POLITECNICO DI TORINO

FACULTY OF ENGINEERING

Master degree in Mechatronic engineering

Unmanned Aerial Systems for Construction Site Monitoring

Supervisor:

Prof. Marcello Chiaberge

Candidate

Santiago Giraldo Manrique

Student number: 216065

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Abstract

In nowadays the construction site is monitored by the staff by taking digital photos to document the progress of the structure, they just take photos in a regular basis and store them together with the construction plan in a data base. The verification should be done manually by the supervisor to check if there are some errors or bottlenecks, this is very time-consuming and leads to areas not being cover very well.

Another technique sometimes applied to construction sites is the use of laser scanners for monitoring the process. In this case a 3D model is created and stored for later inspection, but there are a sort of problems with this technique, the laser scanner is really expensive, the device is big and should be carry around and inspecting the result is challenging because the spatial relationship is missing. But this 2 methods where unprecise and time-consuming, the new approach to monitor the construction sites are the drones.

The interest in UAVs has been in a constant growth, researchers and developers are using a lot of resources and effort to contribute to this topic, mainly in the agriculture and forest applications, autonomous surveillance, emergency and disaster management, traffic management and 3D mapping with photogrammetry. This growth is basically because the UAV systems are low cost, fast speed, high maneuverability and high safety for collecting images.

The research carried out in this thesis is then aimed to find and analyze the best way to accomplish a low cost, time efficient and highly reliable UAS for monitoring construction sites, by testing some software for photogrammetry and detecting which is the best one, also doing some tests in different software dedicated to the flight planning of the UAS in order to obtain an homogeneous dataset of images and then process them in the selected photogrammetry software.

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1 Introduction

This chapter introduces the content of this dissertation, providing the motivations that brought to this project, and giving the objectives of the project.

1.1 Sipal S.p.A

This thesis was made in association with the company Sipal S.p.A.

Sipal S.p.A is a company dedicated to help and solve any kind of engineering problem, their mains sectors are: Aerospace and defense, automotive, electronics, industry, infrastructure, IT security, transport, web marketing and architecture and design. They proposed this thesis since they wanted to enter into the commercial drone world by monitoring construction sites of their partner company INC S.p.A.

This specific project was aim to monitor a construction site in Puglia with the help of the government of the region.

1.2 Overview

The construction industry in now days is lacking of an easy, quick and affordable solution for monitoring the construction sites, there are some mid-low cost solutions such as hiring a person to monitor and take pictures from different angles of the construction in order to compare it to the original model, this requires a lot of time since a manager should collect all the images and verify each one with the designed model and it has a big possibility of human mistake, that off course, is not desired if the specifications should be followed with very low error.

The LiDAR (Light Detection and Ranging) is another way that gives a highly accurate result but is a heavy machine requiring personal to transport it along the construction site, the time for acquiring the data is huge but the processing data is low so is a vastly used method in these days.

There is another photogrammetry method used, a real plane flying along the construction site taking pictures, with this method the results are great but the cost of hiring an airplane with a pilot is enormous.

Taking all these into consider Sipal S.p.A was looking for a low cost, time efficient and easy to use way of monitoring the construction sites of the allied company INC S.p.A and be able to guarantee a satisfactory and accurate method.

The UAV systems where the perfect solution to accomplish this task and that's why this dissertation was made, to test and check if the UAS are a reliable solution for their project and how should the process had to be in order to get results able to achieve the standards with high quality, low error, cost and time consumption.

1.3 Objectives

1.3.1 General

The general objective of this work, as the title announce it, is the development of an autonomous unmanned aerial vehicle for the construction site monitoring.

To be consider autonomous or semiautonomous the system should be able to takeoff, flight and land automatically and the software should receive the images and automatically process them into the desired outputs.

1.3.2 Specific

In order to achieve the general objective some specific objectives should be stated for deeper understanding and well documented result.

- Analyze and study all the previews work done with UAVs in the construction site and how the researchers had approached their work in order to know what can be done and have some background before doing the proposals to the company.

- Define the more suitable type of drone for monitoring construction sites, depending on the drone architecture since each type has some different advantages and disadvantages.

- Decide the best photogrammetry software to use for the process of the images because this is a critical part in order to get the desired results and models.

- Determine the more convenient flight planning software in order to create an automatic flight (including takeoff and landing) and a well distributed dataset of images.

1.4 Thesis Organization

This thesis is divided into 7 chapters. In the chapter 1 is given an introduction to the dissertation, together with the general and specific objectives and a brief description of the associated company Sipal S.p.A.

In chapter 2 the theoretical concepts and the state of the art around unmanned aerial system and more specifically the unmanned aerial systems dedicated to construction site monitoring: each section represent a different part of the process, first the introduction to the unmanned aerial system, then the UAS specifically for construction sites, the next one is an explanation of what has been done in the construction sites with the help of drones and the last one is the explanation of the required sensors for the task.

Chapter 3 is a brief description of the proposals made to the company Sipal S.p.A for the project, it’s divided in 3 stages that represent different moments of the construction.

In chapter 4 the comparison between 2 photogrammetry software is done (Pix4D and PhotoScan), first each software is explained deeply showing each of the steps to achieve the final model and explaining the advantages and disadvantages of each one, then 2 examples are done with both software in order to compare them directly with results and ease to use, finally a direct comparison between both is made and also explaining why the chosen software is Pix4D.

Chapter 5 describes an important issue when automatizing the drones and is the flight planning, first an explanation of the relevant information that should be known before planning a flight, this includes Italian normativity and also how to compute the required values in order to accomplish the desired result, after this an explanation of the flight planning software is made enumerating some examples with advantages and disadvantages, finally a small user manual for the Pix4D capture software and the Mission Planner software .

In chapter 6 the final tests and results will be exposed, first a mining terrain with different depths in order to show the volume and excavation measurements with the 3D model, the next test is a cadastre model that allows to verify the measurements of houses and streets, demonstrating the great result obtained with the UAV systems, after this an example made with Sipal S.pA of the construction of the highway "pedemontana veneta" showing the 3D model with some measurements, and finally a review of what is the relation of all of this with the construction site with its advantages.

The last chapter, the 7, explain the final conclusions of this dissertation, how can it be improved, also, and more important, the future development of Sipal S.p.A around the thesis, explaining their future work and project in association with the Puglia region.

2 State of the art

This chapter describes the basic concepts and the currently known techniques for monitoring construction sites with the help of unmanned aerial systems.

2.1 Unmanned Aerial System

Drones also called UAV (unmanned aerial vehicle) or UAS (Unmanned aerial system) are aircrafts without pilot aboard. The flight path may vary in some degrees of autonomy, fully or partially automatic by onboard computers or remote controlled by a pilot on ground. The drones are categorized by its structure and by its type of taking-off/landing:

- Horizontal flying fixed-wing aircraft: airplane-like drone, it’s capable of flying long distances and offer high efficiency, low building and operation cost. Require a take-off and landing strip. Can be seen in Figure 2.1 b.
- Vertical starting systems: they use rotor blades to lift the platform, normally have also a tail rotor to balance the torque of the main rotor, helicopter-like. High battery consumption so low flight time, vertical takeoff/landing. Can be seen in Figure 2.1 d.
- Airships: Can land and takeoff vertically, long time and range of flight, can carry heavy loads but they are affected by wind and weather conditions, high running costs. Can be seen in Figure 2.1 c.
- Multicopter: is a special type of rotary wing aircraft. The torque does not create energy loss because the rotors rotate in opposite directions. Easy to operate, high flexibility and stability, vertical landing/take-off normally have 4 rotors (qudrocopters) but they can have more for redundancy purpose. [1].Can be seen in Figure 2.1 a.

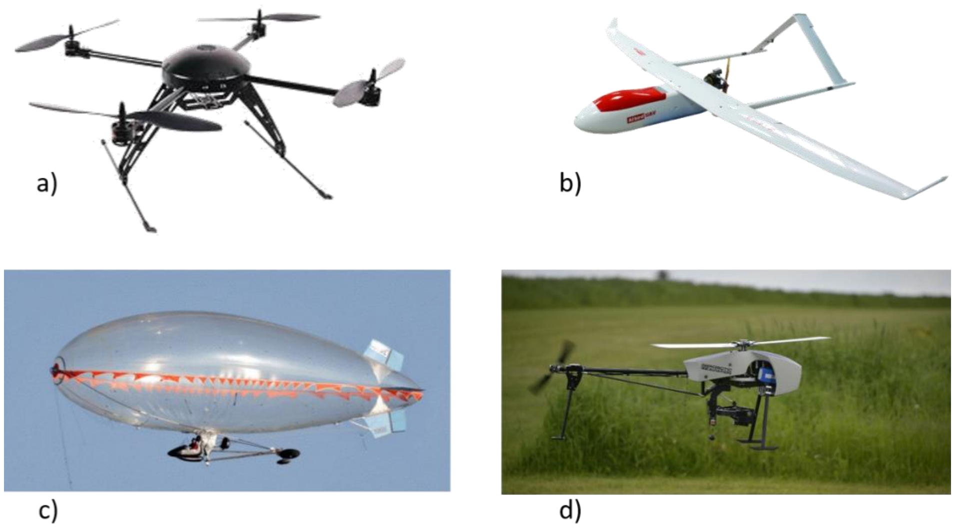

Figure 2.1: Type of Drones

Since a few years, micro UAVs with a total weight up to 5kg (about 1,5kg of payload) and vertical take-off and landing, are used as sensor platforms for aero photogrammetry. They are equipped with GPS and allows an autonomous flight [2]. In terms of value the global UAV market is estimated to be USD 10.1 billion in 2015 and is expected to show a big growth to reach USD 14.9 Billon dollars in 2020. The market is driven by the reduce risk of the UAVs increasing the demand in commercial and defense sectors and a lot of technological innovation. [3].

"The rapid advances in sensing, battery, and aeronautics technologies, together with autonomous navigation methods and equipped low-cost digital cameras have helped make UAVs more affordable, reliable, and easy to operate" [4]. Thanks to this the construction world is starting to get involved with the UAV systems in order to make construction monitoring, and also building inspection. In this way they are saving money and time, and getting quick and precise results in order to make corrections or make a decision related to the process or the status.

2.2 UAS for Construction Site Monitoring

In nowadays the construction site is monitored by the staff by taking digital photos to document the progress of the structure, they just take photos in a regular basis and store them together with the construction plan in a data base. The verification should be done manually by the supervisor to check if there are some errors or bottlenecks, this is very time-consuming and leads to areas not being cover very well.

Another technique sometimes applied to construction sites is the use of laser scanners for monitoring the process. In this case a 3D model is created and stored for later inspection, but there are a sort of problems with this technique, the laser scanner is really expensive, the device is big and should be carry around and inspecting the result is challenging because the spatial relationship is missing [5]. But this 2 methods where unprecise and time-consuming, the new approach to monitor the construction sites are the drones.

Until recently the UAVs were mostly developed and used for military applications. Due to the high cost and size of the sensors, a non-military use and especially smaller UAV systems have not been possible for commercial applications. With the recent development of high accurate and low-cost GPS, it's possible to maintain a UAV system's position in a global reference frame around the world. Thanks to the smart cellphones new cheap and light gyroscopes have been developed helping the alignment and orientation of the drone. With this two developments the performance and flexibility of diverse applications of UAV systems improve significantly. In a most recent time the appearance of small, low-cost and lightweight digital cameras transform the autonomous UAV system into a complete mobile sensor platform. [1]

The interest in UAVs has been in a constant growth, researchers and developers are using a lot of resources and effort to contribute to this topic, mainly in the agriculture and forest applications, autonomous surveillance, emergency and disaster management, traffic management and 3D mapping with photogrammetry. This is basically because the UAV systems are low cost, fast speed, high maneuverability and high safety for collecting images. [1]

Each researcher have different approaches to analyze and investigate the drone usage in construction sites and infrastructures, it's a complex process so different parts of it should be improved.

The process for monitoring a construction site start with the path planning, the idea is to generate an autonomous path for the drone to follow, in order to visit the whole area to be monitored. The next step is deciding at what speed the drone should move and at what high in order to get the amount of pictures necessary for the orthomosaic. The next step is the orthomosaic, which means stitching adjacent images together in order to create a big image with the whole area in it, ideally each picture should overlap about 60% with the adjacent one, If this process is done manually the operator will take a lot of time, so the process is done automatically. After the orthomosaic is done, the process is to create a DEM (Digital Elevation Model) and a 3D model of the terrain. In the next paragraphs the state of the art of each part of the process will be explained.

2.2.1 Path Planning

The path planning is an important issue to take into account when working with drones because you have a small battery so it's better to create an algorithm for the trajectory that consume less battery being equally capable of doing the work. Santamaria et al. 2013 create the path planning algorithm fast and energy efficient, first of all, like in almost every path planning the terrain is considered as a grid of same size blocks, it works with the concept of stride (sequence of consecutive adjacent cells with no turns), in this way the algorithm create big strides, decreasing the number of turns in the terrain, saving some energy [6]. In previous works the method adopted for the path planning was a spiral-like path, which has more turns and consume more energy. In some cases when there's no good GPS signal or there are a lot of dynamic obstacles the path planner is created at the same time the UAV is on flight, generally the used method for this is SLAM (Simultaneous Localization and Mapping), this is more often used in disaster situations where it's impossible to know how the terrain is like.

2.2.2 Orthomosaicking

When the drone is flying it should take a lot of pictures in order to recreate the big image with the whole are, ideally a 75% overlapping in the front and 60% in the side, the process of stitching the images in a way that seems like a big picture taken from a higher distance and with the camera pointing exactly 90 degrees of the trajectory of the drone (NADIR) is called orthomosaicking.

Orthomosaicking is the combination of 2 processes, orthorectification and mosaicking. The orthorectification is the process of correcting the image for distortion using the camera model and the elevation data, by doing this the scale variation should correspond to a map projection throughout the image. This distortion can appear from a number of sources, but the most problematic is the angle of the sensor with respect to the ground plane. If an image is not rectified it can produce a shift in a feature's location so the GIS layer will not line up and the extraction of the data wouldn't be correct.

Mosaicking is the process of tacking 2 or more images and stitching them together as a single image. Normally when inspecting a construction site the terrain will be big so instead of taking 1 picture from a high altitude is better to take several pictures and mosaicking them, in this way you can have a better ground sampling distance, because the overall resolution is the same as the resolution of one of the pictures, with lower altitude better resolution.

The mosaicking process is complex because it should be automatic. The UAV does a zig-zag flight so the images don't always have the same orientation, the mosaicking process should compensate that in order to create a complete image.

The first part of the process is to transform the color images into a gray scale images, then using the GPS position select sufficiently close images in order to compare them in pairs, after selecting the possible pairs some robust key-point or tie-points should be found in order to detect similitudes between the pair and knowing if they can be stitched.

The most common method to find the tie-points and stitch the pictures together is called SIFT (Scale Invariant Feature Transform) but there al also other 2 methods still in use, SURF (Speeded-Up Robust Features) and MSER (Maximally Stable Extremal Region).

The SIFT method is invariant to scaling, rotation, translation and to small skewing. The resulting image has almost no error, regardless of the direction and scaling. The GPS helps to know the position of the drone at the moment the picture was taken and the IMU (Inertial Measurement Unit) give us the information about the camera and drone rotation. [7].

2.2.3 3D Mapping

The last process of the image processing of the drone is tacking the big orthomosaic and extract a 3D model of it, it’s not a simple task because the plane image doesn’t have a depth information, so the depth for creating the model should be acquire by comparing two or more images in order to determine the depth. This process is called SfM (Structure from Motion) and estimates a three-dimensional structure from a two-dimensional image.

The SfM takes the 2D images and extrapolated them into a point cloud, which is bunch of points distributed in a 3D space that represent the 3D structure of the images, this point clouds are the first step for creating the model since they are the describe the terrain. With more points in the cloud, better resolution of the model but more processing time.

In some cases, if the point cloud is very dense, it’s possible to render it directly as a CAD model but a dense point cloud, as stated before, requires a lot of processing time. To reduce the time, the best method is to use a not-so dense point cloud and create a surface with a polygon mesh, more specifically with a triangle mesh.

A triangle mesh is a bunch of triangles in a 3D space that are connected together, their vertices are the points of the point cloud, this is a method used for creating videogames, because with a lower processing time is possible to get good and sharp images. [8]

The next step after the structure is solid is to put the texture in the image since the image is one-color structure, with the help of the orthomosaic the texture of each part of the structure can be applied and the 3D model will be completed with the real aspect of the terrain to be evaluated.

Finally, with the 3D model already created is possible to extract a lot of information from it, since is based in an otrhophoto the measurements are correct, for example, it is possible to know the height of a hill or the inclination of a terrain. It is really useful for recreating real structures and plan modifications with a CAD software.

Periodic monitoring of onsite construction operations it’s a very important help to owners, contractors, subcontractors and sellers giving them the information needed to easily and quickly make project control decisions [9]. The usage of drones on project sites have had an exponential growth in the past years. Now a large number of architecture, construction and engineering firms use them to visually monitor construction and operation of civil infrastructures. Taking pictures and videos and processing them into 3D models the firms usually survey construction sites, monitor work-in-progress and inspecting the existing structures. [4]

2.3 What has been done

In the following paragraphs will be explained in a more detailed way what has been done by different researchers in each of this areas of the construction inspection.

