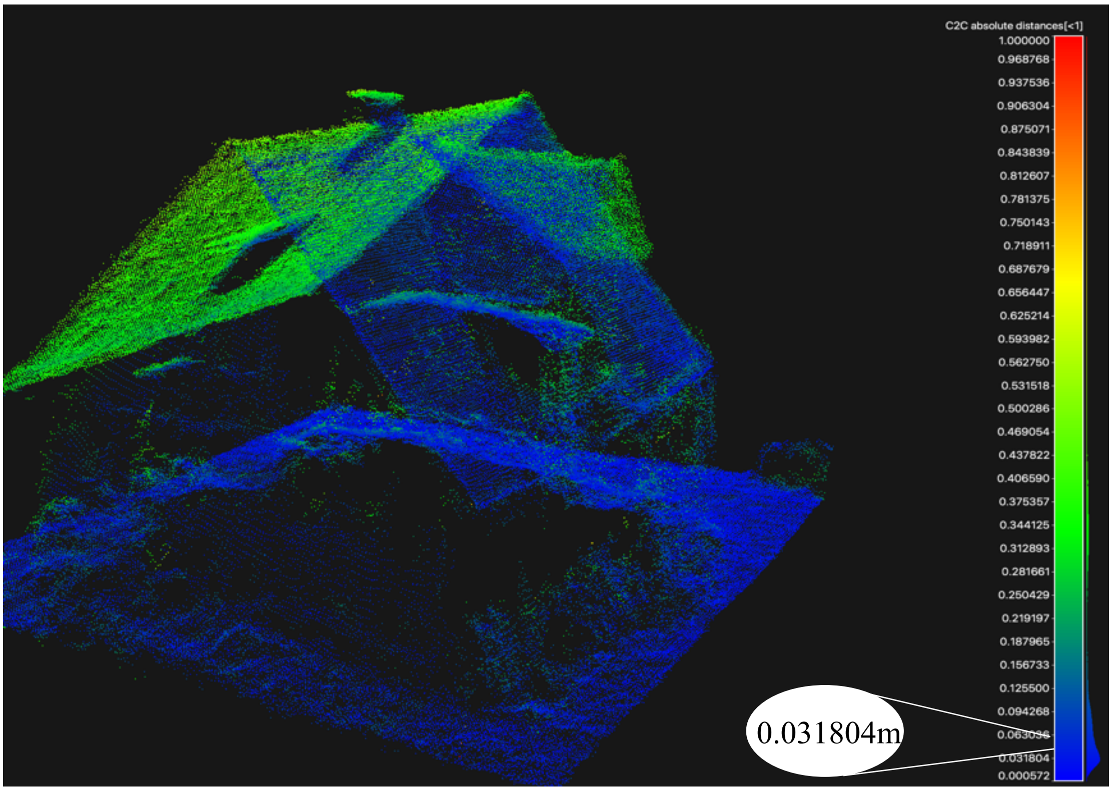


Fig. 5.3. *Comparison between clouds with and without GCPs (distance in meters. Points compared are limited to a maximum distance of 1m.*

5.1.2 Point cloud from oblique images

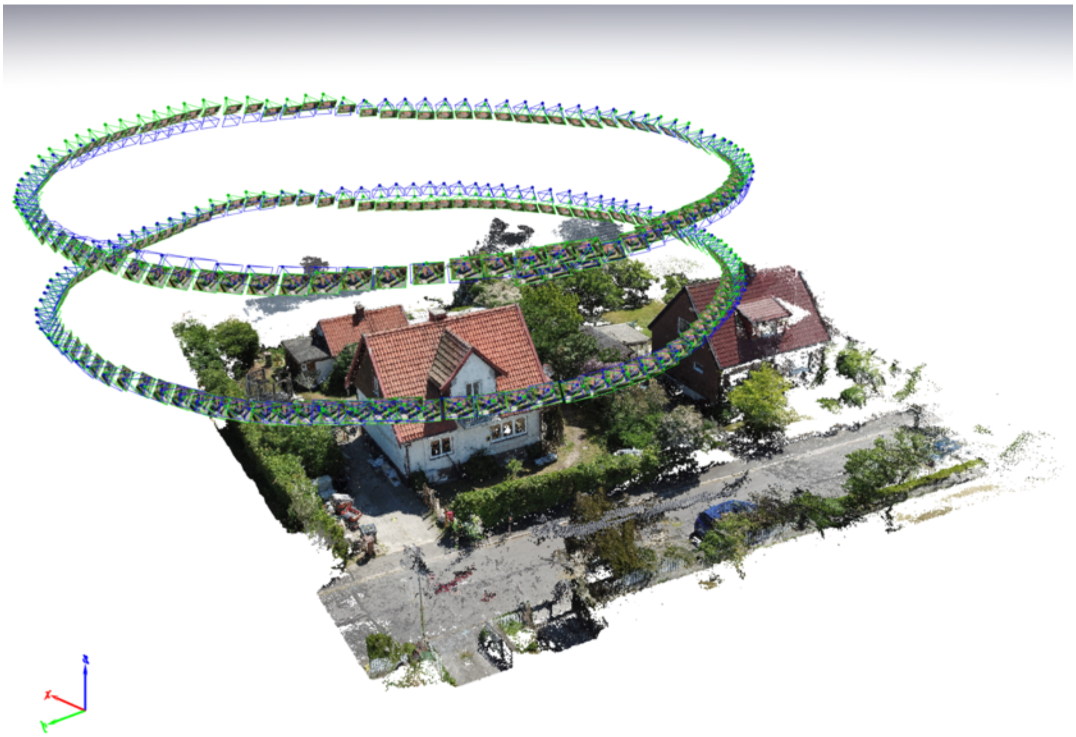


Fig. 5.4. *Densified point cloud with georeferenced images in oblique angles. The blue pyramids show the initial view and position as reported from image Exif information. Green pyramids show position and angle after calibration in Pix4D.*

Oblique point clouds are compared in the same way as nadir point clouds. Point clouds are made from images from the second survey. Root mean square error in the worst dimension (Z) was 2.1cm (Table 5.2).

Table 5.2. *Errors in check points (CHP) related to total station reference measurements. Oblique model with GCPs.*

Check point	*Error X [m]*	*Error Y [m]*	*Error Z [m]*	*Projection error [pixel]*
9	-0.0103	0.0319	0.0289	0.8565
10	0.0407	0.0133	0.0449	0.9960
11	0.0057	0.0037	0.0132	0.8304
12	0.0128	0.0003	0.0105	0.8072
13	0.0183	0.0320	0.0335	1.1041
14	-0.0006	0.0005	0.0001	0.2369
15	-0.0023	0.0005	-0.0005	0.4309
16	-0.0055	0.0052	0.0047	0.6897
19	-0.0060	0.0292	0.0063	1.3273
20	0.0088	0.0088	-0.0055	0.9321
Mean [m]	0.006161	0.012542	0.013615	
Sigma [m]	0.014364	0.012719	0.015804	
RMS error [m]	0.015630	0.017863	0.020860	

Comparison of point clouds with and without GCPs are made in the same way as nadir point clouds.

Mean value of distance between two neighboring points, which is presumed to be equal, is 0.12 cm with a standard deviation of 0.11 cm.

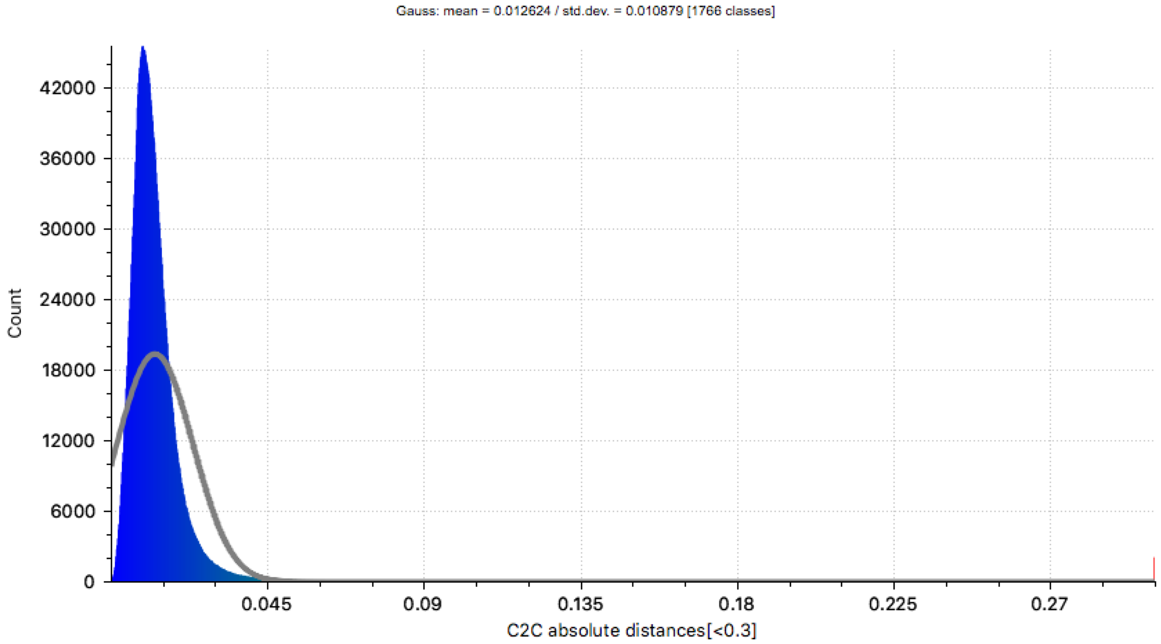


Fig. 5.5. *Comparison of nearest neighbour points in point clouds. Absolute distance in meters.*