2.3.1 Monitor Work in Progress

Monitoring the work in progress is a really important praxis because the personnel involved in the construction should be aware of what is happening and if they are on time and on budget. The UAV systems have help a lot in this, and the different researchers know it, so the majority of them are writing about this topics, focusing in different specific aspects of the work in progress, the main topic is as-planned as-build, but there's also earthwork progress and identification of different materials.

As-planned As-build is a method that refers to a visualization of the BIM (Building Information Model) model and the actual status of the construction, in this way is possible to make a direct comparison of the status of the construction with the 3D plans in order to identify any problem and also to verify the accomplishment of the time schedule." *Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."* [10].

The As-planned As-build method also have different approaches, since is a popular topic of research.

Some of the authors are starting to work with something called 4D BIM that is a 3D model plus the time schedule. The 3D model of the construction (As-build) created by the drone together with the 4D BIM (As-planned) for the monitoring of work-in-progress, have created an extraordinary opportunity for creating a workflow that consistently can record, analyze and communicate progress deviation. [11]. Han et al. 2015 use the same 4D approach and mention a way to categorize the different BIMs, it's called LoD (Level of Development) and refers to the amount of detail the BIM have, its evaluated with numbers (100, 200, 300, 350, 400 and 500), a higher number indicates a higher level of detail. A good model for using this method is from 350 to 500 because they have a good amount of detail for a real comparison. It's also mention another concept, WBS (Work Breakdown Structure), means that in the BIM should be modelled the different layers of construction of each part of the building. If the model have this layers it's possible to identify for example in which layer of the wall the construction is, other methods just see one layer and think the wall is ready. [12]. Both of this articles create an overlay of the 2 images eliminating the occlusions. [12] [11].

Other authors make use of redundancy by doing a comparison of the 3D BIM with the 3D model of the actual construction status and also do a dimension and measurements of the 2D orthophoto of the actual construction with the original designed plans. By making this is possible not only to visualize and compare the 3D model but also, and thanks to the orthomosaic properties, the exact measurements in a planar visualization. [13] [14].

The earthwork progress is the amount of moved earth or flatten earth, every construction need to dig a hole and flatten the surface in order to have a secure structure, and a strong foundations. That's why some people investigate this aspect and find more reliable solutions. For example Siebert et al. 2014 propose a method based on high density point clouds, it's necessary because the data should be the most precise as possible, with this high density point cloud the error minimize and more exact data can be obtained. They use ground control points in some places with an altitude reference, after that they take the pictures with the drone and create a DEM (Digital Elevation Model) with colors, red for the areas that need to be cut, because they are taller than the ground control and blue the areas to be fill, because they are under the ground control. [1].

Rashidi et al. 2015 propose a helpful tool for work-in-progress without being exactly that. The detection of different materials in the construction by machine learning techniques, it's really a comparison between 3 machine learning techniques, Multilayer Perceptron(MLP), Radial Basis Function (RBF), and Support Vector Machine (SVM). After the experiments to try to identify 3 materials, red bricks, concrete and OSB boards it was successfully recognized with a precision rate of 75% - 95%. [15].

2.3.2 Survey Construction Sites

The survey in construction sites refers to a low flight look-out to detect specific aspects of the process of the construction, the two main topics researched are the safety and the daily progress of the construction.

Habitually the safety planning is made by manual observation, which requires a lot of work and time being highly inefficient because of the possible human error. The relationship between the safety planning and the real execution is very weak, in some cases the contractors use 2 dimensional drawings to determine the risk-prevention techniques. [16]. In the las 20 years more than 26000 United States construction workers have died at work. That is approximately five construction workers each working day. Almost half of these incidents are related to falls from heights. Being aware of the safety during the design can reduce hugely the risk of falling. [17].

Zhang et al. 2013 and Sulankivi et al. 2016 propose a framework of rule-based safety checking system. This method compared to the traditional processes can associate the safety rules, guidelines and best practices with the BIM model. The rule checking process have 5 steps: Rule interpretation, is the interpretation of safety rules in a logic-based mapping from human language to machine format; Building model preparation, every building object should be associated with specific object type and characteristics. With this information is possible to check geometric features, all this because the rule checker requires more than just a 2D or 3D model. It's really important that the BIM model have information for every object; Rule execution, this phase bring together the rule sets and the already prepared building model. The objects of the building can be mapped to the rule set; Rule checking reporting, the result of checking the rule will be reported in two ways, the visualization of the usage of protective equipment and a table with the detailed information and the applied solution; safety correction, this point requires human decision makers, using a 3 dimensional immersive environment. This BIM views allows to make better decisions and increase the awareness of project participants. [17] [18].

Teizer 2015 introduce a method of safety checking based in algorithms for tracking. Basically tracking everything, personnel, construction equipment, temporary structures, and bulk materials temporarily occupying site space and changes in site layout.

The tracking of personnel in robust and long-term way is an excellent practice for safety checking, since they are in constant movement and constant risk, doing a trace of them and creating some risky actions recognition is possible to reduce the possible danger for the workers. Other potential risk is the fact that there's a lot of machinery in movement in the construction site, so tracking them and knowing their exact position with respect to the workers or other machines could prevent hazardous situations. This method is not only useful for the safety, it also allows to know the process of the construction by tracking the bulks of materials, this would help to know the supply and depletion rate of these materials providing a time-stamp evidence regarding the state of construction activities. [19].

2.3.3 Inspecting Existing Structures

Existing concrete structures range in condition, age and performance. Some infrastructure maintenance programs have been established in order to monitor the performance. This performance involves the safety of the structure, helping to predict the future conditions in a long term and decision making, allowing the manager to know if a maintenance or a rehabilitation is needed. [20].

This inspection should be done constantly in order to make sure the materials of the structure can handle their day by day work. A good inspection requires a close look of inspector to structure. Normally this is a difficult task because requires, sometimes, the lifting of persons to dangerous areas or in the case of a highway the traffic should be shouted down. In order increase the inspection speed, cost and safety the best way to do this monitoring is with a UAS. [21].

It’s really difficult to create a universal system for monitoring because of the big variety of structures and all of them using different materials and purpose, this is a big problem since the monitoring is difficult to be done with a single sensor. [22]

Jafari et al. 2016 describes a method I which is explained a comparison formula for obtaining the deformation of a structure, in the experiment is a bridge. By the creation of dense point clouds and removing the noise from it, it’s possible to detect minimum deflections of the structure. This method is design for a long-term surveying since is a point cloud comparison between a previous one and the actual one. Ideally this monitoring should be made periodically in order to have more point clouds to reference for the comparison. [23].

Koch et al. 2014 have a different approach to the inspection, the method is to evaluate the various materials or parts of the construction in order to detect a crack or damage using machine vision techniques. The method used to detect the cracks is the combination of edge detecting techniques, that if knowing the original form of the structure will determine if there’s a new edge in the structure or not, and the advantage of the linearity of the crack so it can be detected if a determined number of darker pixels are adjacent maybe there’s a crack. [20].

2.4 Sensors

The vast majority of the researchers agreed that the use of a RGB camera is enough to acquire a good and reliable model. Originally the recommended way was with a LiDAR (Light Detection and Ranging) but that’s an expensive and heavy sensor, but fortunately the development of better and faster algorithms for the creation of the 3D mapping with a plane image allows to get a point cloud quite similar to the point cloud made with the LiDAR.

The LiDAR is a remote sensing method that uses light, specifically laser, in a pulsed way and direct them to the surface that want to be measured. These pulses generate precise, 3D information about the shape and characteristics of the surface to be measured. This instrument roughly consist of a laser and a scanner, measuring the returning time of the laser, this method can determine the surface of land in a forest, since performing this method allows to detect obstacles and map them also. [24].

RGB cameras is the name of the regular and common cameras, its working mechanism is based in RGB color model. RGB color model is an additive model in which Red, Green and Blue lights are added together in order to create a wide range of colors. It has a solid theory behind based on the human perception of colors. Humans and many animals, for seeing, use sensors with 3 different sensitivities in order to make an approximation of the colors in the scene. [25].

The cameras have different specifications that should be taken into account in order to know specifically what is needed for a specific task, the sensor, the focal length, resolution and aperture of the diaphragm.

2.4.1 Camera Sensor

The sensor of the digital camera is, basically, the film. Each time a picture is taken the sensor is exposed to light and the camera records what's seen. [26]

There are several types of camera sensors but the two more used in digital cameras are CCD and CMOS. "A CCD sensor has one amplifier for all the pixels, while each pixel in a CMOS active-pixel sensor has its own amplifier. Compared to CCDs, CMOS sensors use less power. Cameras with a small sensor use a back-side-illuminated CMOS (BSI-CMOS) sensor. Overall final image quality is more dependent on the image processing capability of the camera, than on sensor type." [27].

2.4.1.1 CCD (Charge-coupled device)

IT has been used since a long time in video and still cameras, have a superior image quality than CMOS sensors, with less noise and better dynamic range. Since they have a high power consumption they are being highly replaced by the CMOS. [28].

The CCD has a photoactive region and a transmission region made of a shift register. The photoactive region is an array of capacitors, so when the image is projected through the lens, each capacitor accumulate an electric charge proportional to the light intensity at that specific location. A two dimension array is used for still cameras. When the matrix has been exposed to the image and all the capacitors have the electric charge related to the image, a control circuit creates a shift register by causing each capacitor to transfer its electric charge to its neighbor and the last capacitor transfer its content into an amplifier, converting the charge into a voltage. This process is repeated until all the capacitors have passed their charge and the result is a sequence of voltages that can be used as desire. [29].

The Figure 2.2 show the CCD sensor helping to understand in an easier way the method of acquiring the images. The yellow cones are photodiodes which capture the amount of light in that location of the image, after this process the information is transferred to the each register (purple cones), this registers shift the information one by one to the horizontal registers in the lower part, and this means that for each row of registers there is a horizontal register. The horizontal register is also a shift register and will pass each of the values trough an amplifier that will give the amplitude voltage value of each pixel.

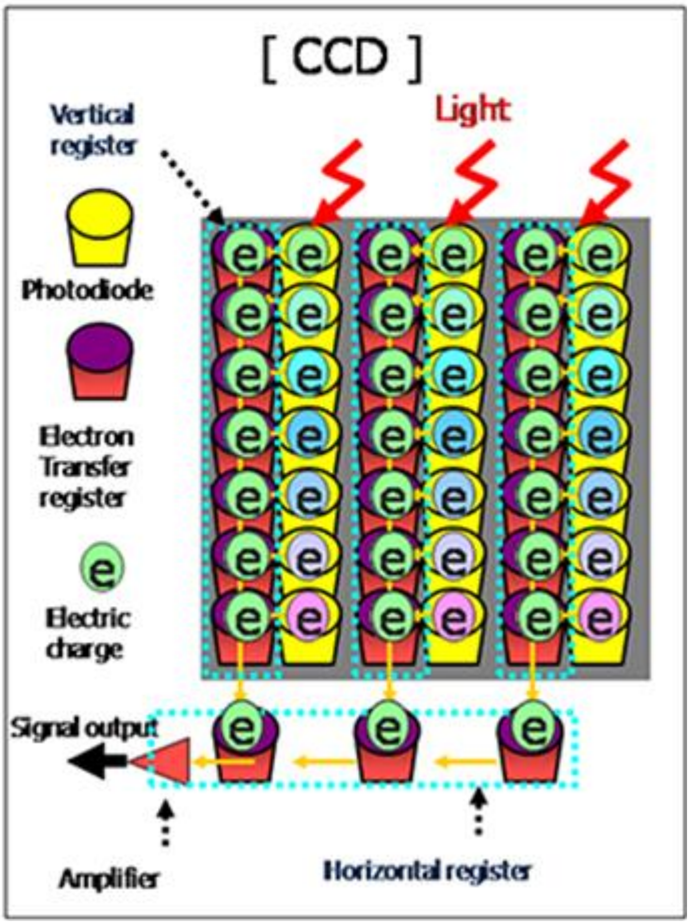

Figure 2.2: CCD sensor

2.4.1.2 CMOS (Complementary Metal Oxide Semiconductor)

Before the CMOS sensors were seen as an inferior competitor to the CCD sensors, but with the years the CMOS have progressed to match the CCD standard. This sensors are able to work more efficiently and require less power, having the advantage to be able to take high speed captures.

The process of the CMOS is really similar to the CCD sensor but have several advantages, incorporates amplifier and converters in each cell, this means that it's not necessary to have a different chip for the A/D converter. Other advantage is that these sensors are more sensible to light so in poor light conditions it can manage it better than the CCD. [28]

As seen in Figure 2.3 the CMOS sensor don't use register since each pixel has its own amplifier so each value is given directly in volts and allow the sensor to be smaller in size than the CCD.

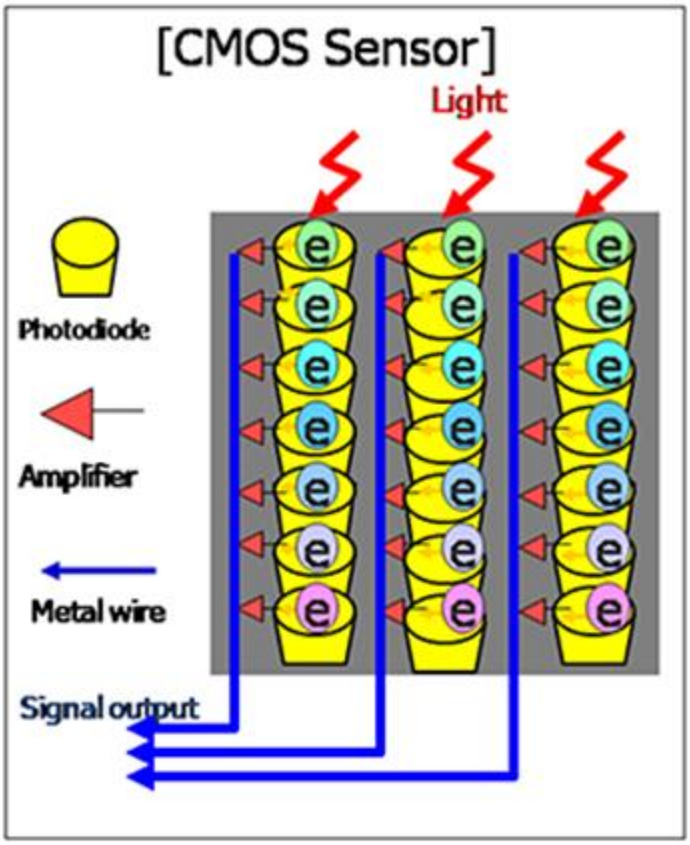

Figure 2.3: CMOS Sensor

2.4.2 Focal length

Focal length is the basic descriptor of a photographic lens, it's usually represented in millimeters. This measurement doesn't represent the length of the lens, is a calculation of the optical distance between the point where the light rays converge and the digital sensor. This measurement tells the angle of view and the magnification. In Figure 2.4 can be seen that the longer the focal length, the thinner the angle of view and higher the magnification, and vice versa. [30].

The angle of view describes the angular extent of a given scene that is imaged by a camera. This data is important because it relates the distance of the camera with respect to the object and the size of the image plane, or the focal length with the size of the sensor.

The different angles of view are divided into subgroups in order to understand its operations, the reference values for this divisions vary depending of the size of the sensor but it's normally given with a 35mm sensor and a crop factor for other size sensors. Extreme wide angle, typically used in architecture, are lenses with a focal length less than 21mm, wide angle, typically used for landscapes, are lenses with focal length between 21 and 35mm, normal, are lenses with 35 to 37mm of focal length, medium telephoto, normally used for portraits, have focal length between 70 and 135mm and last the telephoto, used for birds and wildlife, are lenses with focal length greater than 135mm. [31].

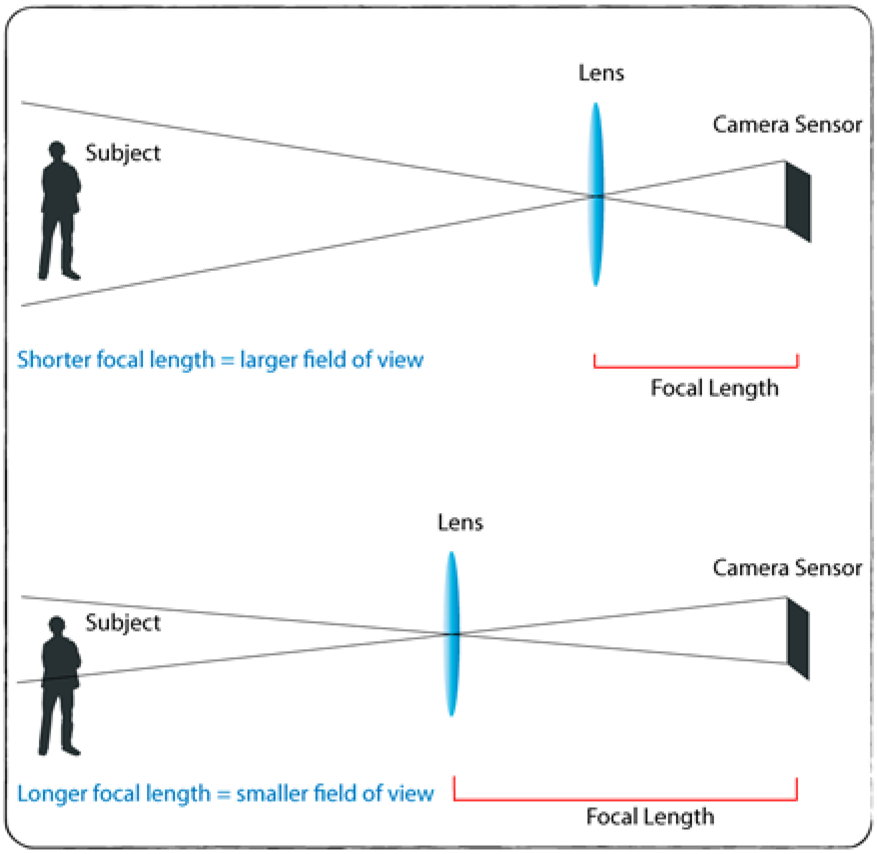

Figure 2.4: Focal length explanation

2.4.3 Resolution

Resolution is a very important concept to understand digital photography, this term describes pixel count and pixel density. It's measured in megapixel (pixel count) or in pixels per inch (ppi pixel density). [32].

The megapixel count is a multiplication between the high of the picture (in pixels) and the width, that's why sometimes is possible to see an image of 2240x1680. What it really means is the amount of detail that the camera can capture, so when enlarging it, doesn't get blurry. If the idea is to print or use the picture in a small visualizer you can get really good pictures with a small amount of Megapixels.

2.4.4 Aperture

The term aperture refers to the size of the opening of the lens. This aperture is regulated by the diaphragm made of overlapping blades that can be adjusted to vary the size of the opening. The size of the diaphragm aperture regulates the amount of light that passes through the lens onto the sensor, this happens when the shutter curtain in camera opens during an exposure process. [33].

The aperture size is normally denoted in f-numbers. They are a way of describing the size of the aperture. A smaller f number means a larger aperture (more light in) and a bigger f number denotes a smaller aperture (less light in) (see Figure 2.5).

This is directly related with the shutter speed because with a small f number the amount of light entering is high so the shutter should be fast in order to not overexpose the picture, and the same if the f number is big there's less light entering and needs more time of shutter in order to avoid underexposed images.

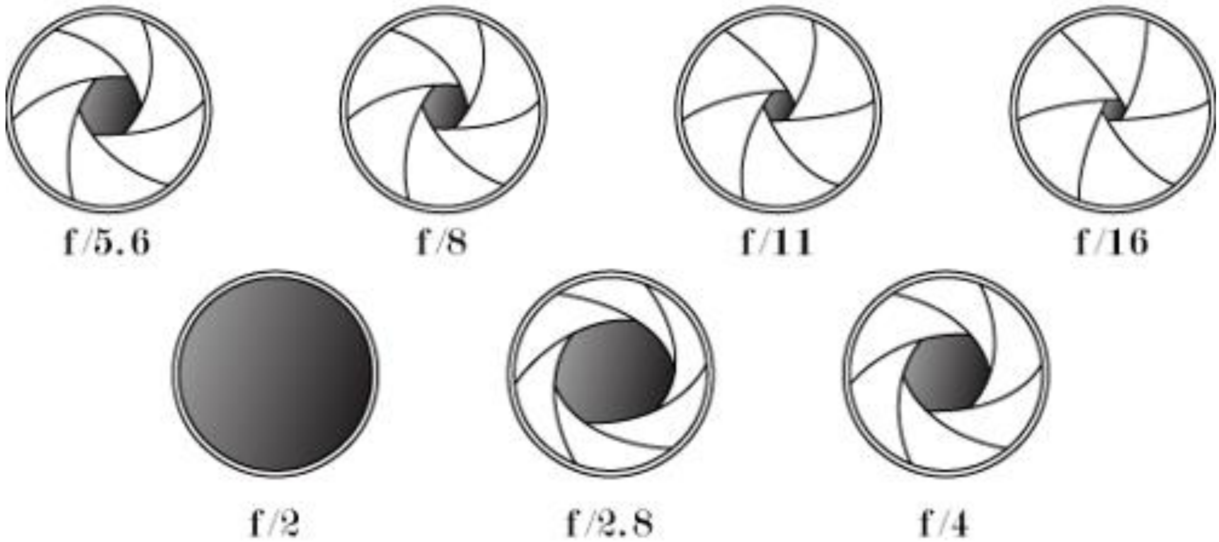

Figure 2.5: Aperture

2.4.5 Sensors for Drones

Knowing the specifications of a camera it's possible to select a suitable camera for a mapping using drones, but before that a las concept should be explained in to make a good choice and understanding completely the cameras, this concept is named Ground Sampling Distance (GSD).

The GSD is the distance between 2 consecutive pixel centers measured on the ground, the amount of land captured by one pixel on the sensor. It's related to the flight altitude, the focal length and the pixel size. A lower value of GSD means a bigger spatial resolution of the image and more visible details. This data is usually given in cm/pixel and influences directly the accuracy and quality of the image and the detail that is visible in the orthomosaic. [34].

Regardless of the flight times, the composite construction and good ground control the value of the operation is limited by the sensor used. The innovation in this matter is lagging and no perfect aerial camera has been made. The limitation on the precision of photogrammetry is 2 times the GSD.

In order to select a camera and a lens for an accurate survey it's important to consider all the camera specifications, in the next paragraphs will be explained briefly the specifications and recommendations about how to decide the right camera and lens.

Since the GSD is a function of flight altitude, megapixels and focal length the selection of the mega pixels in a camera is an important issue, the minimum amount of pixel is 12Mp but normally a 24Mp camera is used. The size of the sensor is also significant, having a larger sensor means a larger camera body and weight, but has the advantage that lets in more light and that means that the camera can shut faster without compromising sensitivity. The photos should not be blurry so a fast shutter speed is obligatory, at least 1/1000s.

The lens should be of good quality to feed the sensor light. Lenses define the focal length and therefore the field of view. The selection of the lens is important because the focal length allows to acknowledge of the size of the footprint.

Some cameras and lenses have image stabilization helping the image to be blur free, however this stabilization systems work at low frequency because is designed for the small vibration of the human hand, with high frequencies the stabilization is useless or sometimes worst because end up syncing with the vibration of the UAV. Definitively no stabilization is required, important to find a camera and lens without stabilization.

The UAV should be of minimum size and weight possible, so the camera should be the same, it’s important to recall that the drone have an internal power source and the camera needs no screen or buttons, so the camera should have only the basic parts, in order to reduce the weight and size.

A small amount of cameras can auto trigger in a certain amount of time, so is important to find one camera that allows an external triggering (wired or wireless) so that the internal processor can manage the triggering time. [35].

3 Proposals

After all the analysis and investigation done, it is possible to make a proposal about the development and the aim of the project. I would like to propose an integral solution for any construction site, including buildings, bridges and focusing specially in highways. Therefore, an integral solution consist in a constant and frequent accompaniment of the construction site in order to give to the construction manager all the information required for the three stages of the construction process: designing, construction and structure monitoring.

3.1 Designing Stage

It is important to do a good design of the structure before the construction begins, in order to accomplish this, the architect should know the terrain and its properties. There's where the drone plays its role, by taking aerial pictures and representing them as a 3D model of the surface, the designer can see the exact elevation and depression in the terrain so he can know the amount of earth that should be moved in order to flatten the area, he can also see the contour lines and the precise size of the field to be constructed.

3.2 Construction Stage

This stage is the one that need more assistance by the drone because is the most critical stage of the process.

The manager or operator will get an orthomosaic, a 3D model and "As planned As build" model, this help to analyze the status of the construction, and with the data given he can know at what percentage of the construction they are and also if it's on-time. This is very useful because they can forget about over budget, over time and construction errors.

Other aspect to be covered is the manager of stockpiles and earthwork, this will help them to know how many material they have left and if it's necessary to buy more, also giving an average of consumption in a certain period. The earthwork allows to know how many earth has been excavated and how much is missing.

3.3 Structure Monitor Stage

This stage is not so frequent because is designed to monitor the state of the structure time after the construction to find possible problems such as cracks and bending. This is a useful stage because sometimes the asphalt of the road is deteriorated due to the constant use and the time, the constructor would like to know this on time in order to fix it before the road have a major damage.

4 Photogrammetry Software

A photogrammetry software is a computer program that takes the pictures previously saved on the computer, in this case taken from the drone, and process them, initially by calibrating the camera parameters, in order to rectify or correct distortions due to the camera and lens, after this the software check the gps positioning of each picture. With the correct positioning of the pictures the software search for Tie Points, this means looks for key points in each pictures and then compare this points with all the other pictures in order to find matching points and with the help of SIFT or SURF stitch them together. After this point all the images are together and the software will extrapolate the 2D images into a 3D model with a method similar to the stereoscopic view, seeing the same point from different perspectives allow it to do so. At first the software will create a sparse point cloud, for the user to check if everything is going well and after that will create a dense point cloud, which show the 3D model with good quality but without the texture, after that the software will apply texture and a solid mesh in order to get the full 3D model. Now with this model the process can be finished or if the user decides an orthomosaic can be created, it depends on the desired output. The big advantage of this software, beside the fact that is practically automatic, is that all the measurements and data extracted from the model is accurate, so it’s possible to extract volumes, areas, distances with a very small error.

Thanks to this software and the low error is possible to use them to monitor construction sites, the 3D model created from the real images should be equal to the model designed. And also allows to measure stock piles in order to know the rate of consumption.

4.1 Pix4D

Pix4Dmapper software automatically converts images taken by hand, by drone, or by plane, and delivers highly precise, georeferenced 2D maps and 3D models. They’re customizable, timely, and compliment a wide range of applications and software.

Key outputs:

- 3D point Clouds
- Texture Model
- True orthomosaic
- NDVI Map

Pricing: there are 3 methods of paying for the license, monthly at 260€, annually at 2600€ and one-time charge at 6500€ (plus after second year supports and upgrades at 650€/year). [34].

This Software is highly accurate and is specially designed for drones, having a lot of camera models and parameters and also allowing to create NDVI maps that are not useful for this project but are widely used in agriculture. The interface is very user friendly and easy to use.

When the pictures are uploaded and geolocated the software shows a map with the possible flight route of the drone and the geoposition as seen in the Figure 4.1. (Dataset taken from sensefly. [36], captured with an ebee drone which has an RGB camera of 18.1Mp).

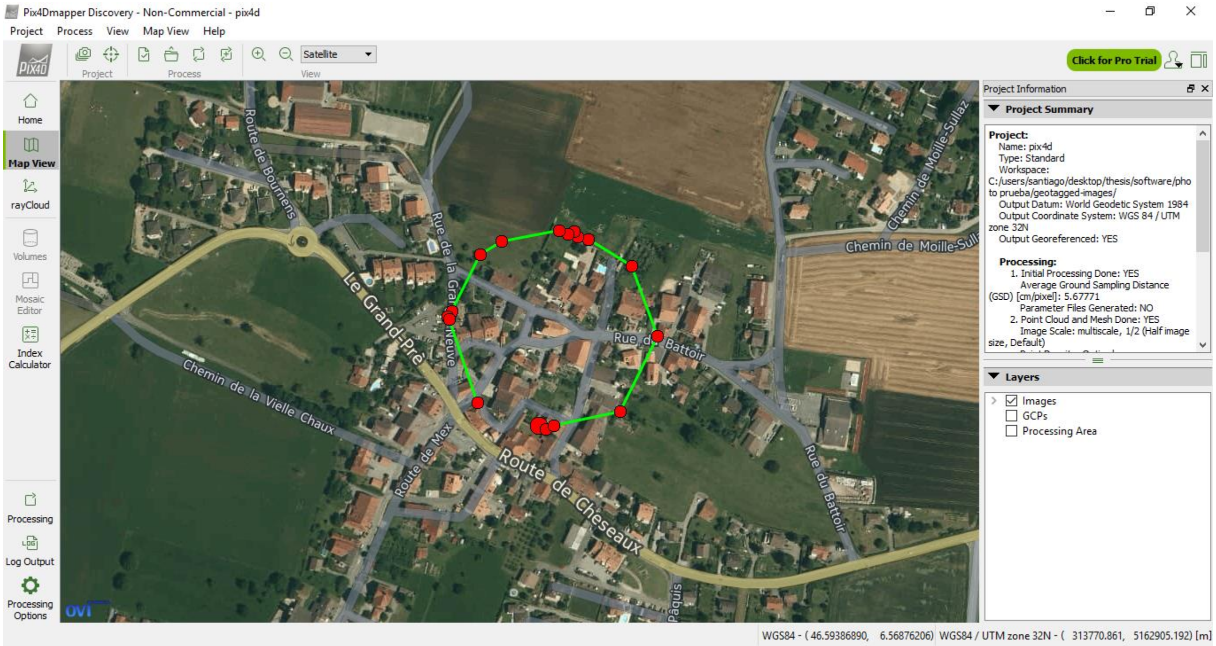

Figure 4.1:Drone and photo position, Pix4D

After this process is done, the software will start to process the images, the first step, as explained before is the sparse point cloud that show roughly how is going the process, it can be seen in Figure 4.2, and at the same time it will give a report with a detailed explanation of the process, the most important part of the quality report is the quality check that shows the possible problems of the process, it can be seen in Figure 4.3.

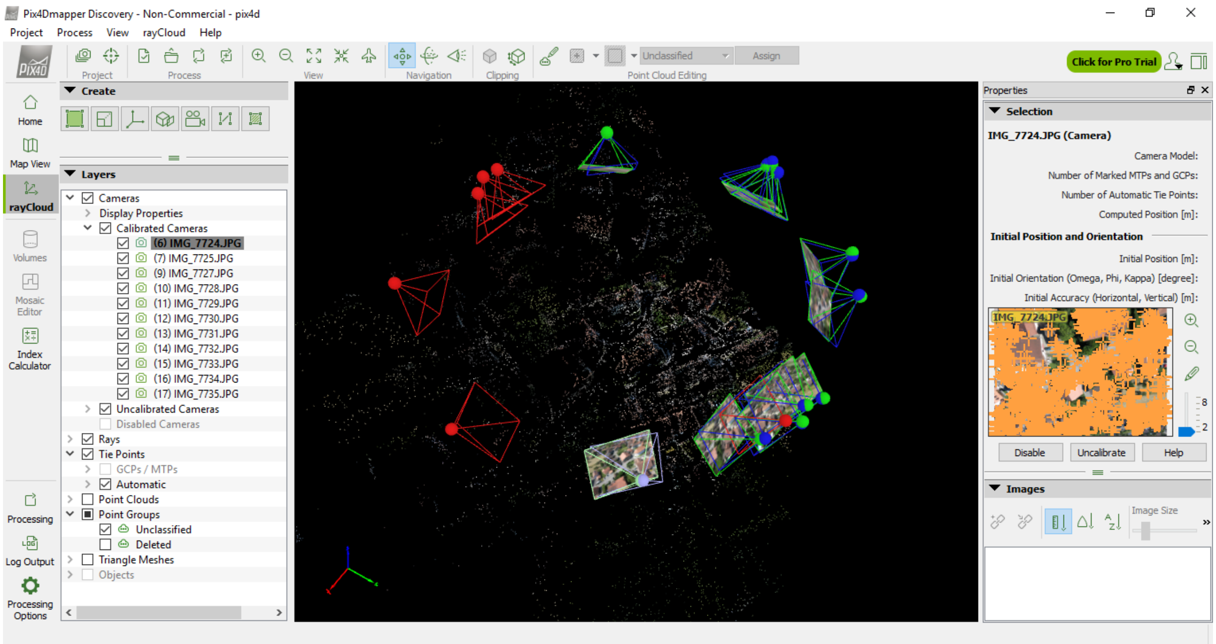

Figure 4.2: Sparse point cloud, Pix 4D

Quality Check

Images	median of 35706 keypoints per image	✓
Dataset	11 out of 17 images calibrated (64%), all images enabled	⚠
Camera Optimization	0.36% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 15786 matches per calibrated image	✓
Georeferencing	yes, no 3D GCP	⚠

Figure 4.3: Quality report, Pix 4D

In the report can be seen that not all the images where calibrated, just 11 out of 17 that means that the final model will not be very good, this can also be seen in the Figure 4.2 where the cameras are of different colors, the red ones are uncalibrated and the green-blue ones are calibrated.

After this step the software will create the dense point cloud and the triangle mesh in order to get the full model. The final model is shown in Figure 4.4.