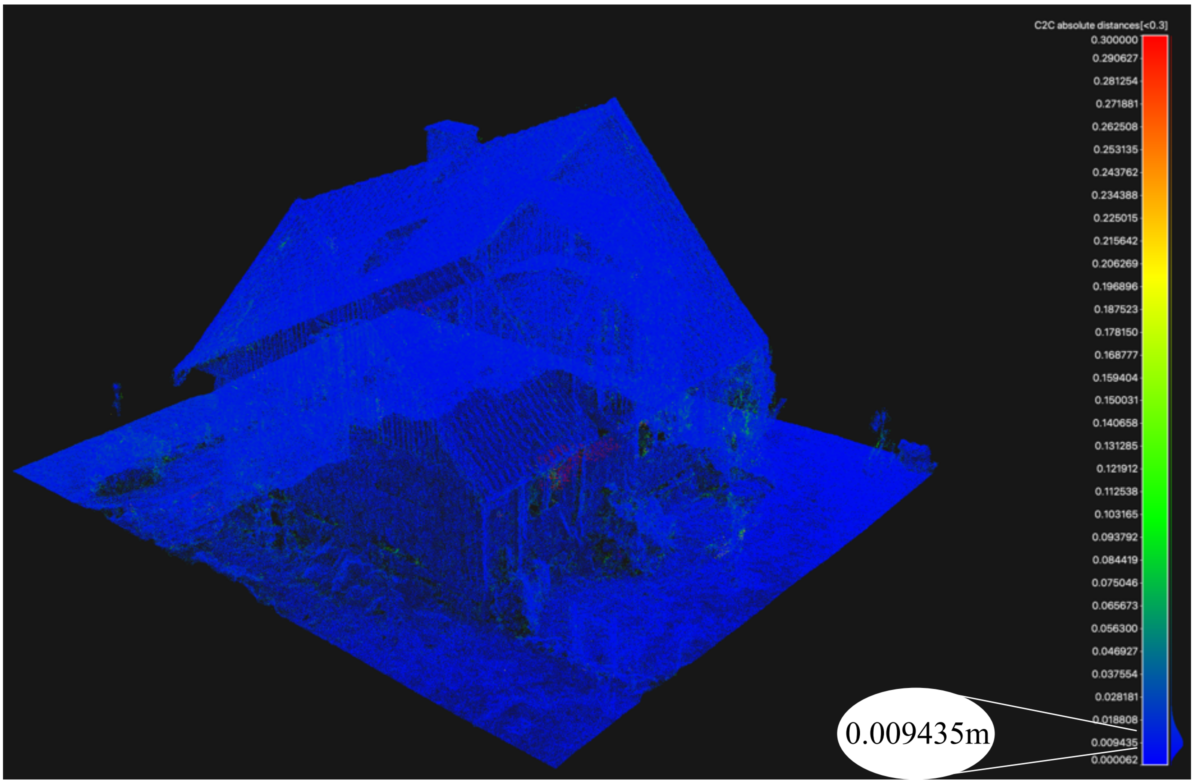


Fig. 5.6. *Comparison of nearest neighboring points between oblique point clouds with and without GCPs. Maximum distance between compared points are 0.3 m. The difference is indicated by different colors*

5.1.3 Oblique and LiDAR

For further validation, a comparison between a point cloud derived from an aerial LiDAR scan and the oblique point cloud (Fig. 5.4) was made. The LiDAR scan was not made at same time as the UAV flights and this can affect objects on the ground being moved. Mean value between neighboring points are 3.5cm with a standard deviation of 5.3

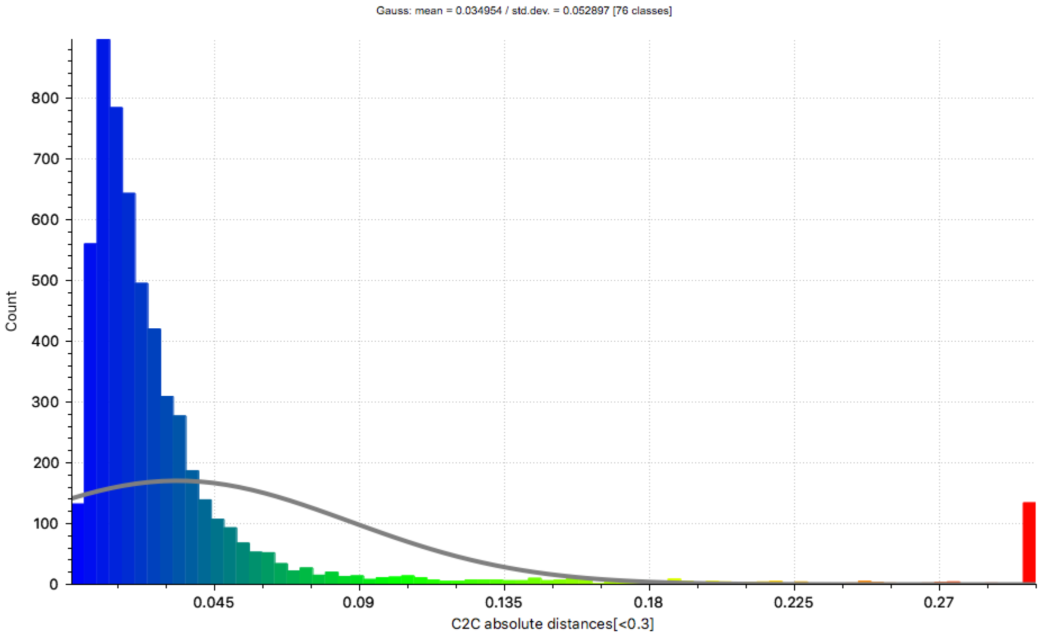


Fig. 5.7. *Comparison of nearest neighbouring points in LiDAR and oblique point clouds. Absolute distance in meters.*