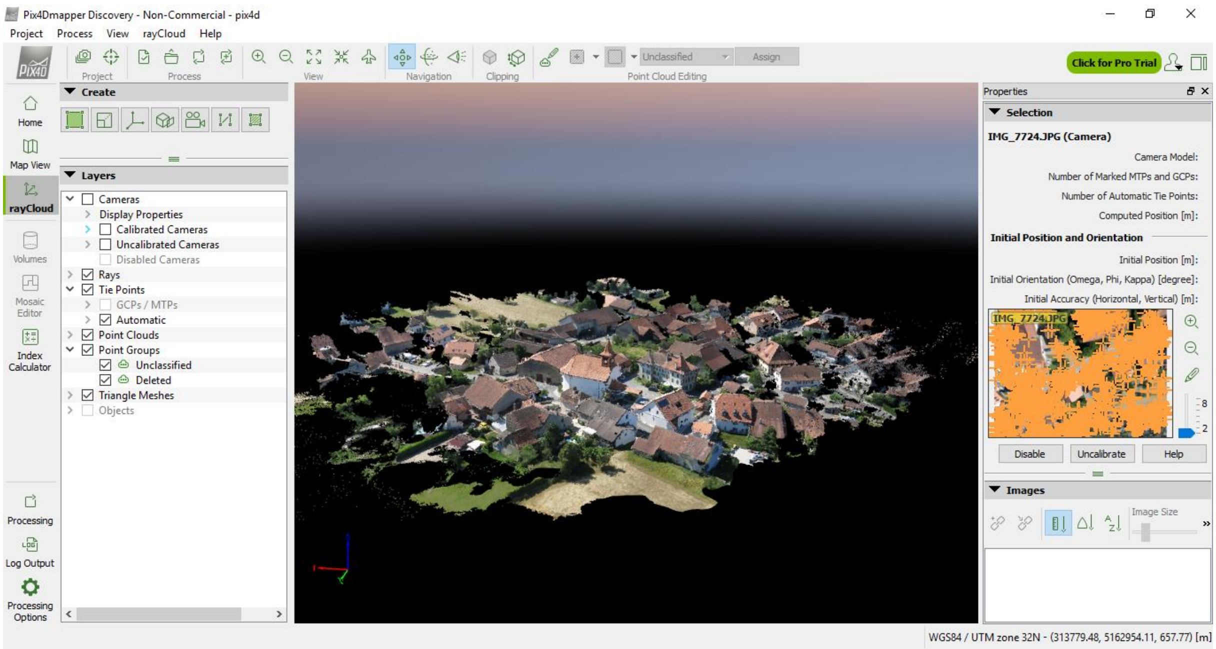

Figure 4.4: 3D model, Pix 4D

After having the complete model it's possible to make some measurements in the model, as explained before the measurements will be almost perfect and they can be considered as real, in the following images some measurements are going to be shown.

In Figure 4.5 is shown a car that was parked in the city, the green line is the distance to be measured, to make more emphasis in the location of the car Figure 4.6 and in Figure 4.7 the measurement of the line is shown.

Figure 4.5: Car measurement, Pix4D

Figure 4.6: Zoom out car, Pix4D

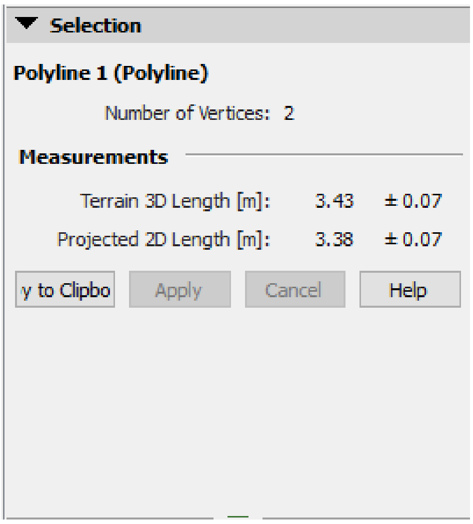

Figure 4.7:Measurement of car, Pix4D

As seen in the measurement in Figure 4.7 the length of the car is 3.38 meters with an error of plus or minus 7 centimeters, checking the real measurements of small cars like this is possible to verify that their measurements vary between 3.4 and 3.55 meters so, the measurement is quite good.

Another measurement that can be done is the area of a terrain or an object, in Figure 4.8 a backyard of a house will be measured.

Figure 4.8: Backyard, Pix4D

The green selection in the Figure 4.8 is the backyard to be measured and in Figure 4.9 the measurement will be display.

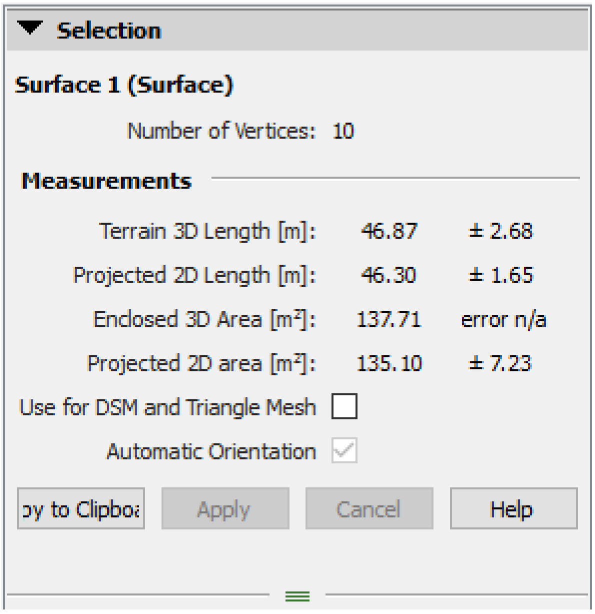

Figure 4.9: Measurement of the backyard, Pix4D

As seen in Figure 4.9 the measurement of the area is 135.10 meters with an error of plus or minus 7.23. This is a really considerable measurement for a backyard so is possible to assume that the measurements are really good.

There's another measurement that can be done, the volume of an object, in this example is not worth it to do it since there are not piles or elevated terrain to measure the volume but in the construction site it will be of enormous help since allow the user to measure the volume of a stock pile or the volume of excavated soil.

Whit the use of ground control points the error in each measurement can be reduced significantly and in a very good case reduce it almost to zero.

4.2 Photo Scan

Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales.

Features:

- Photogrammetric triangulation
- Dense point clouds
- DEM
- Georeferenced orthomosaic
- Measurement of distances, areas and volumes
- Python scripts
- Multispectral image processing
- 3D models
- 4D models
- Panorama stitching
- Network processing

Pricing: There are 2 kind of licenses standard and professional, the standard is really basic, almost useless for this work it cost $179 USD and the professional cost $3499 USD.

Works in Windows, Linux and IOS [37].

This software is really good but is a little bit more focused on modelling objects more than 3D mapping, it doesn’t give an NDVI map that, as stated before, is not useful for the project.

After the pictures are uploaded the user should put them to align and then create a sparse point cloud, it’s no so automatic, and the result can be seen in Figure 4.10.

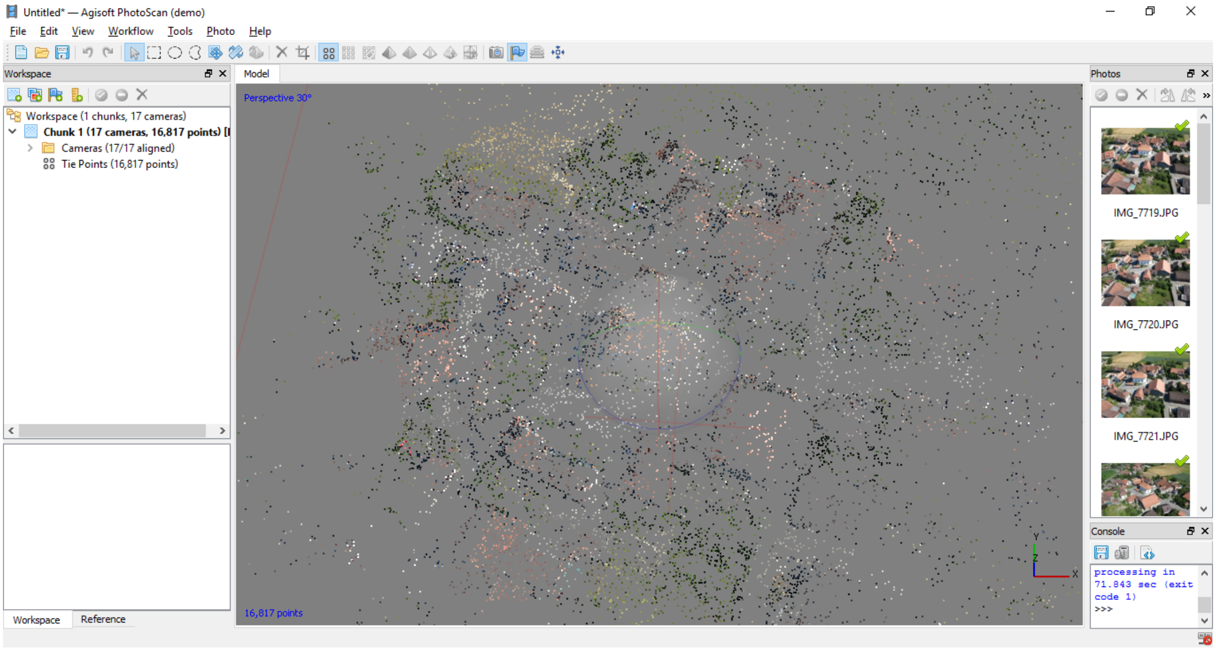

Figure 4.10: Sparse point cloud, PhotoScan

Photo scan doesn’t give any report but in the right bar it can be seen the process of the model, and how many aligned pictures are. In Figure 4.11 the bar is zoomed in.

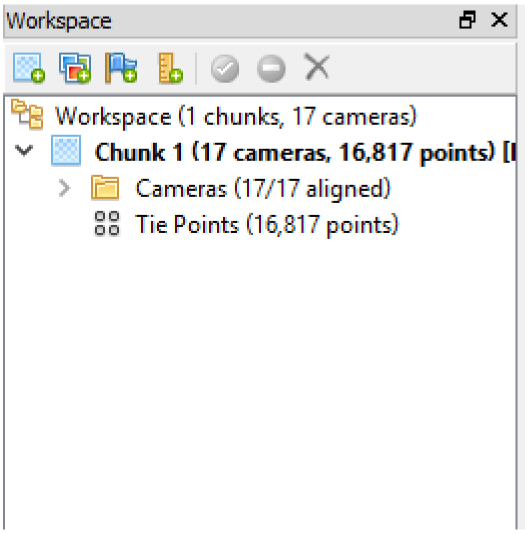

Figure 4.11: Pseudo Resport, PhotoScan

All the images where aligned so the expected result should be good. After this the user should build the dense point cloud, as stated before, is not so automatic so each step is done by the user, the dense point cloud is shown in Figure 4.12.

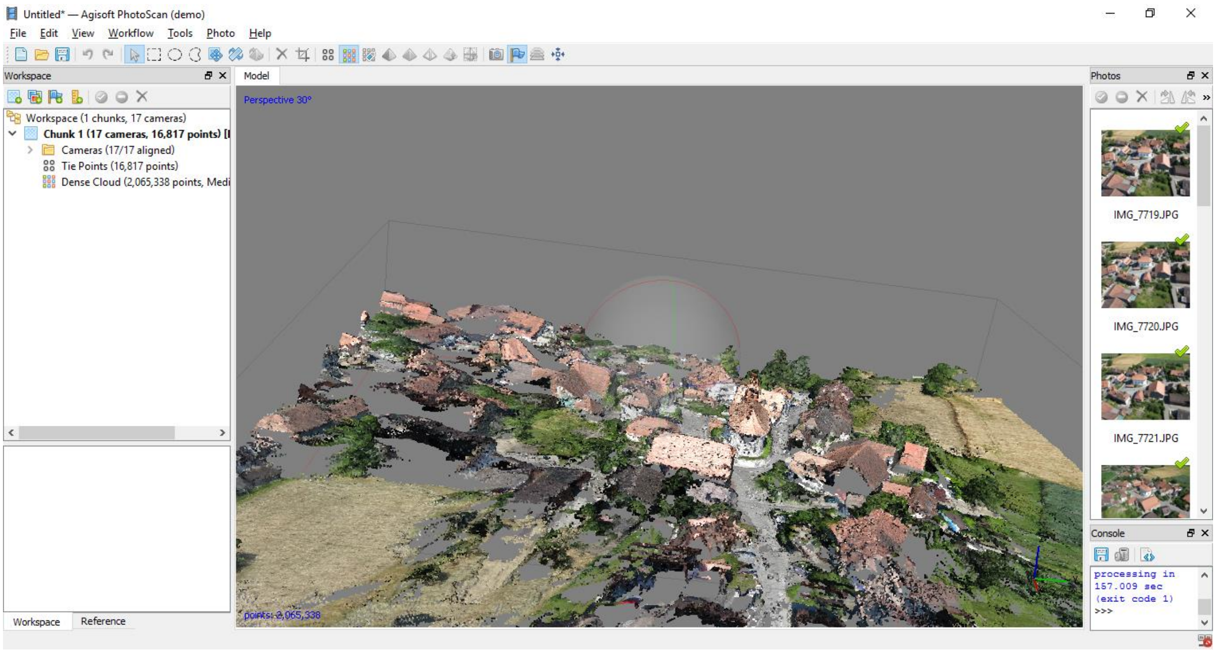

Figure 4.12: Dense point cloud, PhotoScan

The dense point cloud seems good, now the user should create the triangle mesh and the texture, the final model is shown in the Figure 4.13.

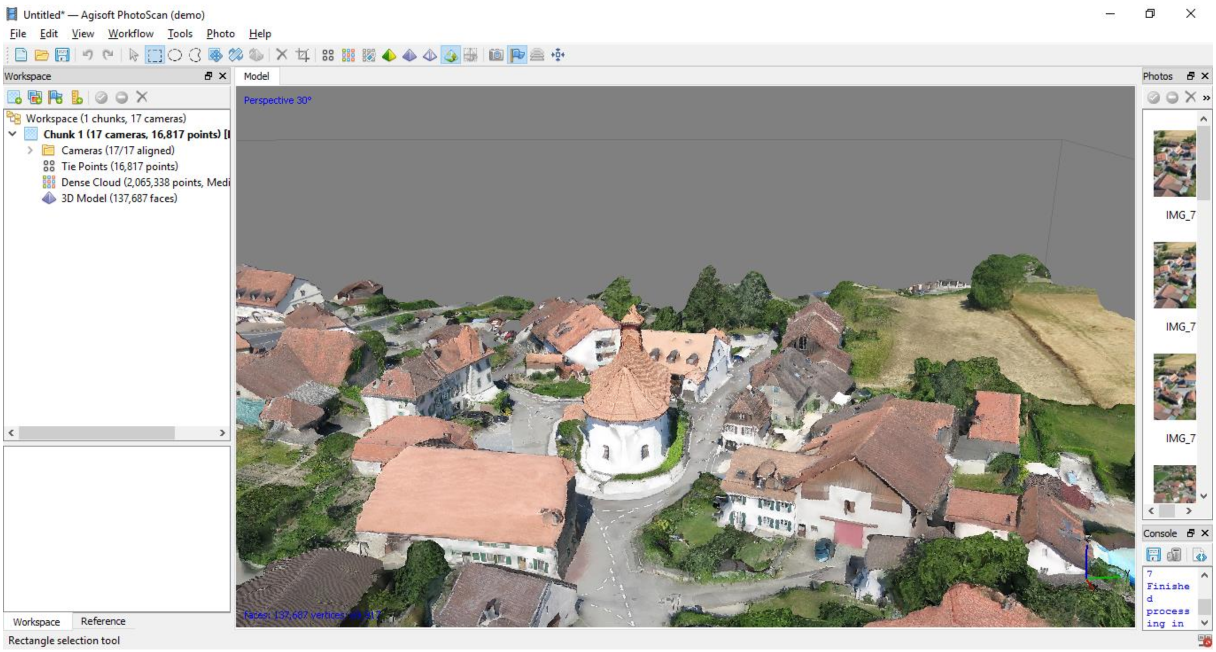

Figure 4.13: 3D model, PhotoScan

Now some measurements should be made in order to demonstrate the capability of the software, an important note to say in this point is that finding the measurements in

PhotoScan is really complex and not friendly at all, not as easy as Pix4D. In Figure 4.14 the backyard shown in Pix4D will be shown, and measured.

Figure 4.14: Backyatd, PhotoScan

As seen in the Figure 4.14 all the image should be crop in order to find the area of a section, this require more time and effort since it is not an easy task. In Figure 4.15 the measurement dialog box is shown.

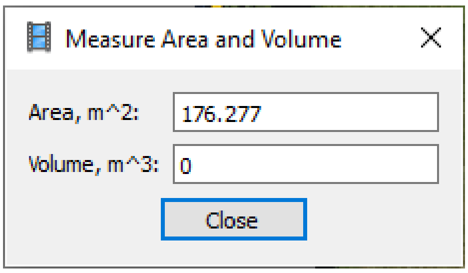

Figure 4.15: Area of backyard, PhotoScan

As it's possible to see the area of the backyard in PhotoScan is approximately 50 meters different, and it requires a lot of extra work, the other measurements will not be taken since the software doesn't accept line measurements, just areas and volumes.

4.3 Comparison and Examples

Both Software can manage the work so now some examples must be done in order to see which software is better for the project, just one can be selected since a license should be bought.

4.3.1 Eagle

This is a dataset downloaded from Pix4D. [38].

The images where taken with an RGB camera Canon EOS 7D, with 18Mp.

It's an eagle statue and is created without GPS, rotating around the eagle at different heights and angles.

The process of the completion of the data set is not worth showing since each step of the procedure was shown before, the comparison will be made between the final result and the quality report.

Since this example is just a statue, there is no need of orthomosaic nor NDVI map.

4.3.1.1 Pix 4D

After processing it in 58 minutes and 24 seconds, the results we get are outstanding, the final result is shown in Figure 4.16.

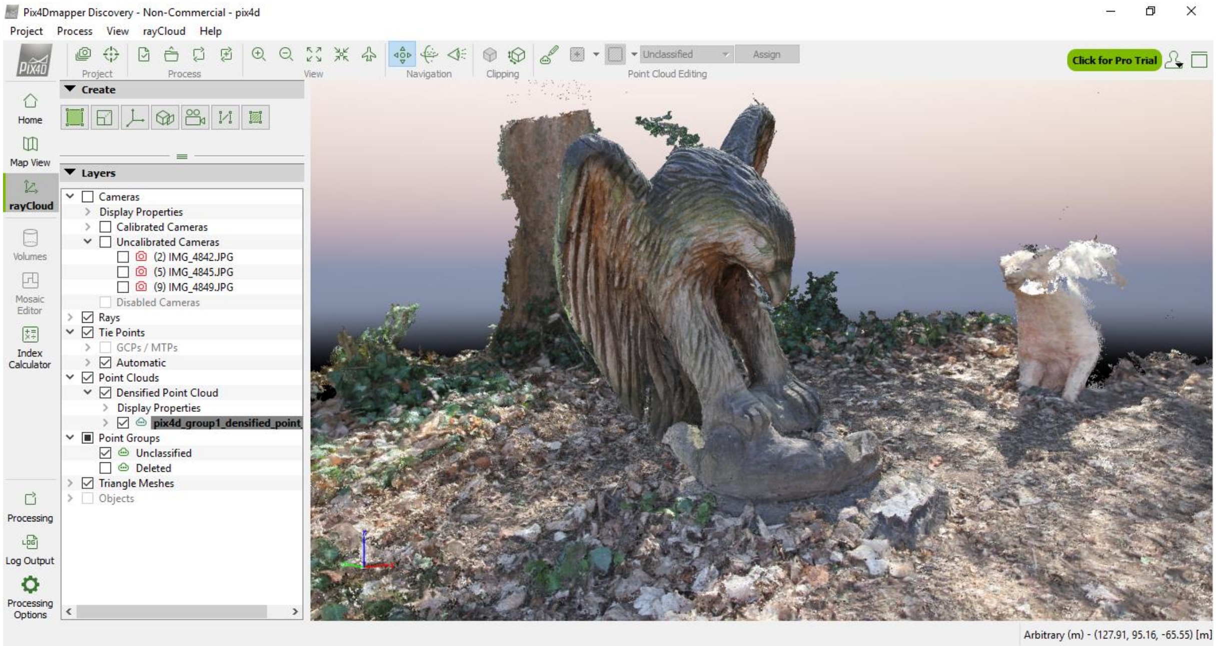

Figure 4.16: Eagle1, Pix4D

As seen the form and texture of the statue are wonderful, for a closer and more detailed look of the eagle see Figure 4.17.

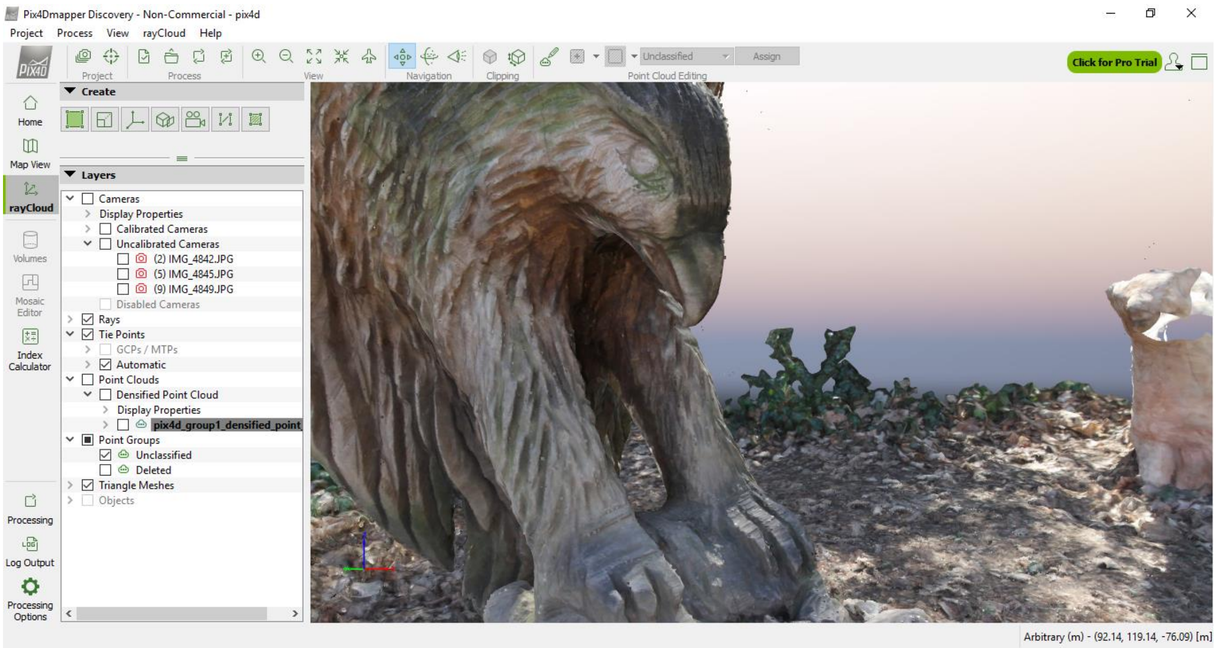

Figure 4.17: Eagle2, Pix4D

Now in order to do a more precise analysis the quality report must be analyzed, in Figure 4.18 the quality check is shown.

Quality Check

Images	median of 76231 keypoints per image	
Dataset	41 out of 44 images calibrated (93%), all images enabled	
Camera Optimization	0.21% relative difference between initial and optimized internal camera parameters	
Matching	median of 11770.8 matches per calibrated image	
Georeferencing	no, no 3D GCP	

Figure 4.18: Quality report eagle, Pix4d

As seen in the quality check, the images where not georeferenced, and because of this not all of the pictures where aligned causing some errors due to lack of tie-points. This software have some problems when processing images without geolocation, or when all the images are close to each other since the geoposition is almost the same, for this project this is not a problem since the construction site normally is a big land and the drones will geotag each image.

4.3.1.2 PhotoScan

When processing the images there is no way to know the amount of time the whole process takes, because, as stated before, the software don't give any report and there are

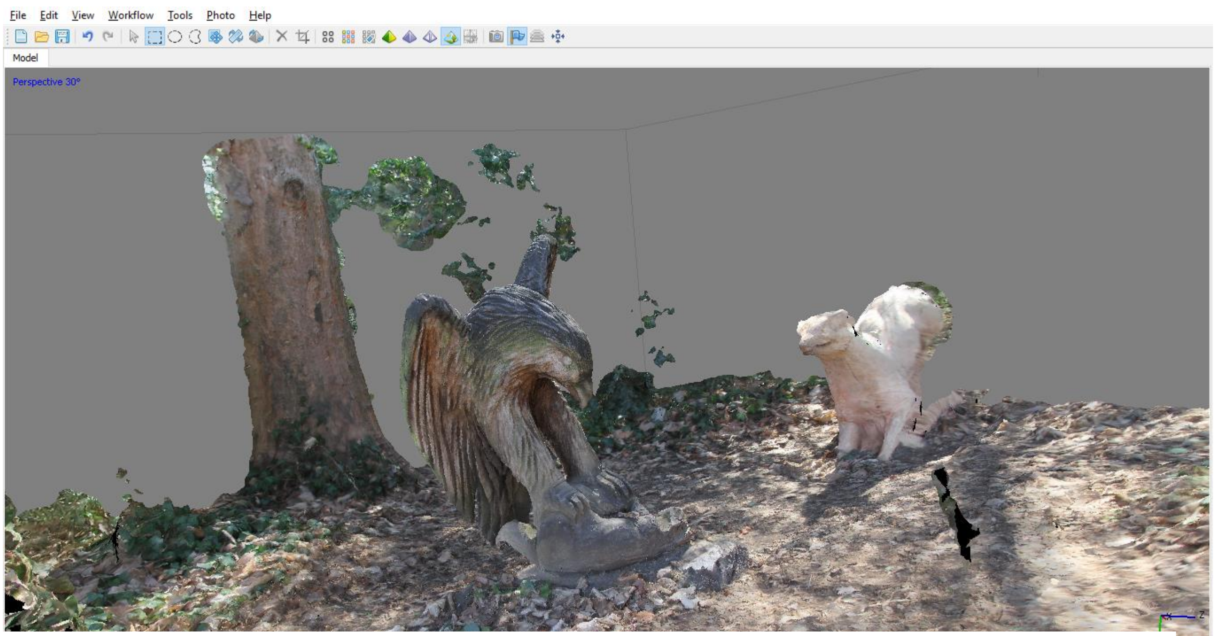

Figure 4.19: Eagle1, PhotoScan

a lot of individual steps to do in order to finish the project, the final 3D model is shown in Figure 4.19.

The figure shows how amazing is the quality of the model, with a good texture and form but also with a great background. In the Figure 4.20 a close up of the model is shown.

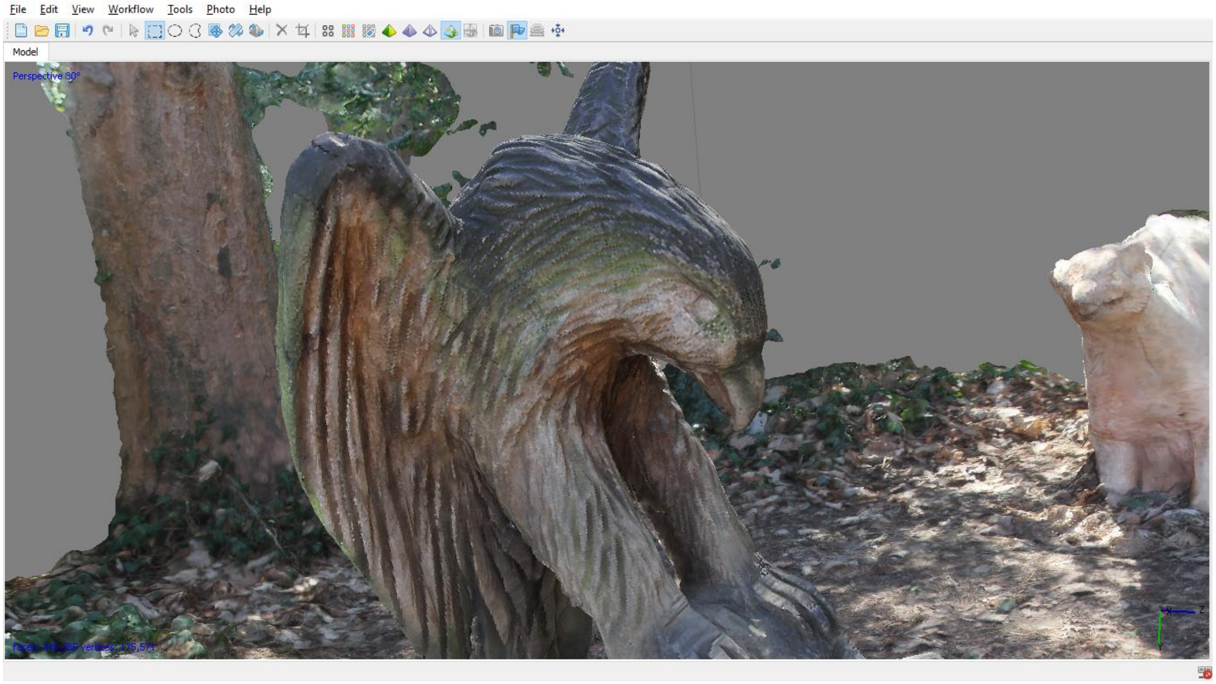

Figure 4.20: Eagle2, PhotoScan

After verifying that the model is good, we proceed to verify if all the images where aligned with the pseudo report that we have, its shown in Figure 4.21.

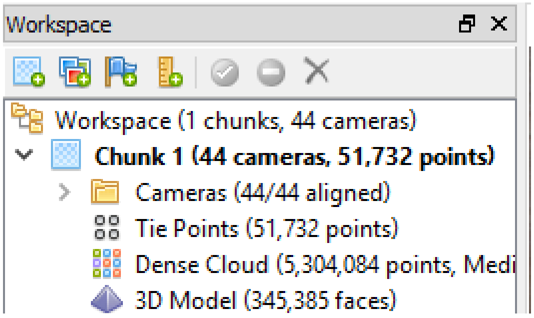

Figure 4.21: Pseudo report eagle, PhotoScan

4.3.2 DJI House

This data set was downloaded from Pix4D [39].

The pictures where taken with a DJI phantom 2 vision plus drone that has a 14 megapixel RGB camera.

Is a house and the pictures were acquired using a DJI phantom 2 by doing two round flights around the house at different altitudes and angles.

The process of the completion of the data set is not worth showing since each step of the procedure was shown before, the comparison will be made between the final result and the quality report.

Since this example is just a house, there is no need of orthomosaic nor NDVI map.

4.3.2.1 Pix4D

After completing the process in 37 minutes and 10 seconds the final model is shown in Figure 4.22.

Figure 4.22: DJI house 1, Pix4D

In Figure 4.23 another perspective of the model can be seen.

Figure 4.23: DJI house 2, Pix4D

In both Figure 4.22 and Figure 4.23 is possible to see that the result is amazing, the model is really good and the applied texture is perfect, now the small quality check should be analyzed in order to verify this, in Figure 4.24 the quality check.

Quality Check

Images	median of 11543 keypoints per image	
Dataset	71 out of 71 images calibrated (100%),all images enabled	
Camera Optimization	0.02% relative difference between initial and optimized internal camera parameters	
Matching	median of 3170.29 matches per calibrated image	
Georeferencing	yes, no 3D GCP	

Figure 4.24: Quality check DJI house, Pix4D

As seen in the quality check all the images where calibrated and all the important points are with the green checkmark which state that are in perfect conditions, the georeferencing is with a warning mark since in this project the where no ground control points and Pix4D recommend the use of GCD in every project for better results, but does not mean there's any problem with the model.

4.3.2.2 PhotoScan

After doing all the steps for creating the model, and as stated before there's no way to know how much time it takes to process everything, in the Figure 4.25 the final model is shown.

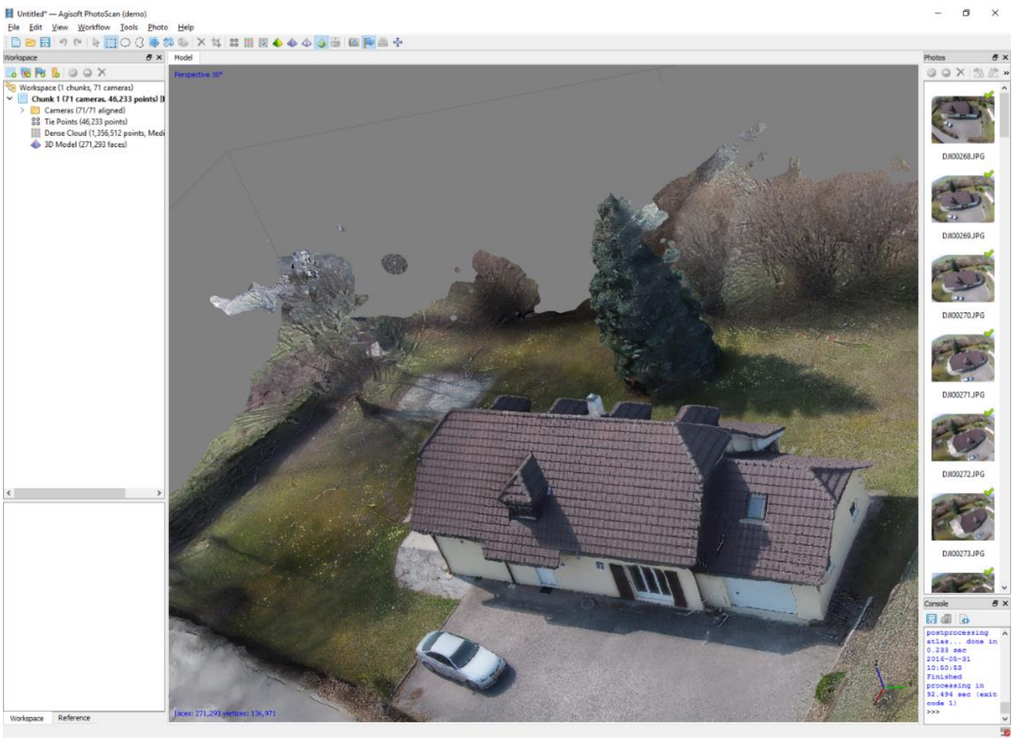

Figure 4.25: DJI house 1, PhotoScan

In Figure 4.26 the house is shown with a different perspective.