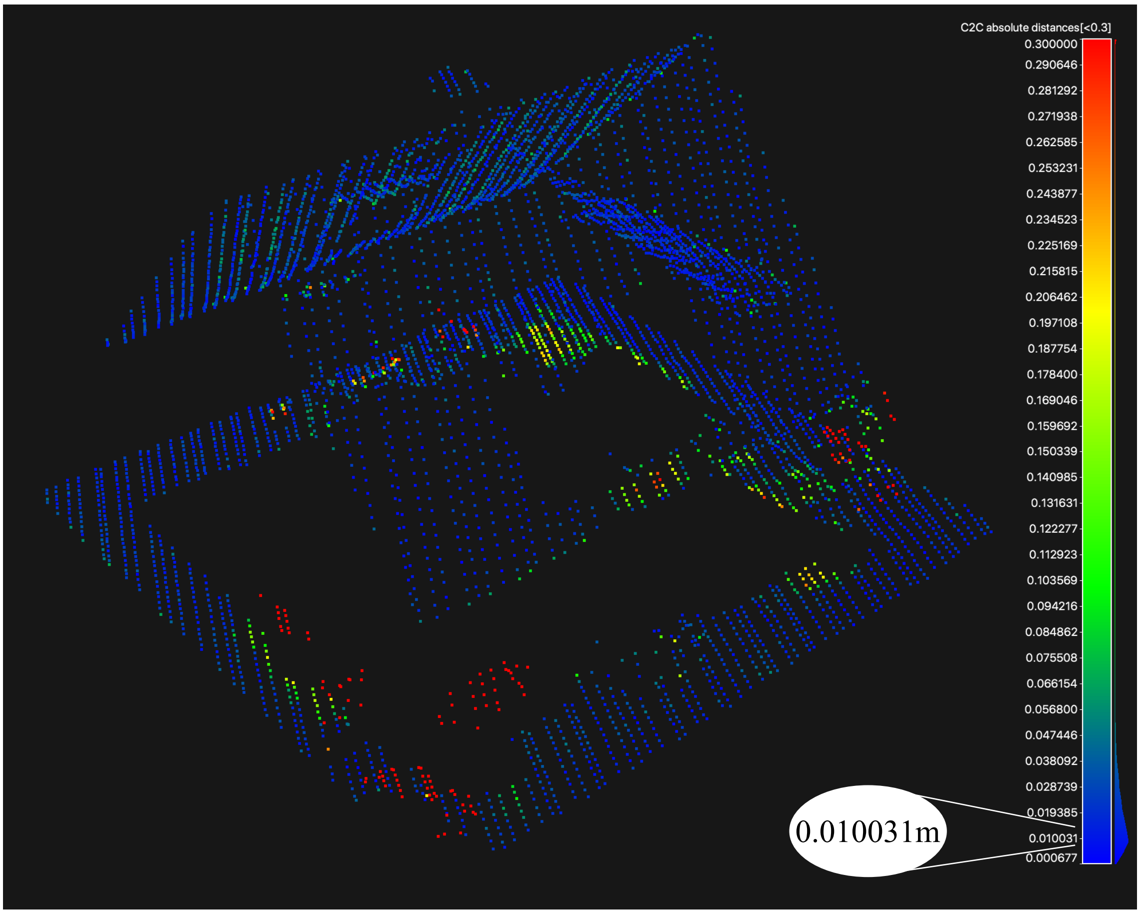


Fig. 5.8. *Comparison of nearest neighboring points between LiDAR aerial scan and oblique with GCPs. Absolute distance in meters is indicated by different colors.*

5.1.4 Pix4D and Agisoft Photoscan

A complementary comparison of point clouds made in Agisoft Photoscan and Pix4D with the same images and equivalent settings were also conducted (Fig. 5.10). All Exif geotags were removed in Photoscan and coordinates of checkpoints and GCPs were imported from the same .csv file as with the Pix4D project.

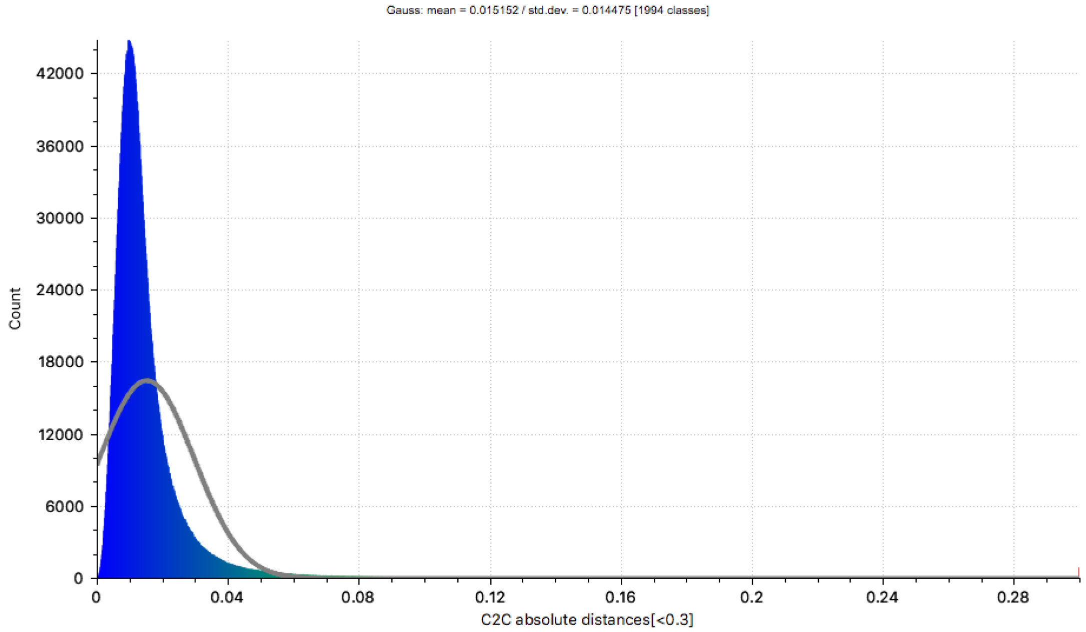


Fig. 5.9. *Comparison of nearest neighbour points in point clouds. Absolute distance in meters.*

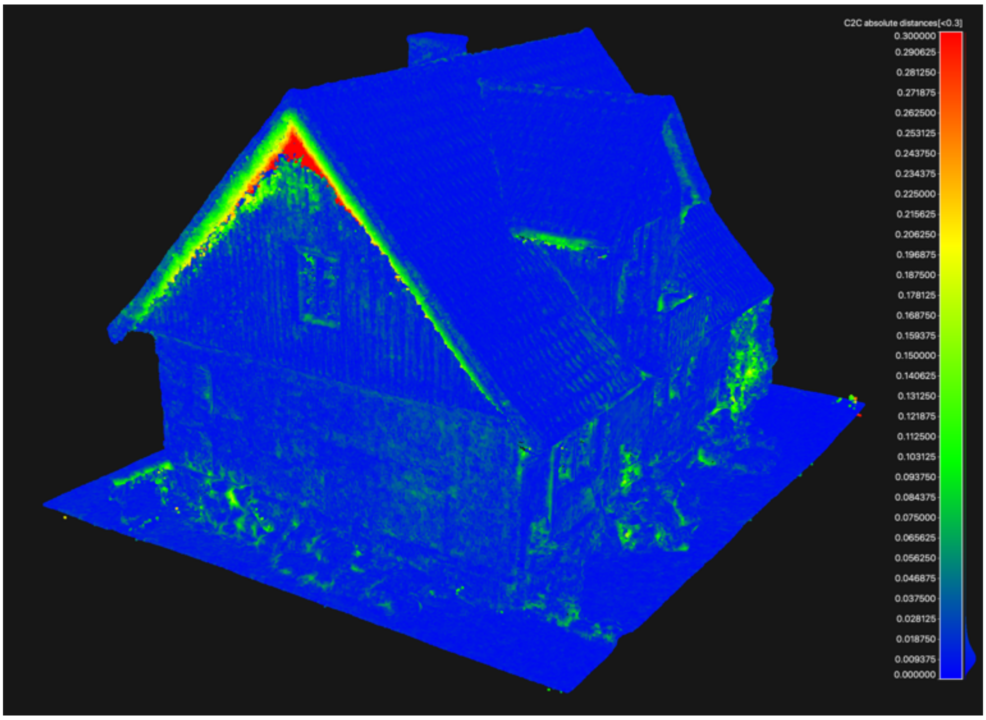


Fig. 5.10. *Comparison of Agisoft Photoscan and Pix4D mapper Pro. Absolute distance in meters.*

5.1.5 Correlation between nadir and oblique point clouds

A last comparison (Fig. 5.11) was made in Cloud Compare to illustrate discrepancies between the following:

- Reference Total station – white
- Oblique Pix4D - yellow
- Nadir Pix4D - red
- Nadir Photoscan – blue

The small white dots represent the true geometry as measured with the total station. Red, blue and yellow point clouds use the same GCPs for scaling and geometric constraints. Red and blue point clouds are computed from nadir images while yellow uses oblique images.