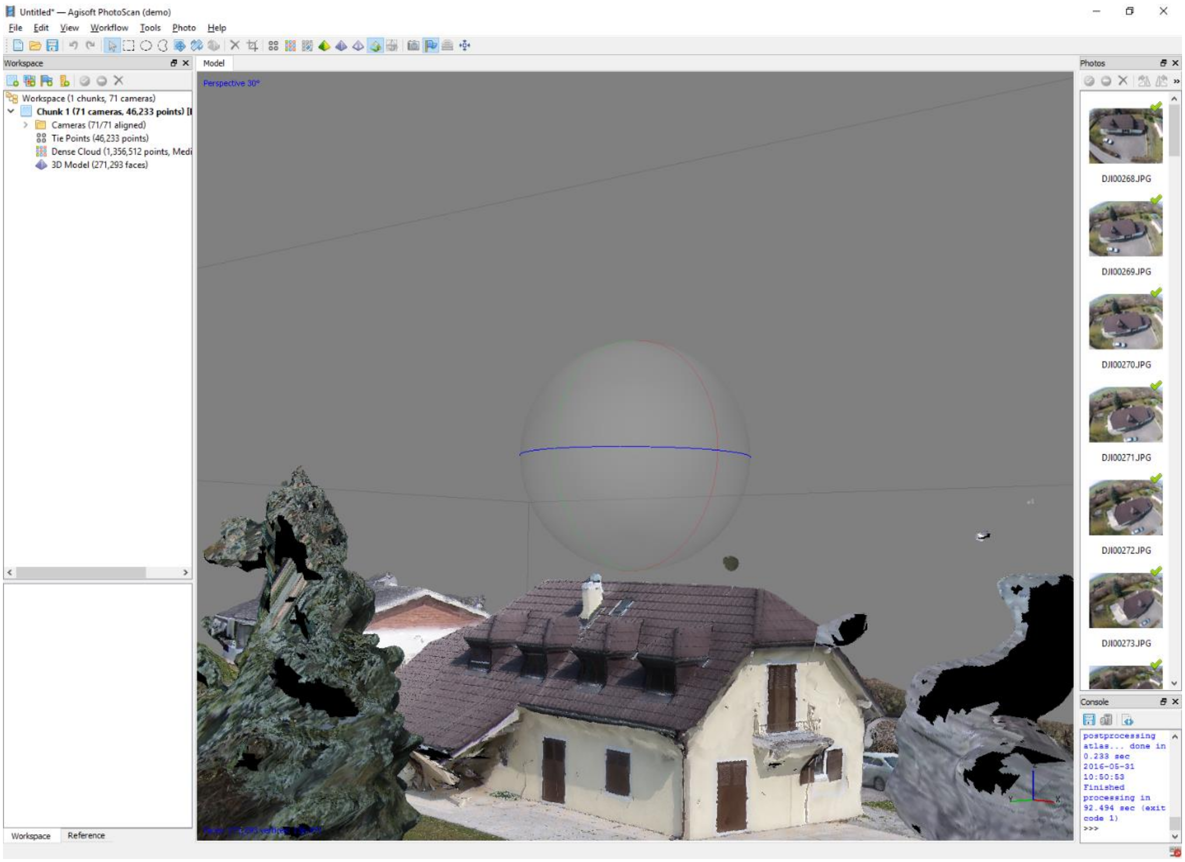

Figure 4.26: DJI house 2, PhotoScan

After seeing the Figures 4.25 and 4.26 it's evident that the results are really good but in comparison with the ones obtained with Pix4D they are a little bit below. In Figure 4.27 the pseudo report is shown in order to verify if all the images where aligned correctly.

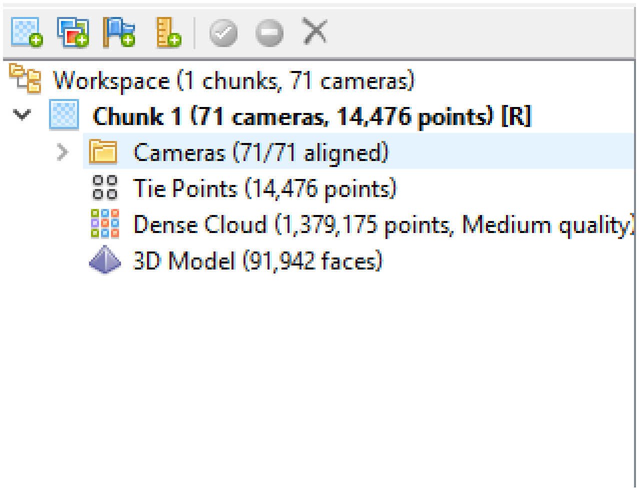

Figure 4.27: Pseudo report DJI house, Photocan

As seen in the so called pseudo report all the cameras where aligned but as commented before the result is not as well as the Pix4D one, the GPS signal is not helping the final result, this model is acceptable but the best result is always selected.

4.3.3 Comparison

Both Software are really good, getting amazing results in almost every case, but just one should be selected.

When creating 3D models of an object the 2 programs get similar resolution and quality, but PhotoScan have an advantage since does not have problem when the images are not geolocated. Pix4D can handle it but not getting the same results.

When creating a map, which means orthomosaic, DSM and 3D model, Pix4D stand out because it gets outstanding results, and also allows the user to get more outputs like de NDVI map.

Pix4D is a lot more automatic than the PhotoScan and more user friendly.

When taking measurements in PhotoScan a lot of work should be done, with a quite difficult interface. Pix4D make this task really simple, just one click and does not require to eliminate all the model and just leave the desired area to measure.

Although both software are great, the final decision for using in this project is the Pix4D not just because all the previously mentioned but also it is created specifically for drones having also a flight planner software for mobile devices, used for flying the drone. In the next chapter this will be explained more deeply.

5 Flight Planning

The flight planning is the most important part of the process, firstly because the objective is to do an autonomous flight that covers all the desired terrain in an efficient and low consuming way and secondly because the image acquisition must be stable, meaning that all the images should be capture at the same height, with the same time interval between them and with the geographic position tagged in them.

5.1 Before starting

There are some aspects that should be considered before flying the drone, of this considerations depend the quality of the images and the model because it’s different taking a picture at 70m than at 150m and also the amount of pictures in a certain space because, as stated before, the software find equal points between each picture and if it found more tie points better the model.

First of all the decision required for the planning is the angle of the camera, in order to make a correct decision the usage of both types should be explained:

- Nadir: The Nadir type is when the camera is positioned perpendicular to the trajectory, this means with a 90° angle, and the trajectory is a grid above the terrain. This type of camera positioning is used when a mapping is desired, for example an agriculture field, a construction site or just a city mapping.
- Oblique: The oblique type is when the camera is positioned at a certain angle different than 90°, the trajectory is circular or cylindrical around the object or structure. This type is used when recreating structures or objects in 3D, normally more than one circle is done with different altitudes and camera angles.

5.1.1 Nadir Flight

As explained before the nadir flight is dedicated mostly for mapping terrains, depending of the terrain and the kind of images the user wants to get different path plans can be selected. The most general and basic way is taking the images in a regular grid pattern like shown in Figure 5.1.

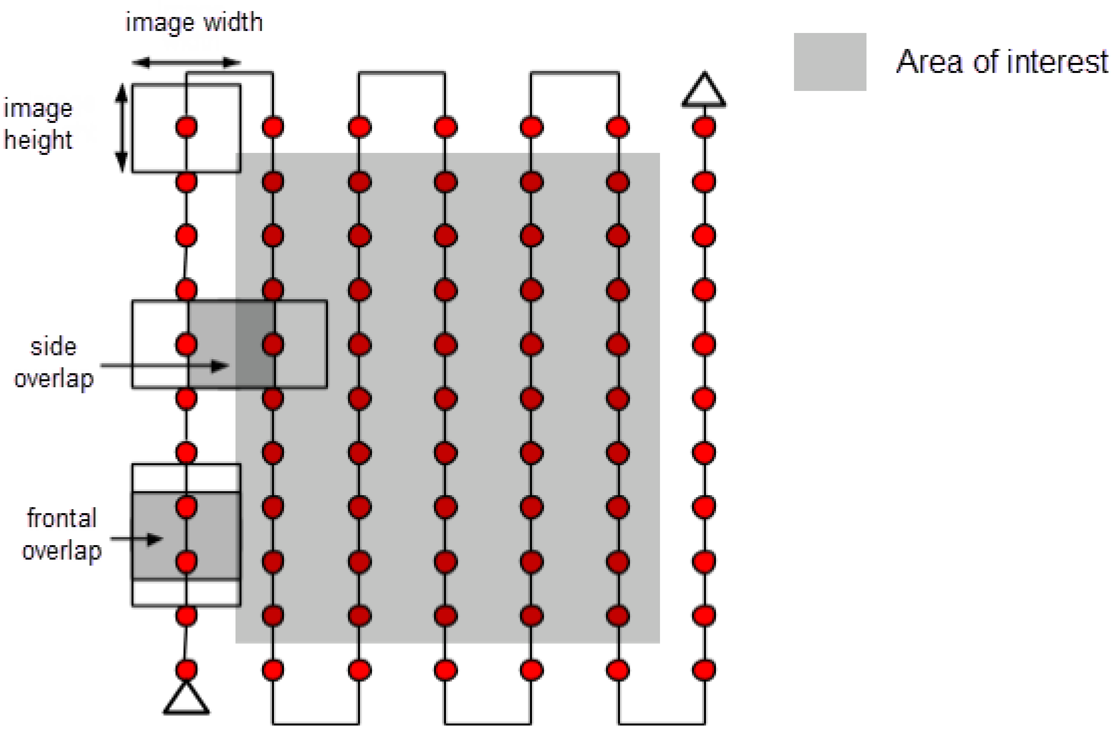

Figure 5.1: Nadir flight general way

As seen in the picture all the images are homogenously taken in order to get the desired overlap, and also is important to maintain the same height of the camera during all the flight in order to get the desired GSD (Ground Sampling Distance).

If the terrain is huge and one battery of the drone is not enough for doing it all, two flight plans should be done but always remembering to maintain a good overlap between the 2 flight plans because if this overlap is low there would not be enough tie point to correlate both data sets, in Figure 5.2 is shown how should it be done.

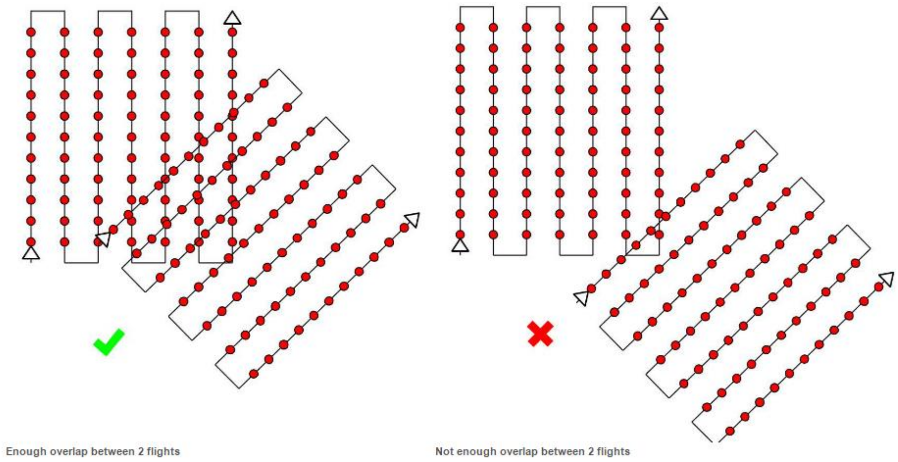

Figure 5.2: Good overlaping between 2 flight plans

In order to get a good distribution of the pictures and a homogeneous flight altitude is better to use a flight planning software than flying manually since the software allows to be precise and is responsible of the correct flight and picture capturing.

The nadir flight require a frontal overlap of around 85% and a side overlap of around 60% for getting acceptable results.

5.1.2 Oblique Flight

As stated previously the oblique flight is use for structures and object modelling, depending on the type of structure a different kind of flight plan should be done.

In order to model a building or a similar construction 2 or more round flights should be done, first a flight at about the height of the building with a 45 degrees camera angle, and he next flight should increase height and camera angle. In Figure 5.3 an example of how to do the flight is shown.

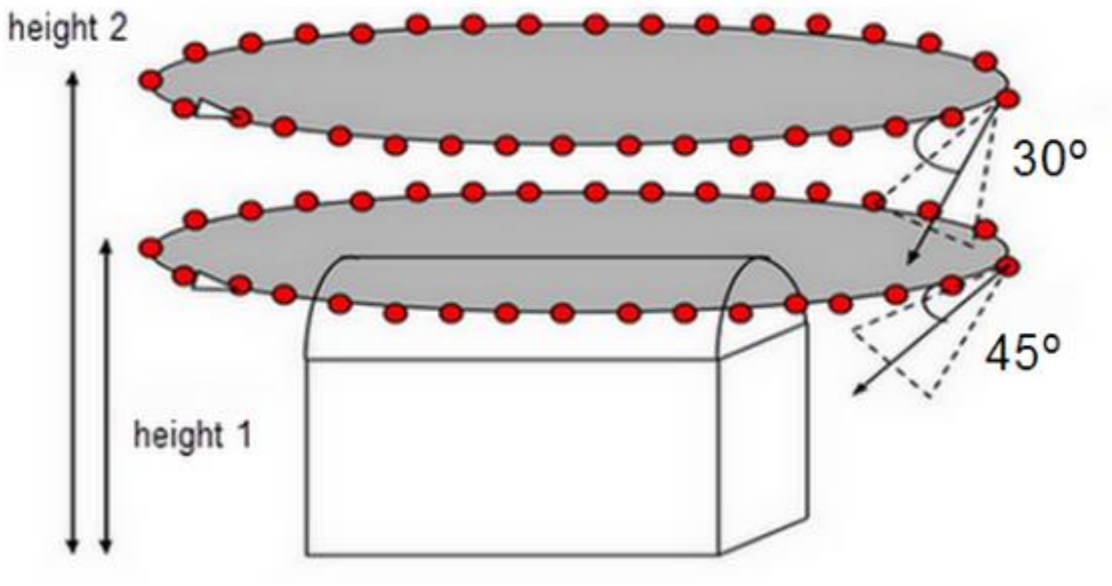

Figure 5.3: Building reconstruction

The angle in the Figure 5.3 is measured in a different way, saying that the perpendicular value is 0 degrees but commonly this is the 90° measure. This round trips can be done as many times at desired and also can be combined with a nadir flight of the terrain in order to get a high resolution and great detail in the final reconstruction.

Another case in which the oblique flight is required is when the desired model is a city with all the detailed facades, in this case the flight plan is similar to the nadir's one but

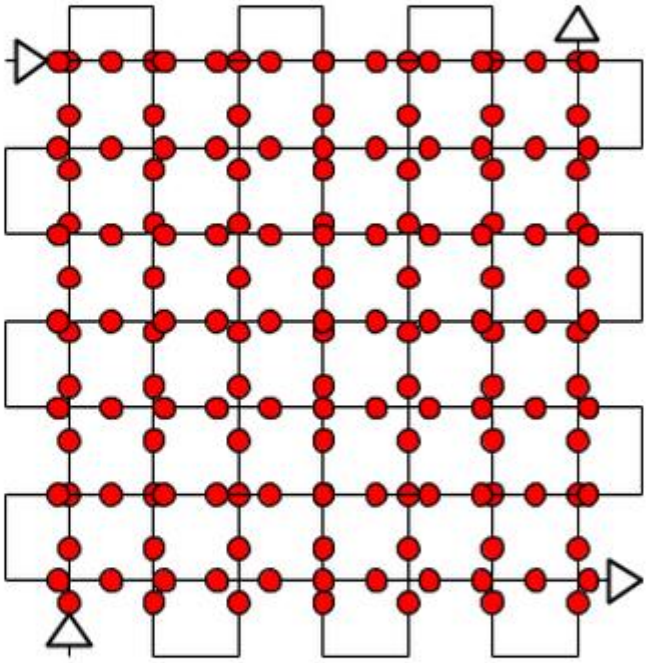

Figure 5.4: Oblique reconstruction of a city

with a double grid to get all the possible sides of each construction, in Figure 5.4 the flight plan is shown.

In order to get a well reconstructed facades the angle of the camera should be between 80° and 55°, this guarantee the complete model and detailed facades.

This model can be complemented with a nadir trip to get an extra detail of the city. [40] [41].

All the oblique models should be done at least 90% is recommended to get a good resolution model.

5.1.3 Flight Planning and Quality

The quality of the images and the final model depends directly on the flight planning as stated before but in a deeper way it depends on the altitude of the flight and the focal length of the lens, this two values and another characteristic values of the camera are the managers of the ground sampling distance (GSD), that is the value that represent the quality of a model is normally expressed in centimeters per pixel and means the amount of centimeters that are in one pixel so in simple words it measure the amount of zoom that can be done before pixelating the image. This relation exist since, as stated before, the focal length manage the size of each picture at a specific distance, in this case the altitude.

5.1.4 Normativity

The drone usage is highly regulated around the world but each country has different normativity, this is an important aspect before starting the flight since the sanctions for the one that break the rules are very high and strict. Since this thesis is going to be applied in Italy a brief explanation of the ENAC (ente nazionale per l'aviazione civile, the national entity of the civil aviation) rules for drones written in the **Regolamento "Mezzi Aerei a Pilotaggio Remoto"** explaining what to do in order to do a legal flight.

This regulation difference the RPAS (Remotely Piloted Aircraft Systems) and aeromodells stating that the aeromodells are designed and used just for hobby and sport and the RPAS are intended to work in specific or scientific operations, in a few words are intended for work.

The ENAC is responsible of the RPAS with an operational takeoff mass not greater than 150kg and all those designed or modified for research, experiment or scientific purpose which take place within the Italian airspace.

This RPAS are classified by the ENAC based on the operational takeoff mass:

- RPAS with takeoff mass less or equal to 0.3kg: the pilot do not require any permit to fly the drone but should guarantee that the operations are done according to the flying rules.
- RPAS with takeoff mass less or equal to 2kg: are considered non critic operations in all the possible scenarios so the asked certifications are really easy and quick.
- RPAS with takeoff mass less or equal to 25kg: are considered mid critic operations, would require the permits.
- RPAS with takeoff mass between 25kg and 150kg: are considered critic since they have a high weight and may be harmful.

The classification of each RPAS has been shown but that's not the only thing that concern the ENAC, the type of operation is the real point of this regulation, there are 3 types of operation VLOS, EVLOS and BVLOS:

- VLOS (Visual Line of Sight): Are operations conducted within a distance, both horizontal and vertical, in which the remote pilot is able to maintain continuous visual contact with the aircraft, without the help of any instrument that enhance the view, like a binocular as shown in Figure 5.5.
  All the VLOS operations should be done during daytime, at a maximum distance of 500m from the pilot and a maximum height of 150 m. For operations with superior heights and distances is necessary to obtain a specific authorization from the ENAC. If the flight is in a place less than 15km away from an airport the maximum flight altitude is reduced to 30m.

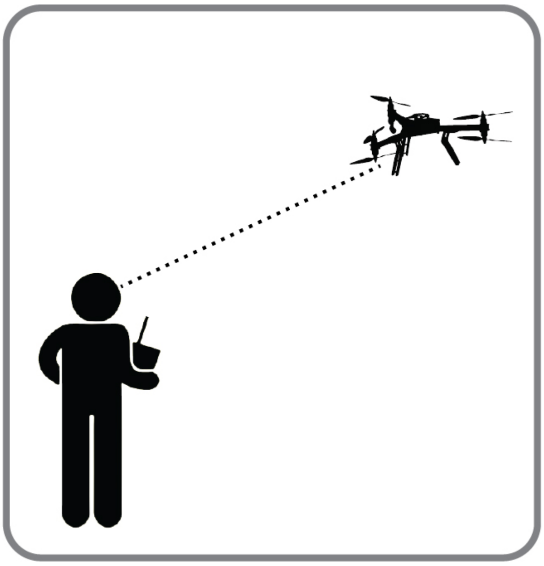

Figure 5.5: VLOS Operation

- EVLOS (Extended Visual Line Of Sight): Are operations conducted in an area that exceed the limit conditions of the VLOS conditions and that why this category was created, to create alternative methods to satisfy the VLOS conditions.
  As in VLOS the drone should be within the line of sight but in this case this line of sight don't necessarily had to be from the pilot, he can have some observers,

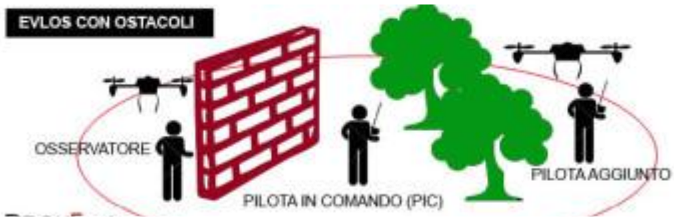

Figure 5.6: EVLOS with obstacles

that should be able to control the aircraft in case of any problem. Two cases in which this can be used are, in a small area with obstruction of the view like shown in Figure 5.6 or extending the field of view along a large terrain as can be seen in Figure 5.7.

The Figure 5.6 show a small area that has 2 obstructions of sight, a wall and some trees, that's why there are two extra pilots and observers, in case there's any problem during the blind spots of the pilot.

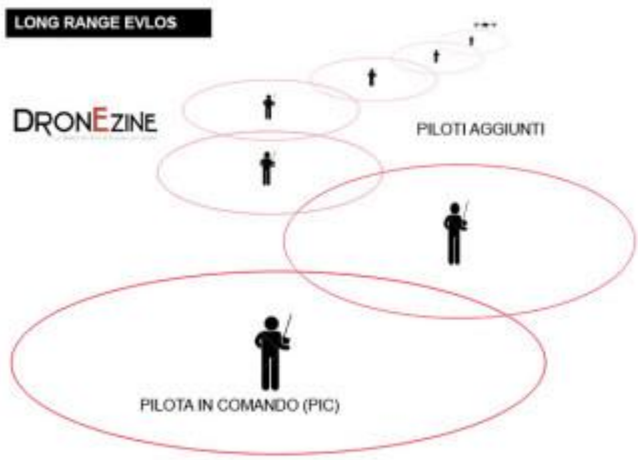

Figure 5.7: EVLOS long range

In Figure 5.7 many pilots (observers) are aligned creating an extension of the range of view, at least one pilot is observing the drone at all moments along the flight.
This operations can be conducted only with the specific approval of the ENAC, although in itself it's not necessarily a critical operation. The flight area is the same as for VLOS operations, then 150 meters of altitude and 500 meters of radius, limits that if authorized can be exceeded. In theory is possible to flight all along Italy with one drone in EVLOS operation, is just needed a sufficient number of observers along al the flight. It's important to say that the EVLOS operations require a strict coordination between the pilot and the observers.

- BVLOS (Beyond Visual Line Of Sight): Are operations conducted in a distance that doesn't allow the pilot to maintain a constant and direct sight of the aircraft, not allowing him to manage the flight avoiding collisions and risky situations.

The BLOS operations need systems and procedures for maintaining separation and collision avoidance that require approval by the ENAC, and can be conducted in segregate areas and should be approved case by case.

As stated before this is just a brief explanation of the normativity of the ENAC related to RPAS, before doing any flight is better to check the **Regolamento "Mezzi Aerei a Pilotaggio Remoto”** to check updates and possible changes, if the flight is going to be done outside Italy is important to check the local legislation in order to avoid sanctions and problems. [42].

5.2 Flight planning Software

The development of flight planning software is in a huge growth in this moment, some of them are open source other not. In order to decide which is the most useful flight planning for each project is important to know 2 things, what is going to be the drone for the flight and how do the flight is going to be performed since not all of the software allow every drone and some just allow the user to do predefined shapes of flight (normally just a square area). Here some flight planners are going to be introduced explaining their characteristics and advantages/ disadvantages.

5.2.1 Pix4D Capture

This software is created by the homonym photogrammetry software, Pix4D, this is an advantage since all the images have the perfect format and conditions for the Pix4D mapper pro and the software will recognize them easily with the correct geolocation.

The Pix4D is just suitable to some drones:

- From the DJI family:

  - Phantom 4

  - Inspire 1

  - Phantom 3 professional

  - Phantom 3 advanced

  - Matrice 100

- From the parrot:

- Bebop 2

This is a free app for android and IOS.

The biggest disadvantage is the shape of the flight, allowing just square areas to flight for the DJI family and also a circular mission for the bebop 2, this means that if the user need to flight through an irregular area, has 2 choices or do a bigger square area having some useless pictures or doing 2 different flights to reach all the desired terrain.

In the Figure 5.8 the logo of the app is shown.

Figure 5.8: Pix4D capture

5.2.2 Mission Planner

This software is created by the ardupilot developer ecosystem, more specific Michel Oborne, Is an open source software in constant update. The flight plan is really stable and reliable with a huge amount of options and customization.

The mission planner software allows almost all the open source flight controllers like the pix hawk and the ArdupilotMega (APM), this flight controllers are created for developers and enthusiast that decide to create or build their own drone.

One of the biggest problems of this software is that is only available for windows computers, not mobile devices, which may be a difficulty since the flight are normally made outside and the user should carry the computer. Ardupilot has a solution for this problem and is the offline flight planner that allows the user to upload the map and the flight instructions to the drone at home so the ground control station can be just the radio controller.

The great thing about this software is that allow the user to create any shape for the area which is of huge help because, as stated before, not all the cases require a square area to be covered, some are of different shape.

In Figure 5.9 the logo of the software is shown.

Figure 5.9:Mission Planner

5.2.3 Map Pilot for DJI

This software was made by the company Drones made easy which is an online store for drones and components.

Beside the app Drones made easy has a cloud service for processing the images with high resolution, this is helpful for a user that doesn't have a good computer but want to process the images with high resolution in low time, it's not obligatory to use this service when using the app.

The Map Pilot for DJI app as the name stated just work with DJI drone:

- Phantom 4
- Phantom 3 professional
- Phantom 3 standard
- Phantom 3 Advanced
- Inspire 1
- Inspire 1 Pro
- Matrice 100

- Matrice 600

This app is not free, it cost $9,99 and is just available in IOS.

This software has a huge amount of information and tutorials which is good for new users, one of the biggest advantages is the area of interest, and it can be of any shape as the Map Planner. The real disadvantage is the cost of the app and the fact that it just works with DJI drones. In Figure 5.10 the logo of the app is shown.

Figure 5.10: Map Pilot for DJI

5.2.4 Tower

The tower app is made by the company 3DR which is one of the biggest drone companies in the world, this app is the successor of the well know Droid Planner and Droid Planner 2, it is an open source app that allow all the users to modify the code and use it in commercial flights but under a free to all license.

Primary the app is designed for the 3DR drones but allow a huge amount of drones that is in constant growth by the developer community, most of the open source flight controllers are also compatibles.

This is a free app just for android but 3DR says that they just guarantee full usage in the nexus family, so it’s a little bit constrained with that.

This software allows the shape to be of any form and has also some other features, not useful for this project but interesting, like the follow me ability.

In the Figure 5.11 the logo of the app is shown.

Figure 5.11: Tower

5.3 Usage of the flight planner

This part of the dissertation is reserved to do a small user guide of the two selected flight planner software, the Pix4D Capture and the Mission Planner, is just a small review to show the capability of the software.

5.3.1 Pix4D Capture

Pix4D Capture is a really intuitive and easy to use software, with a simple configuration method. When the software is open the first screen that can be seen is shown in Figure 5.12

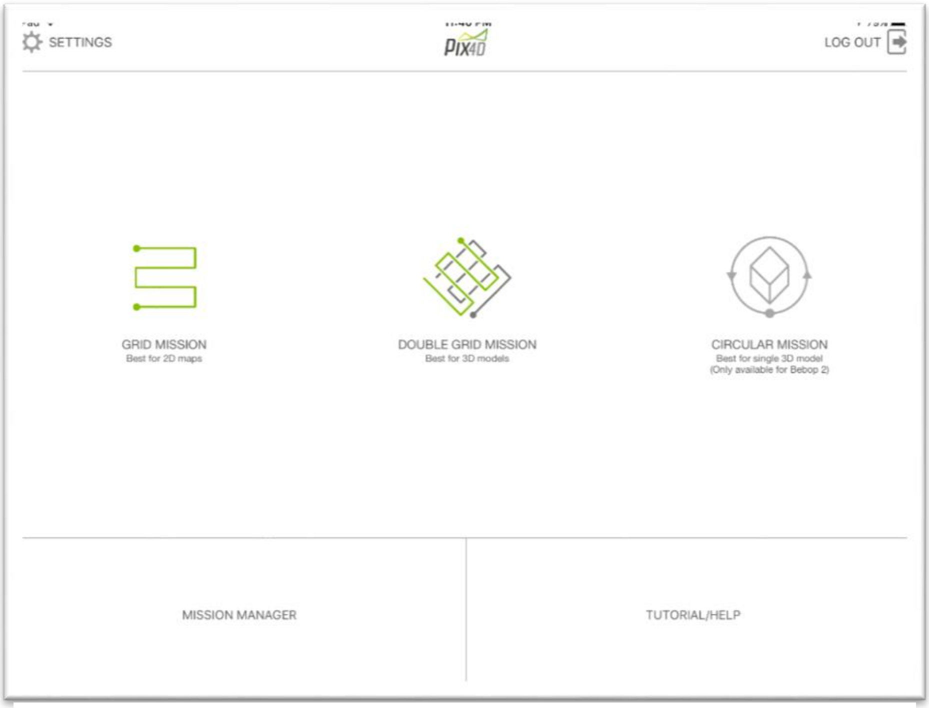

Figure 5.12: Pix4D Capture first screen

This screen allow the user to select the type of flight as explained in chapter 5.1, the grid mission for simple and general flight, the double grid mission for more precise 3D models and last the circular mission, which is only available for bebop 2 in this software, that allows the reconstruction of buildings and structures.

When clicking the setting button in the top left of the screen the options are the ones shown in Figure 5.13

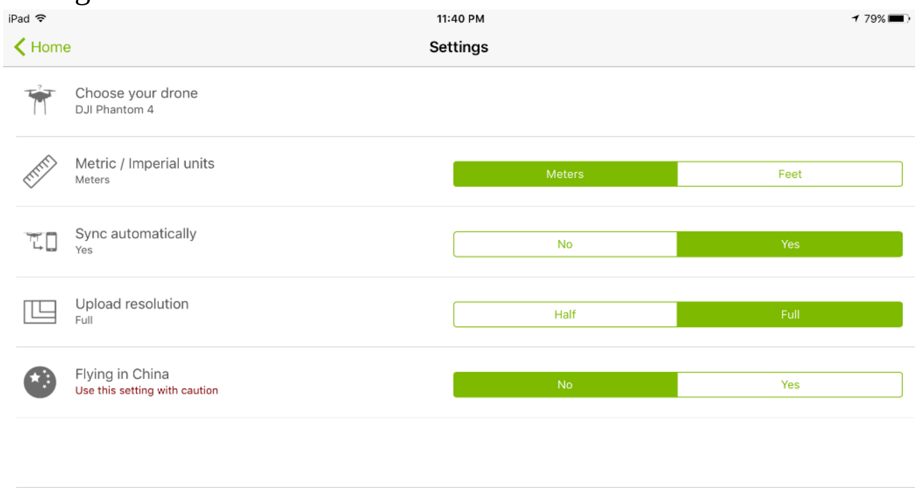

Figure 5.13: Pix4D Capture Settings

Version 1.4.0 (20)

In the Figure can be seen all the general settings of the software:

- Choose your drone: when clicking this option a new screen is displayed showing all the possible drones in order to select the one that's going to be used, in Figure 5.14 this screen is shown.

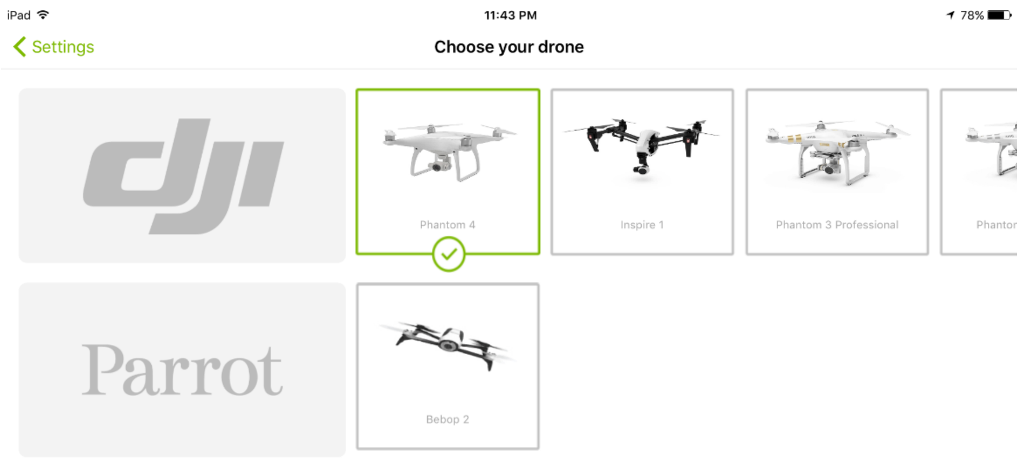

Figure 5.14: Pix4D capture drone selection

The page can be scrolled to see all the possibilities of the DJI family.

- Metric / Imperial units: There are just two options here, meters or feet, is just the units to be used during the flight plan.
- Sync automatically: Defines whether the mission is synchronized right after the flight (yes) or manually by the user later (no).
- Upload resolution: Defines the resolution of the images to upload and process on the cloud
- Flying in china: Improves the geolocation of images if flying in China only (yes), otherwise it should not be activated.

After selecting all the desired settings the user should press home and go back to the original screen, then the desired flight should be selected, for this example a single grid will be shown, in Figure 5.15 this screen can be seen.