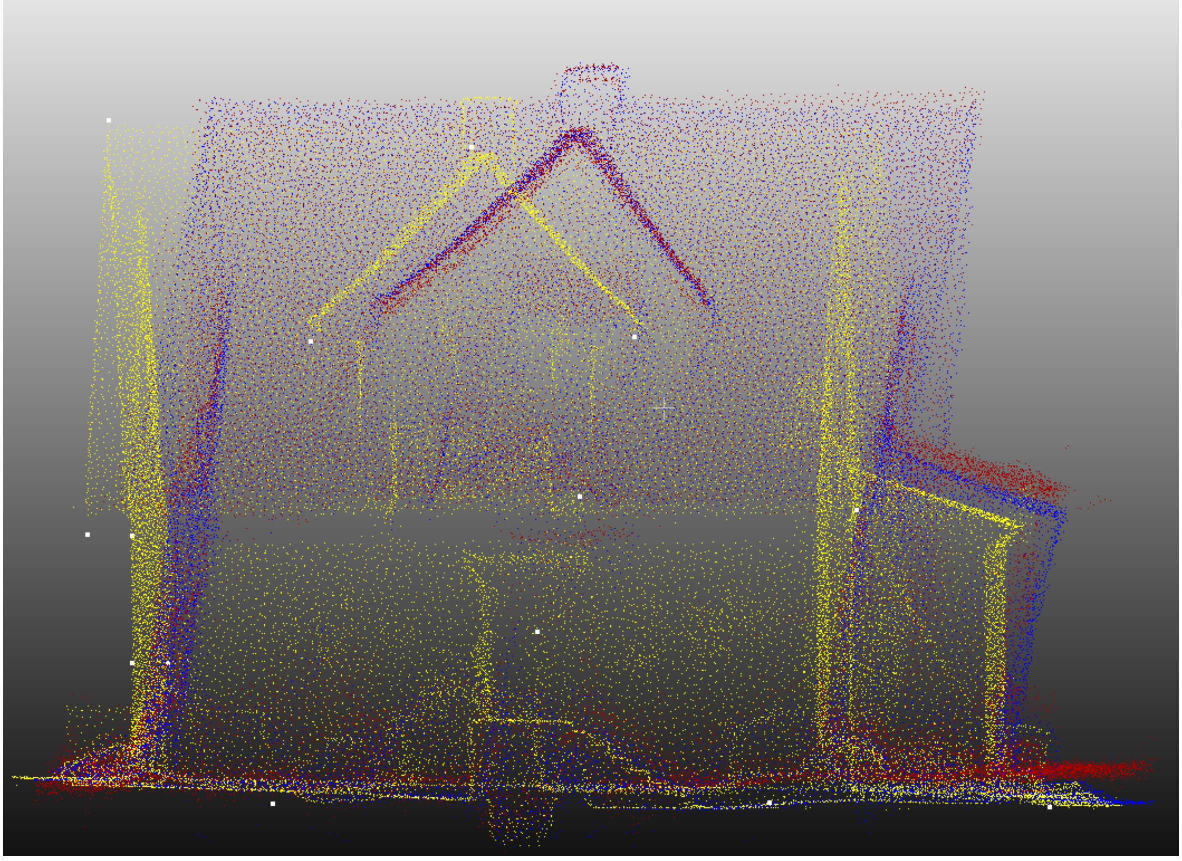


Fig. 5.11. *Comparison of the total station reference measurements (white) with nadir models (red and blue) and oblique (yellow)*

5.2 Interviews

In the interviews, a lot of opportunities and issues around the UAV technology were discussed. The impact of the UAV technology on the construction industry was captured through the interview with the person in charge of measuring projects from Skanska Sverige AB. The interviewee stated that the UAV plays a big part in the digital transformation and many major projects are using drones for several different kinds of applications. We also learned that one issue with low-cost UAVs is strong magnetic fields that can interfere with the electronics, and the interviewee thinks that this is an issue that the producer of UAVs must focus on and try to solve. Furthermore, he believes that the UAV technology is still undergoing expansion and development, which means that better and better products can be excepted, which will lead to a more efficient data acquisition process. This is also confirmed by the architect at Fojab Architects AB, who stated that the UAV could be a good complement for companies that provide basis for projects. Greater knowledge about the object, where as-built documentation might be missing, can lead to better quality and economic savings. According to the interviewed architect at Fojab Architechts AB, an implementation of low-cost UAV into their business could and probably would be an option in the future. One interesting finding was that the most beneficial area for a low–cost UAV to operate in, is so called transformation projects where documentation is missing. This could make the design process of projects without basis more efficient. The architect at Fojab Architects AB is concerned about problems such as people and integrity issues.

6. Discussion

In this chapter, the result from the UAV together with interviews and some of the most significant factors for the UAVs future, will be discussed and analyzed. All this will work as basis for the conclusion.

6.1 Accuracy

In this report, we use the term accuracy in accordance with the Handbook of surveying and mapping issues - HMK - by Lantmäteriet, the Swedish mapping, cadastral and land registration authority. HMK defines measurement accuracy as well as absolute and relative uncertainty. HMK also defines different levels of quality for measurements based on the intended use of the data. HMK standardnivå 0-5 where level 0 has the lowest requirements and level 5 the highest. The intended use of the point clouds in this report is on level 5 which has a requirement with regards to relative uncertainty of less than 5 cm (Lantmäteriet, 2018). If necessary, the point clouds can be fitted to a reference system with the help of GCPs. If that is the case there will also be an absolute uncertainty with regard to the reference system.

Photogrammetry is not a way of directly measuring anything but rather information derived from a set of images. Therefore, the quality of the output has to be verified by the operator. One way of assuring quality is to use a sufficient amount of ground control points (GCPs) in combination with check points (CHPs). As we have seen in the nadir models, GCPs alone are not enough to get accurate models. CHPs shows that models created with only nadir images can have significant distortion along Z axis. The issue seems to be present when objects are rising high combined with a low flight altitude which is necessary to have a low ground sampling distance. All GCPs were distributed on the ground leaving no constraints along the Z axis.

6.1.1 First survey

Our first survey involved both traditional aerial surveying with parallel flight paths, with camera in nadir position, as well as orbiting around the object with camera in oblique position.
The nadir flight had good overlap of images, both along the path and in between which is important to get a detailed and reliable result. (Westoby, Brasington, Glasser, Hambrey, & Reynolds, 2012)

We did encounter some issues, mostly during the first part of the fieldwork.
One problem was that the camera in the Mavic pro has the ability to change focus and apps can have different approaches to handle this. It can be difficult to see if the image is properly focused when in flight because of limited bandwidth for the video link.

Another issue was the way that DJI handles the altitude information. It is still unclear what is actually being recorded; it could be the height given by the onboard GPS which is unreliable or some mix of a height model combined with relative height from the take-off position.

According to DJIs specifications, the Mavic pro uses a combination of GPS, barometric altitude sensor and IMU data control to navigate. It is evident that this is working because of how stable it is in the air when hovering. Therefore, we can assume that even though the height information can be shifted several meters, it is consistent during a flight giving a low relative uncertainty regarding the image positions.
A problem in the first survey was that because of problems with autonomous circular mission (3D Map – POI, in Ground Station pro) we had to operate the UAV manually. Therefore we used two different take-off positions, one in the back yard and one in the front driveway. Because of how DJI records altitude information stored in the Exif data of the images, the final model was heavily tilted (Fig. 6.1).
The solution to this could have been either to always take off from the same spot to make it possible to calibrate the height information in the images Exif file information afterwards, or to use GCPs to calibrate the model in post processing.

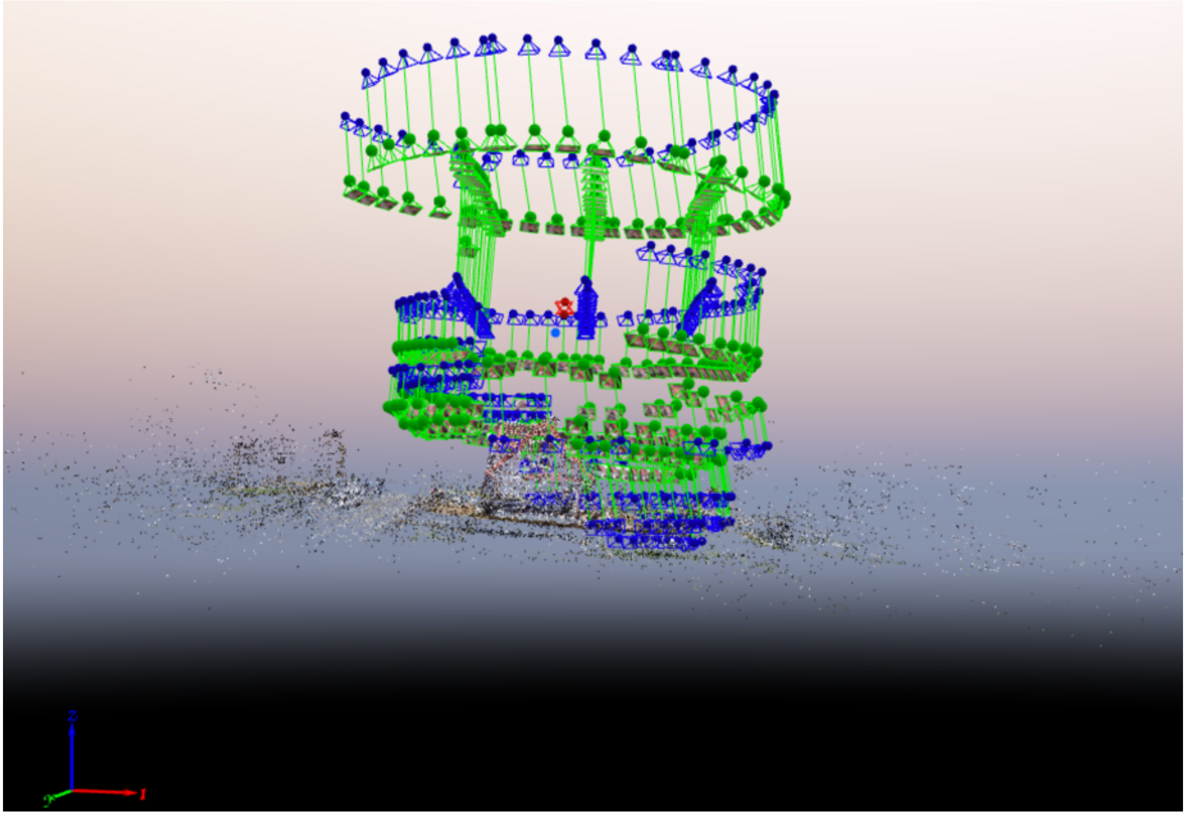


Fig. 6.1. *Result from the first survey, in which a clear tilt to the right can be seen. This is due to a combination of images from different flights with contradicting altitude information and no GCPs. Blue pyramids show initial position from Exif data and green show the aligned position after calibration in Pix4D.*

Finally, validation by taking measurements on the facades requires that the geometry is correct because skewing or warping cannot be detected with this one-dimensional measurement. Only scaling can be validated.

6.1.2 Second survey

With the weaknesses in the first survey in mind, we wanted to reliably verify our data, and the only way to do this was to have a more reliable reference. A total station has the benefit of giving very reliable data at the expense of ease of use and time needed to acquire the data. Depending on targets and errors in the readout, a realistic uncertainty would be less than 1 cm in the reference model.

To further validate our models, we compared them with aerial LiDAR data of the same building.

6.1.3 Evaluation of nadir point clouds

Our results show no clear difference between compared point clouds. This is regardless of the use of GCPs or without it (Fig. 5.3). The same can be said for the comparison of Pix4D and Photoscan (Fig. 5.10). Note that this is after correction by translating in X, Y and Z, but not in scaling. Unfortunately, all nadir point clouds are inaccurate (Fig. 5.11). All buildings in the model shows tilting in the same direction as the flight path (Fig. 6.2). It should be noted that in the autonomous flight mode used, the drone is always facing the same direction, meaning that on the return from the first line it will fly backwards. This indicates a systematic error, possibly because of faulty calibration of the gimbal. This is on the other hand something that both Pix4D and Photoscan should be able to take into account and correct for.

We have also compared models without yaw, pitch and roll information (gimbal information recorded in Exif meta data) with the exact same tilting as a result.

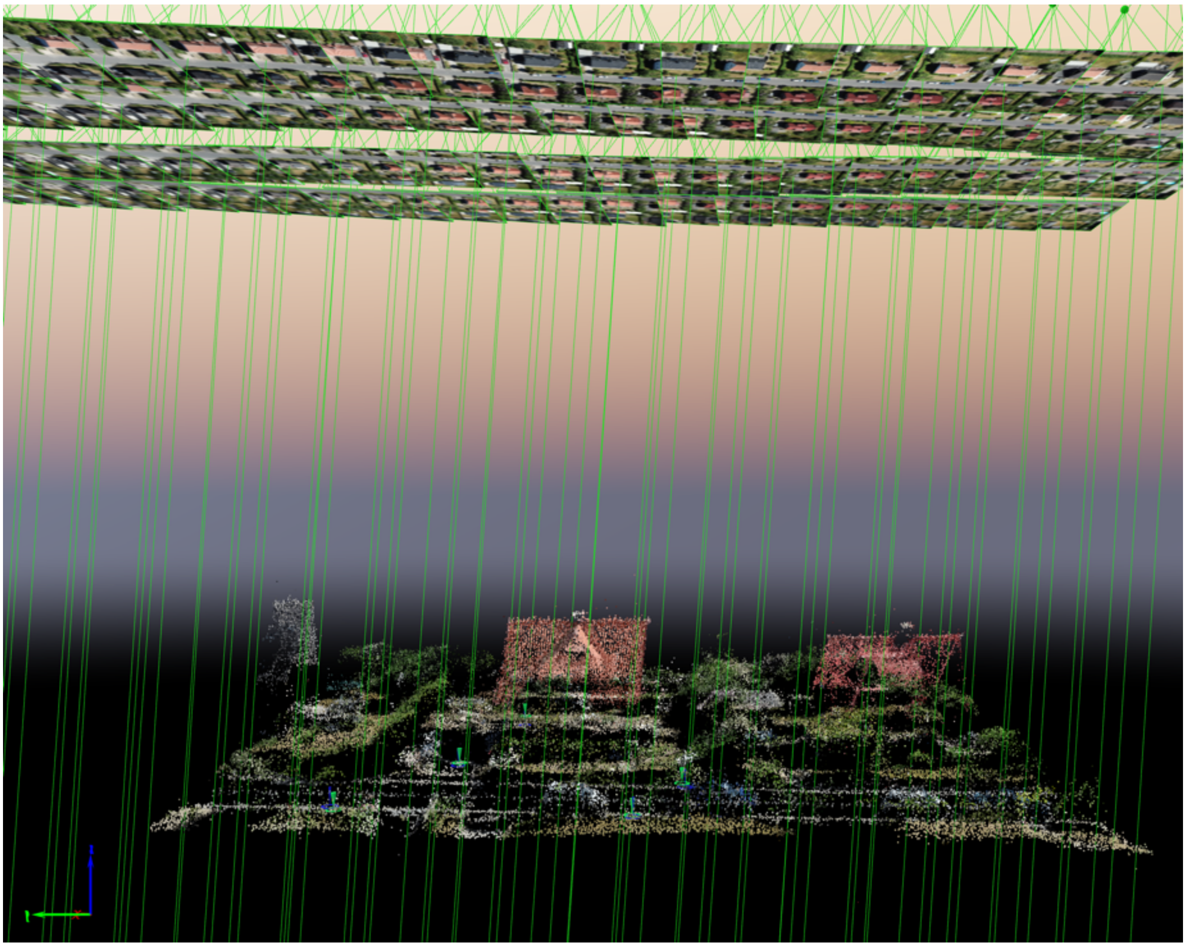


Fig. 6.2. *Error in geometry shows correspondence with camera tilt.*

Check points #12-13 (Table 5.1) show an error in X and Y of more than 1 meter which of course makes those point clouds unusable.

6.1.4 Evaluation of oblique point clouds

The results for oblique images point cloud are similar to the nadir point clouds. If only information about the objects' dimensions and geometry is needed and not its absolute location, it does not matter if GCPs are used or not.

The mean error compared with total station data is less than 2 cm (Table 5.2). Some readings push this value upwards significantly. Those errors might be attributable to reading error with the total station measuring. The angle from PP2400 to CHP #10 related to the facade is small which can introduce errors in the EDM reading for example. Ideally, all such measurements should be perpendicular to the surface. Figure 5.8 indicates a definitive correspondence with aerial LiDAR.

6.1.5 Importance of GCPs

Based on how well the point clouds correspond to the total station reference model, it is probable that having a large number of images significantly contributes to an accurate model. Even though the accuracy of consumer grade GPS typically is around 10 meters, the large amount of observations can help to increase the accuracy. If the images are captured in a limited time frame in a relatively small area it is not likely that the spatial error will fluctuate within as much as 10 meters. Typical errors in GPS and GNSS positioning consist of errors including ephemeris as well as clock errors and disturbances in the atmosphere (Lantmäteriet, 2018). Those errors will mostly be systematic errors affecting all the measurements equally.

GCPs are typically used to either solely give the point cloud georeferencing (and by that also scale and dimension) or to enhance the alignment of cameras in conjunction with GNSS.

Our nadir point clouds show that it is precarious to use GCPs when there are significantly higher objects in the scene (Fig. 6.3).

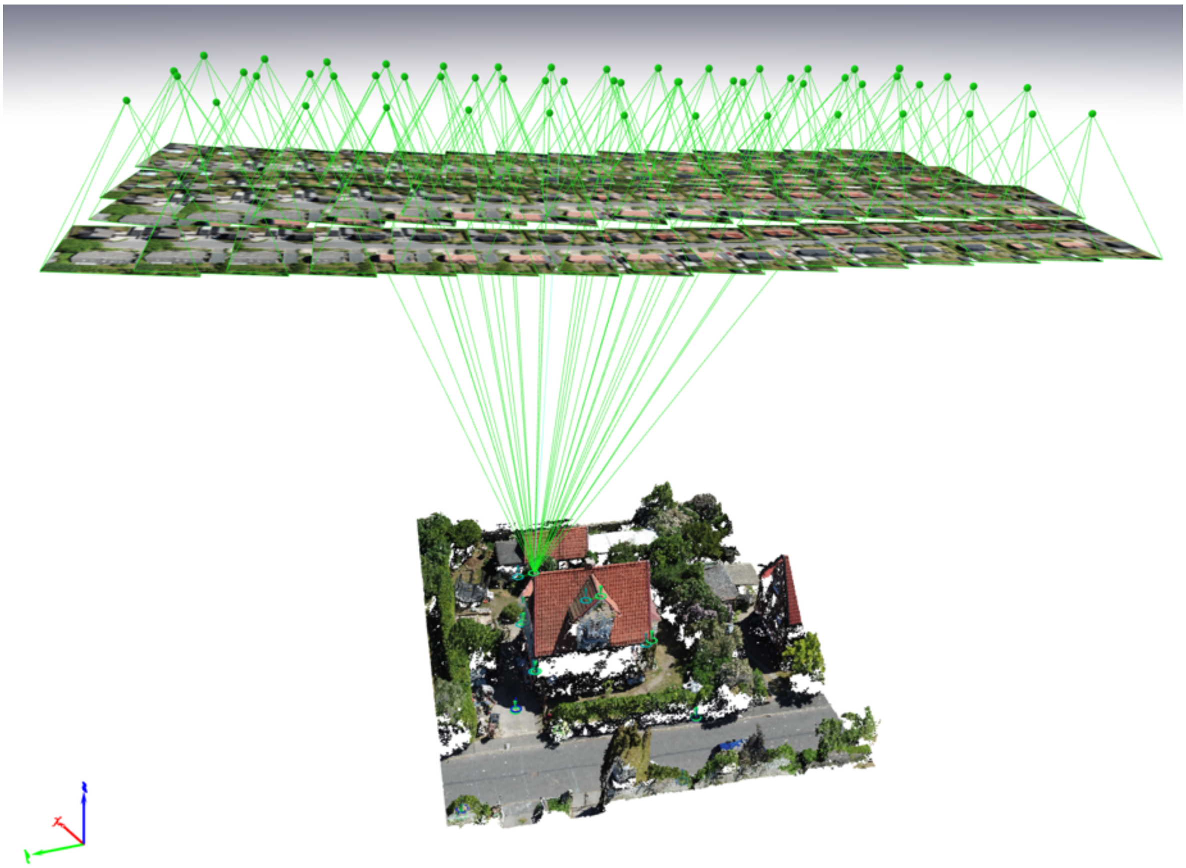


Fig. 6.3. *Nadir images gives less constraints, especially for higher objects*

If this is the case, the GCPs should be placed not only on ground level but also on these tall objects to lock drifting in the model. This problem is not evident in the case with oblique images. This probably depends on the large amount of image data locking tie points from opposite directions (Fig. 6.4).

Based on our findings, it is reasonable to claim that it is possible to achieve a spatial accuracy of at least 10-20 mm. Table 5.2 shows root mean square error of about 15-20 mm but CHP #9-10 have a large impact on this and the error can be attributed to uncertainty in the reference because of the angle of measurement from PP2400. It would have been useful to have verified coordinates of those check points with an extra station setup but it was not possible due to time constraint in the field work.

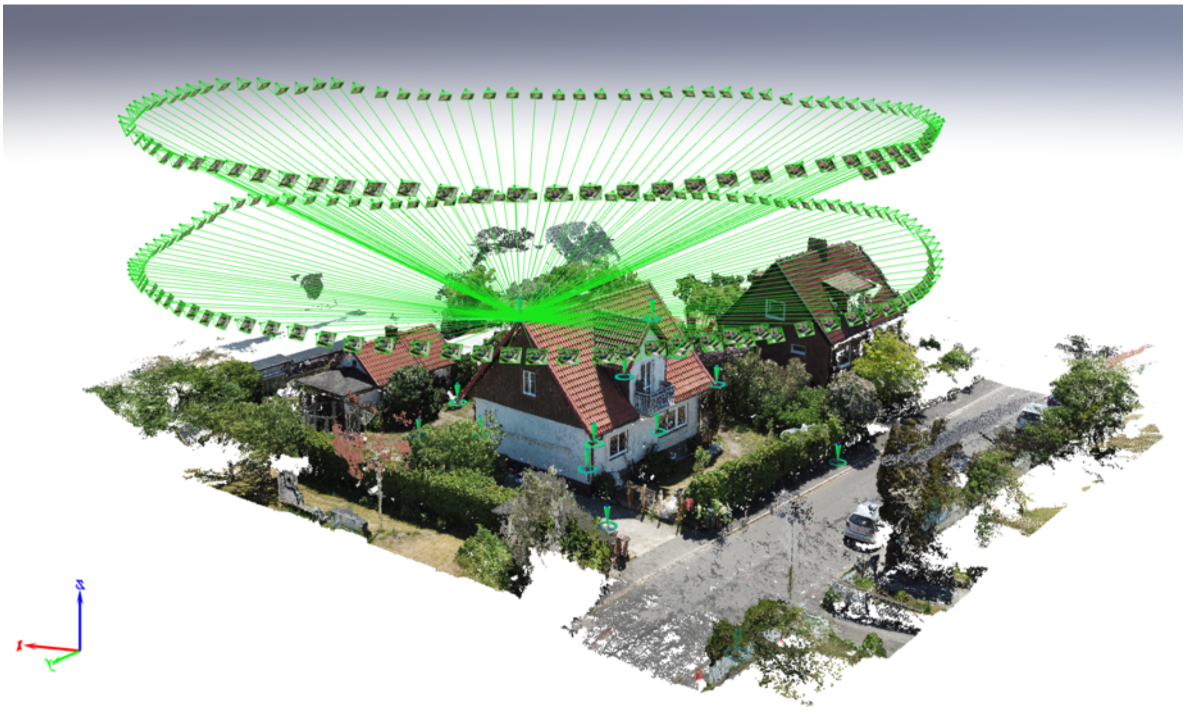


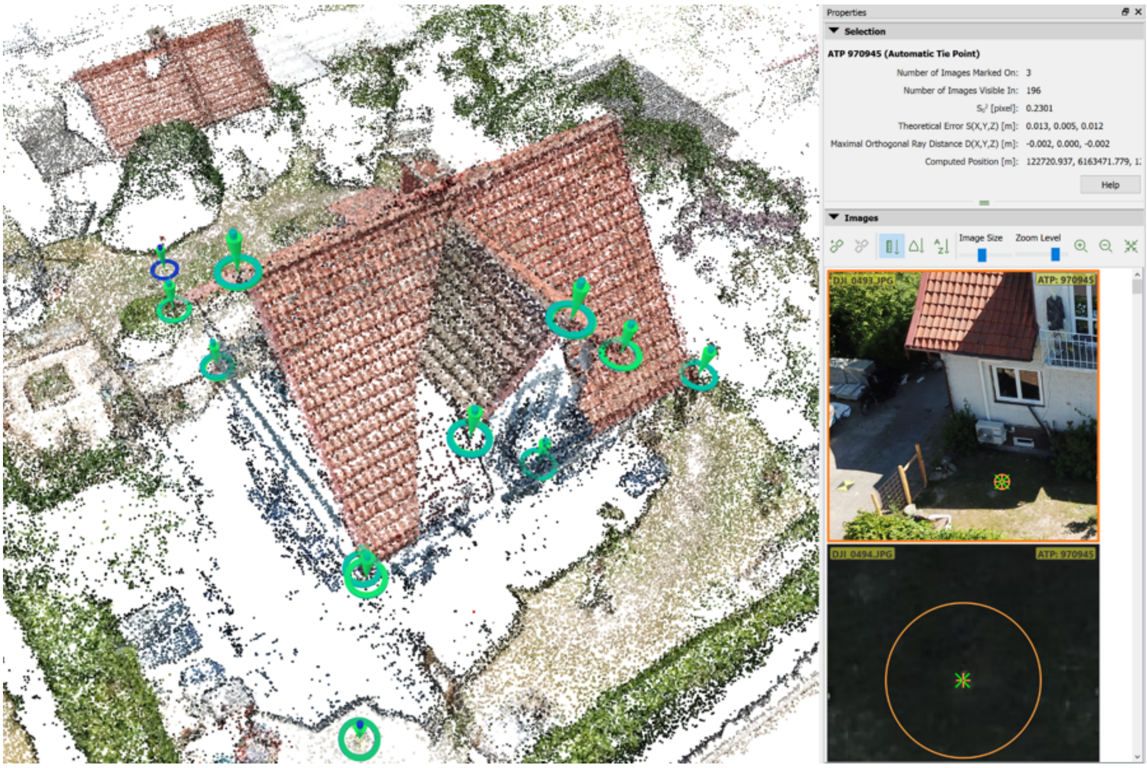
Fig. 6.4. *Oblique images from opposite directions gives the model constraints in the degrees of freedom.*

6.2 Sources of error

The error sources are divided into three categories: ambient factors, human factors and measuring instrument errors. Each method is evaluated based on these three categories.

6.2.1 UAV – photogrammetry

Ambient factors
Weather and sunlight conditions are of great concern to the usage of UAVs. Too much sunlight creates shadows which makes it harder for the computer vision algorithms to detect and create automatic tie points. Dark areas interfere with the program and makes it harder to detect automatic tie points (Fig. 6.5). Smaller and cheaper camera sensor means lower dynamic range and reduces the information in the images. A more advanced camera on a more expensive UAV could potentially have handled this better. Another way to handle the problem is to increase the number of images from different angles so that at least some images cover the darker shadowed parts better.



ATP 970945 (Automatic Tie Point)
Number of Images Marked On: 3
Number of Images Visible In: 196
S_0^2 [pixel]: 0.2301
Theoretical Error S(X,Y,Z) [m]: 0.013, 0.005, 0.012
Maximal Orthogonal Ray Distance D(X,Y,Z) [m]: -0.002, 0.000, -0.002
Computed Position [m]: 122720.937, 6163471.779, 1

Fig. 6.5. *Screenshot from Pix4D mapper pro desktop application showing the initial sparse point cloud constructed from automatic tie points. Notice the lack of points coinciding with shadows seen in the image to the right.*

Wind is another problem that besides making the UAV struggle to avoid drifting, also invokes movement in objects. If an object is moving it will appear in different places in each image and this will create noise in the model.

Human factors

Much of the fieldwork is done automatically once the setup is finished, and it is therefore crucial to do a thorough and correct setup. A faulty setting can render many images useless. One problem we experienced was that the camera lost focus. It took some time for the autofocus to regain a sharp picture, probably because of movement. This can be hard to see out in the field with the limited bandwidth from the video feed and ambient light hitting the display. It is recommended to download the images directly in the field to double check for low quality and unclear images. This way you can easily redo the mission.

Measuring instrument errors

The photogrammetry software is able to detect some but not all errors in the model. The quality report warns if some criteria are not met, such as the number of keypoints per image or large re-projection errors. However, the model can have a good fit with the GCPs and still be inaccurate. The GCPs must be placed in a suitable pattern and if necessary also at different heights. CHPs must be used to check for errors in the model.

6.2.2 Measuring with Total station

Ambient factors

Direct sunlight can have an effect on the measurements from the total station. This depends on thermal expansion which can alter the position of the tripod and possibly also components inside the total station. Since the total station is an opitcal instrumnt, it obviously needs a free line of sight from the instrument to the object or feature to be measured. This can greatly reduce the number of possible places to put the GCPs. An RTK GNSS receiver could be better suited for this task.

Human factors

Assuming the setup is correct and that the total station is calibrated accurately, human error sources are few. Potential errors are reading errors and incorrect aim. If the receiving prism is not held perfectly vertical the reading can have quite a large error. In prism-less mode the EDM is less accurate and it is also possible to miss the target and measure some other feature behind it. Multiple readouts or some manual assessment of the length could possibly rectify this error.

Measuring instrument errors

The margin of error in the instrument is small but must still be considered. More than one station setup at different locations would make it possible to measure more GCPs around the building, and to measure the same check points on the building from different angels. This could lower the measurement uncertainty of the reference points because of overdetermination of the position of GCPs and CHPs.

6.3 User-friendliness

The UAV technology is becoming more user-friendly and easier to understand. Manufacturers strive to make it simpler and more automated with collision warning systems and automatic take-off and landing.

A flight mission setup can be done in a few minutes and it is easily modified in the field if the operator has some experience. This differs from the total station and laser scanner that often require a setup at more than one place and a setup that is more time-consuming. When the UAV is airborne and is executing the mission you do not have to do anything besides check the image quality. It collects the data and information itself and this minimizes the human error sources.

Safety is an important aspect when flying UAVs. Flying in a city surrounded by high buildings can lead to a lost connection because of interference of GNSS satellite reception. An uncontrolled fly-away in a crowded area could be dangerous and lead to severe liability claims. The low-cost drone used for this thesis, DJI Mavic pro, has some safety features to avoid injury and property damage. For example, it has an intelligent flight battery which forces the UAV to return to the exact position where it started from when the battery is getting low. In case of lost contact with the remote controller, the UAV is also programmed to return to home. It is vital to set the correct altitude for this, since the UAV flies the shortest route home, and it is essential to check that the home position is correct before take-off. Otherwise in case of lost connection, it will fly “home” to an unknown location. Most commercial UAVs have some sort of safety features.

Small UAVs also comes with some drawbacks such as high demands on weather conditions, since a low-cost UAV cannot handle high wind or rain. However, those conditions are not suitable for a photogrammetry mission anyway.

6.4 Economy

To explore the economic aspect of UAVs, we show three potential sets were each set contains the low-cost UAV and Pix4D (one year) but with different measuring tools to measure the GCPs. The drone market offers a lot of different UAVs and the price heavily depends on the model. The focus for this thesis is low-cost UAV and in this case the DJI Mavic pro. The measurement equipment used for this thesis, a Leica TS06 total station is considerably more expensive. The laser scanner, Leica als80 hp is not an alternative, but used for reference only.

If you are not interested in location, it is not necessary to use GCPs, and therefore one alternative is without GCPs (Table 6.1).

GCPs must be measured for quality assurance and this can be done with an RTK or PPK GNSS receiver as a great alternative to a total station.

One of the most well-known manufacturers is Leica, and their products are often used for high accuracy GPS measurements (Table 6.2). New low-cost alternatives from start-up companies are becoming more common, and they now perform with a high degree of accuracy, allowing them to compete with established brands and manufacturers (Table 6.3). A workstation class computer will be needed for all alternatives given that a more advanced output is needed. The included online cloud version will be sufficient for simpler orthomaps. Cost of equipment are approximate and gathered in mid 2018.

Alternative 1 –Low-cost UAV and Pix4D

This is the cheapest alternative and works excellent if one is interested in making models, illustrations and simple measures.

Table 6.1. *Basic costs for a UAV and annual subscription license fee for photogrammetry software.*

Material	**Costs (SEK Excl. VAT)**
DJI Mavic Pro	10 000
Pix4D	26 000 / year
Total:	**36 000**

Alternative 2 –Low-cost UAV, Pix4D, GCP and Leica Viva GS08plus

This is the most expensive alternative, the Leica viva Gs08 Plus costs 140 000 SEK (Survey equipment, 2018). This alternative is suitable for more complex projects were the coordinates and absolute position is important.

Table 6.2. *High-end alternative with possibility to quickly and accurately measure GCP positions.*

Material	**Costs (SEK Excl.VAT)**
DJI Mavic Pro	10 000
Pix4D	26 000 / year
GCPs	500
Leica Viva Gs S08 plus	140 000
Total:	**176 500**

Alternative 3 –Low-cost UAV, Pix4D, GCPs and REACH RS+

Another alternative, with a low-cost RTK GPS receiver the price drops significantly. The producer Emlid Ltd. offers a model called reach rs+ which costs 800 USD.

Table 2.3. *Low-cost alternative with simpler RTK GNSS receiver from start-up company Emlid Ltd.*

Material	**Costs (SEK Excl. vat)**
DJI Mavic Pro	10 000
Pix4D	26 000 / year
GCPs	500
Reach rs+	8 000
Total:	**42 500**

6.5 Time

It is difficult to conclude how much time can be saved using a UAV. This thesis has showed that the process from the setup and flight to finished model is surprisingly fast. The time depends on the extent of the mission and it is important to emphasize that our mission was very simple and small which in turn makes the model easier to create. Many missions in the construction industry includes surveys of large areas and this makes the UAV an excellent choice because it is quick and efficient. A mission with larger scope and higher detail level would make the processing in Pix4D more time consuming while not any more work from the user.

6.6 Software

The aim of this thesis is not to evaluate different software and how well they perform. We have noted largely equal results in both Pix4D and Photoscan (Fig 5.10) with a slight discrepancy where Photoscan had some problem with reconstruction of points under the protruding ridge.

6.7 Interviews

In the interviews, a lot of opportunities and issues around the UAV technology were discussed. The impact of the UAV technology on the construction industry may be large. Skanska Sverige AB are using UAVs regularly for planning, calculations, inspection and progress reporting with great success. There are issues including unclear regulations as well as some technology problems. They see great potential in the use of UAVs.

Fojab architects are not using drones or UAVs at the moment but can see use cases, predominantly for transformation projects and other projects where documentation is absent.

In our opinion, there are great potential for UAVs in the architectural engineering. Limitations like susceptibility to magnetic interference and weather conditions can be mitigated by good planning and experience.

The interview respondents think that the UAV has a positive impact on the construction industry and find our 3D-models and findings on accuracy inspiring and interesting.

7. Conclusions

In this chapter, we conclude our findings based on the results. The chapter ends with a discussion on future research.

By analyzing the accuracy of our generated model as well as the interviews with persons with expertise and experience in UAV–technology, we predict that implementation of UAVs will become more common in the construction industry. The analysis shows that accuracy for a low-cost UAV is sufficient for many applications and the interest in UAV- technology is growing. We conclude that drones and UAVs are very useful in the construction industry and will see a bright future. If drones are to be widely adopted, they need to be reliable, not too expensive and easy to use.

Our conclusion is that images captured with a low-cost UAV can provide sufficient accuracy in the final model. The results show that with correct methods and conditions a reliable 3D point cloud with an accuracy of 10-20 mm can be derived using photogrammetry. With substantially lower cost equipment it is rivaling for example LiDAR data scans.

To accurately model a building, it is necessary to use oblique images and not only nadir images, since otherwise the errors in Z direction will be too large, causing distorted point clouds. Our results show that it is image overlapping and restriction in degrees of freedom given from oblique images rather than accurately positioned GCPs that provide spatial accuracy to the point cloud. Smaller projects can do without GCPs although this results in incorrect absolute position.

Low-cost in this sense is mostly affecting the sharpness and resolution of the images acquired by the UAV but this can be mitigated by a lower or closer flight which are going to produce the same equivalent GSD. It is probable that larger and more expensive UAVs are capable of handling heavier winds. It can however be a problem to fly in such conditions because of moving objects that will introduce errors into the model.

Finally, we have showed that with a larger number of geotagged images, it is possible to get a good result for production of for example building plans and integration with BIM even without GCPs. For quality control purposes and larger projects, it will be necessary to use GCPs.

Future research

During this thesis, a lot of challenges were encountered, and this probably depends on the fact that the field is under constant development with new and better technologies. This means that there are many things to explore within this area. One suggestion for future research is to study accuracy in 3D modelling with RTK or PPK GPS-equipped UAVs. A possible setup could be a fixed RTK GPS as a base station together with a small RTK-rover on the drone. A setup like this would mean that it is unnecessary to use GCPs since all images are geotagged with subcentimeter accuracy.

One area where the UAV technology could create value is integration with BIM (Building information modelling) and from that get basis for different kinds of drawings. This thesis has not focused on integration with BIM. We have included some samples of how our point clouds can be used in Autodesk Revit (and in appendix) to show that it is feasible. Future research could explore automatic classification of elements in the point cloud to possibly speed up the process of integration of point cloud data into BIM.

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Appendix 1

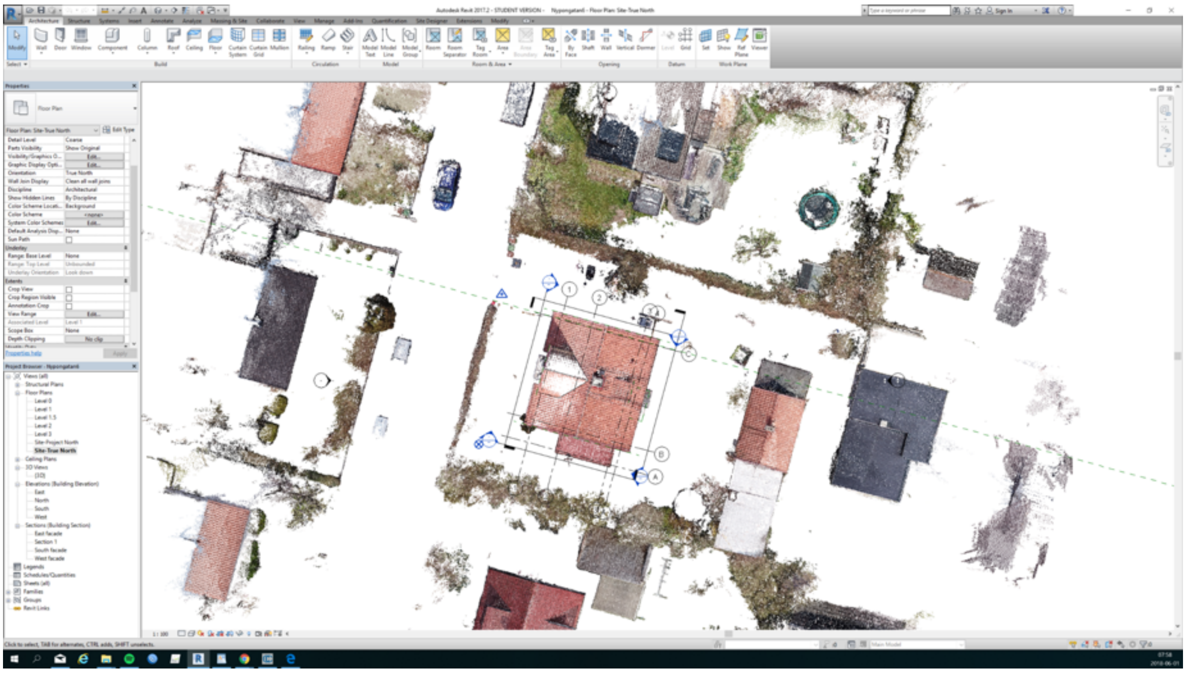

Figure 31 Screenshot from Autodesk Revit showing our point cloud integrated as a basemap.

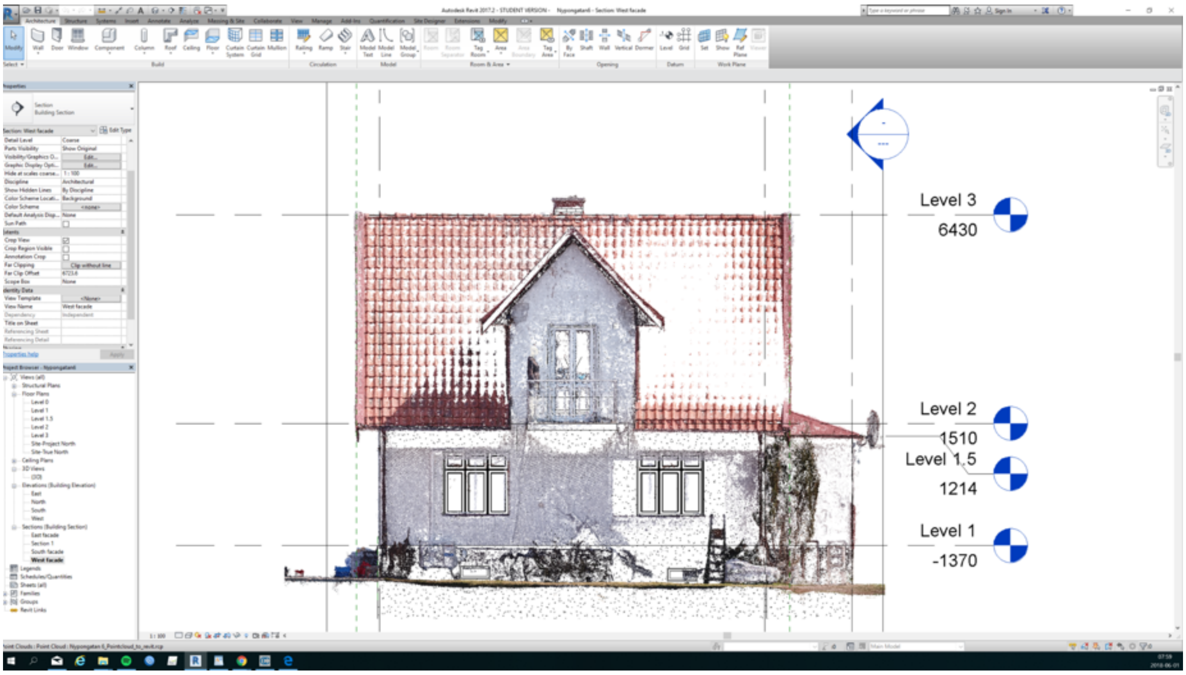

Figure 32 Our point cloud in orthometric facade view, without any corrections applied.

Autodesk screen shots reprinted courtesy of Autodesk, Inc.

Appendix 2

Intervjufrågor - Interview questions

Inledande - Intial

- Kan du berätta om dig själv och vilken roll du har? – Tell us about yourself and what your professional role is.
- Vilken bakgrund har du? – What Is your background?

Digitaliseringen - Digitalization

- Vad innebär digitaliseringen för dig? – What have the digitalization in the construction industry meant to you?
- Hur gör ni för att arbeta mot digitaliseringen? – How do you work towards ditigitalization?
- Vilka mervärden skulle en digitalisering kunna innebära? - What values does the digitalization provide, in your opinion?

Drönaren - UAV & DRONE

- Vilka möjligheter ser du med drönaren? – What possibilities can you see regarding drones?
- Vilka hinder ser du med drönaren? – Do you think there are any drawbacks or obstacles with drones?
- Vilken typ av drönaren använder ni av er idag? – What type of drone are you using today?
- Vilka mervärden skapar drönare för er verksamhet? – What benefits are drones giving you today?
- Vad skulle ni räkna som en lågkostandsdrönare? – What would you consider to be a low-cost drone?
- Vilka metoder kan drönaren ersätta? – What working methods could be substituted or assisted with a drone?

Drönaren och framtiden – The future of UAV

- Vad anser du är de viktigaste pusselbiten för att drönaren ska slå igenom? – What do you consider to be the most important key for the implementation of drones?
  Inom vilket område tror du drönaren kommer användas till i framtiden? – How do you think drones will be used in the future?