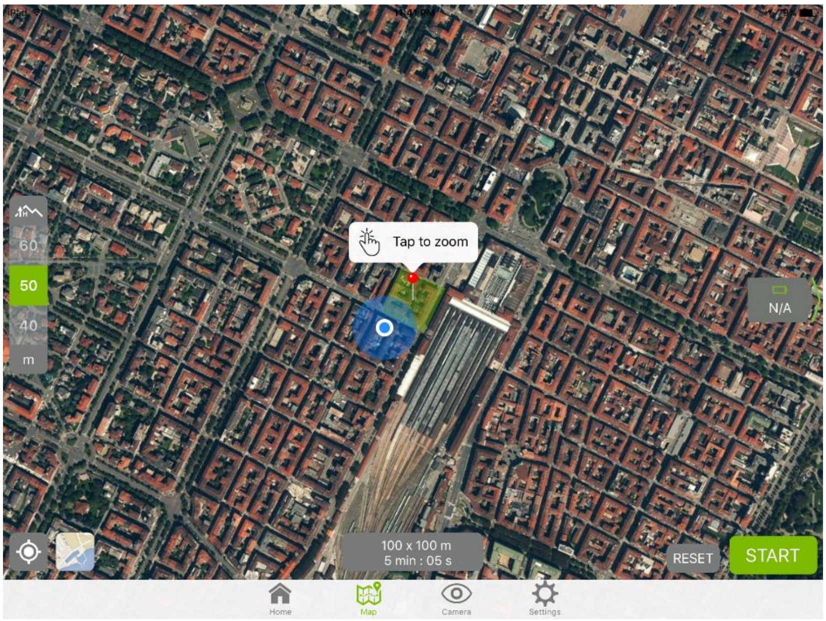

Figure 5.15: Pix4D Capture single grid 1

This is the map view of the flight planner, it shows the current location of the device and it can be seen in the center of the image a note asking to tap to zoom, after doing that the map will zoom in, the result will be shown in Figure 5.16

Figure 5.16: Pix4D capture single grid 2

The green square in the Figure represent the area to be scanned, and the white lines inside it show the flight of the drone, this square can be rotated, translated and resized. At the left of the screen it is possible to change the flight altitude, this will automatically change the flight trajectory and the time of flight that can be seen in the bottom of the screen. In Figure 5.17 a different altitude flight is shown.

Figure 5.17: Pix4D Capture single grid different altitude

As seen there are more trajectories with less altitude and the flight time augmented from 4 minutes and 26 seconds to 5 minutes and 5 seconds. At the bottom of the screen some options are exposed, the home button put the main screen of the app, the camera shows the real time view of the drone and the settings open a new configurations specific for the single grid flight, this screen is shown in Figure 5.18.

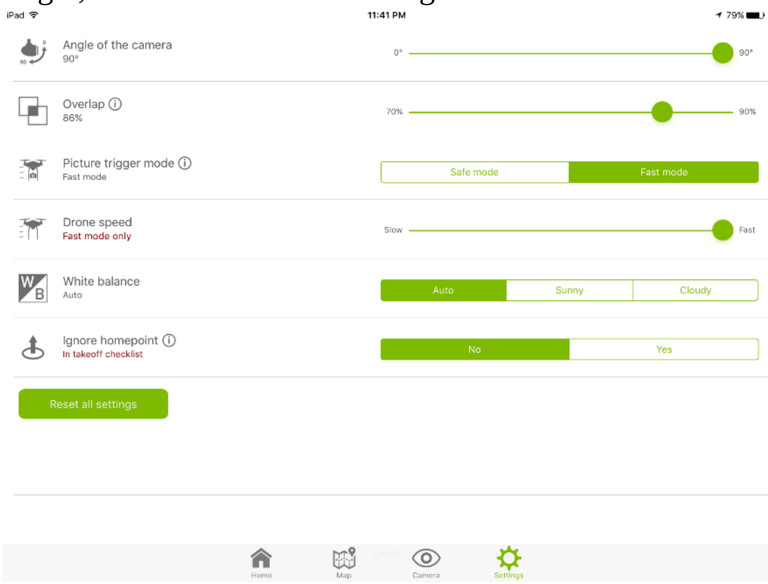

Figure 5.18: Pix4D Capture specific settings

In this screen there are 6 settings that can be modified:

- Angle of the camera: This setting allows the user to select 90° if the flight is going to be nadir or the desired angle if it’s going to be oblique, 0° means that the camera is pointing straight, in the same direction as the flight trajectory.
- Overlap: Defines the front overlap from a range between 70% and 90%. The side overlap is computed such that he side distance between 2 images is 2 times the distance between 2 images on the same flight line.
- Picture trigger mode: there are 2 options to select in this setting, safe mode and fast mode.
  - Safe mode: Drone will stop at each waypoint when taking images. If the drone-app connection is lost during flight, the application will continue to trigger image capture.
  - Fast mode: Drone will fly through waypoints while taking images. If the drone-app connection is lost during flight, the application will not continue to trigger image capture.
- Drone Speed: Defines the drone's speed from a range between *Slow* and *Fast* (default). Only applies to Fast mode. Slow means 60% of the maximum speed of the drone and fast is the maximum speed of the drone
- White balance: Selects between auto, sunny or cloudy depending on the light conditions of the terrain to be inspected.
- Ignore homepoint: Selects between no or yes to start the mission even if the homepoint is further than 150 meters from the grid's center.

After configuring all the settings the user should go back to the map screen and do click in the start button, the instruction show in Figure 5.19 show the manual configurations and recommendations before starting the flight.

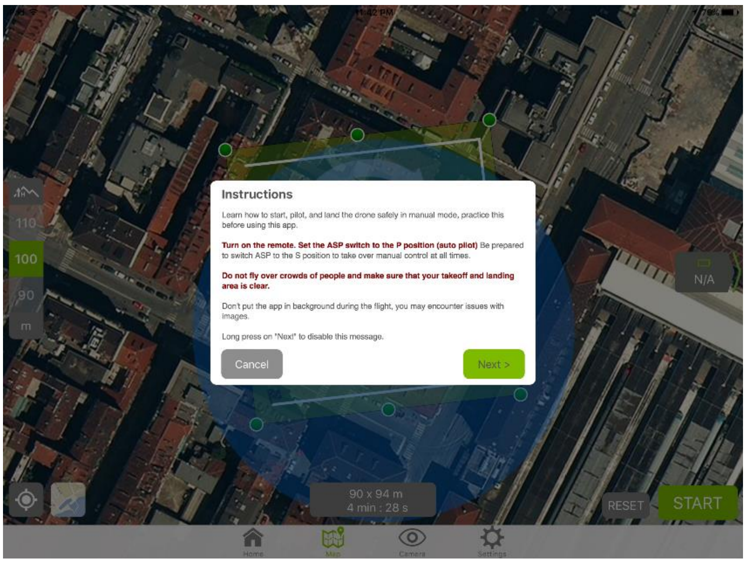

Figure 5.19: Pix4D Capture final instructions

The next step is just connection of the drone and flight. The process is quite intuitive and easy.

5.3.2 Mission Planner

Mission Planner is quite complex to use and configure since it is suitable for a huge amount of drones, luckily the software has a wizard that helps the user to configure the drone. When opening the software the first screen that's seen is the flight data, shown in Figure 5.20.

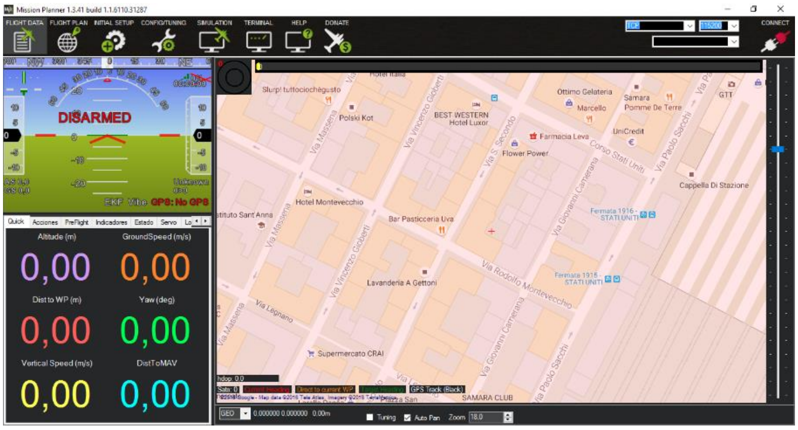

Figure 5.20: Mission Planner flight data screen

This screen shows the status of the drone and flight, but before watching this screen is important to configure the drone, so the first step is to click the initial setup button in the top. After clicking the button the screen shown in Figure 5.21 is shown.

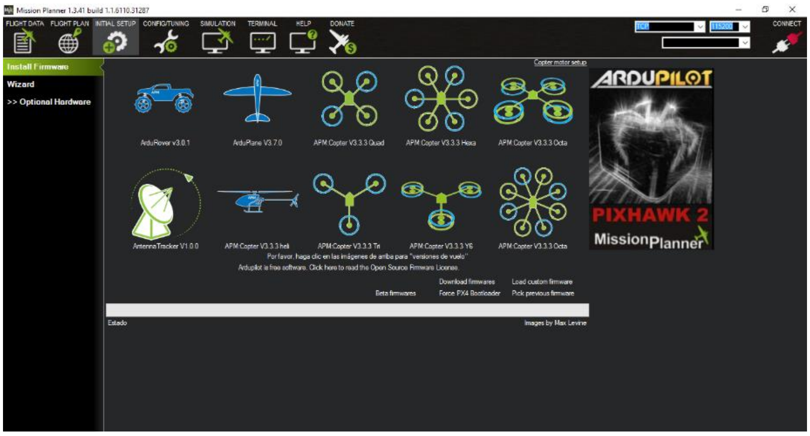

Figure 5.21: Mission Planner initial configuration

If the drone that is going to be used is in the list shown in Figure 5.21 there's no need of the wizard, if that's not the case the wizard button at left should be clicked and the window shown in Figure 5.22 will be displayed.

Figure 5.22: Mission Planner Wizard

After following all the instructions in the wizard, the drone will be ready and it's time to plan the flight. For this the button Flight plan should be clicked and the screen that will be displayed is shown in Figure 5.23.

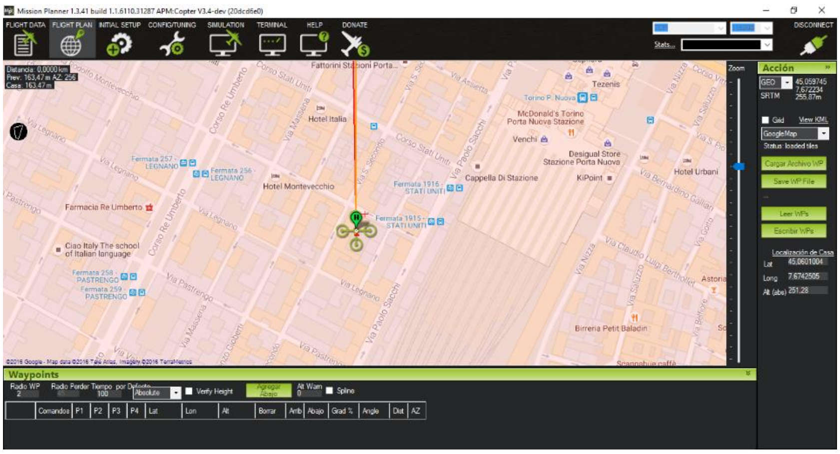

Figure 5.23: Mission Planner flight plan

In the figure the drone can be seen in the center of the map, from this point 2 possible actions can be done the first one is to put waypoints and the drone will follow all the way points, each waypoint is collocated using the left click of the mouse in the desire location, after putting all the waypoints the path will be shown, this can be seen in Figure 5.24.

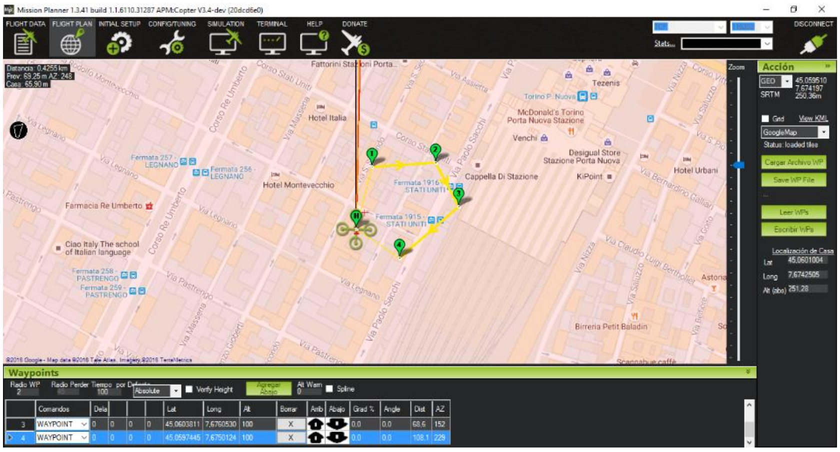

Figure 5.24: Mission Planner waypoint path

In the waypoint menu at the bottom of the screen all the set waypoints are shown and can be modify individually, the 2 modifiable parameters are altitude and commands, this second one is to set the takeoff and landing spots.

The second action that can be done is the drawing of a polygon in order to survey that specific area, just like in Pix4D Capture but can be of any shape. To do this the user have to do a right click and select Draw polygon and the add polygon point, in order to create the polygon the user should left click in every vertices of the desired polygon, in Figure 5.25 an example polygon is shown.

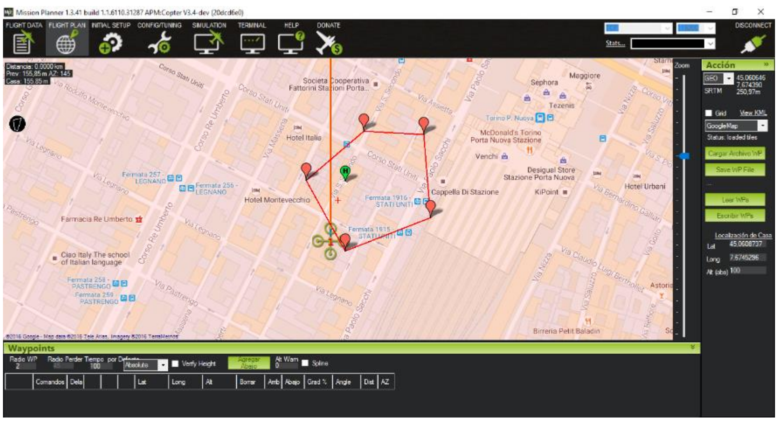

Figure 5.25: Mission Planner polygon creation

Each of the red marks is a desired vertices of the polygon, now in order to create the flight plan, a right click should be made and after this Auto WP and then survey (grid). When this is done the window in Figure 5.26 will be displayed.

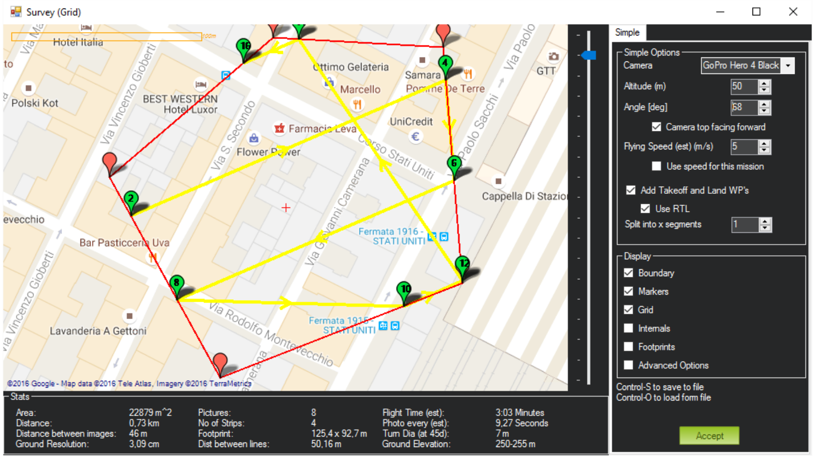

Figure 5.26: Mission Planner grid design

This window allow the user to modify the parameters of the flight and will generate automatically the path of the flight, in the bottom it’s possible to see all the aspects of the flight and the time that is going to consume, when all the aspects are selected as desired click the accept button and the flight plan will be uploaded to the previews screen, as seen in Figure 5.27.

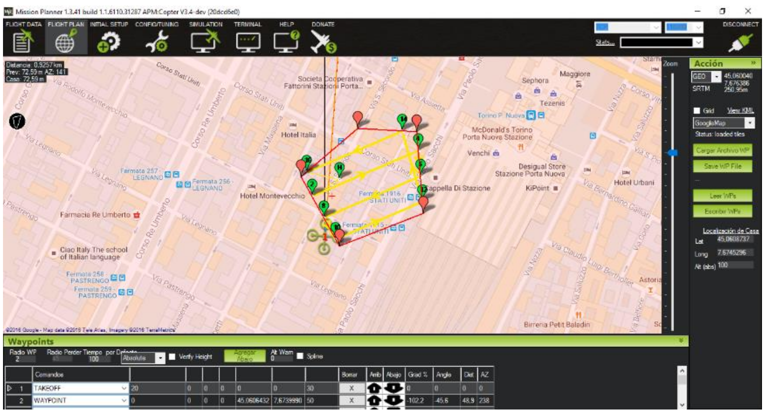

Figure 5.27: Mission Planner planned flight

The only thing that’s missing is to write this flight plan in the drone, which is made by clicking that option in the action menu in the right. When this is done just go to the flight data screen and start the drone with the left joystick of the controller and that’s it, the software will guide the drone by itself.

6 Tests and Results

In this chapter the tests made are going to be exposed with all the detailed results. There were 3 model studied, a quarry, a cadastre and the pedemontana venta highway. Each of this cases where reconstructed and modeled in 3D using the software Pix4D mapper pro, after modeled the orthomosaic is done for the correct geolocation in a google map, at the end some measurements of volume and distance are made in order to check the correct distances and the usage of this for measurement earthwork and stock piles. The last part of the chapter will do a relation with the construction site monitoring to fully understand its potential in the related matter.

6.1 Quarry

This data set was downloaded from Pix4D. [43]. The images where taken in Switzerland with the drone swinglet CAM of senseFly which has an RGB camera Canon IXUS 120IS with 12 mega pixels. During the flight 127 pictures where taken and 7 ground control points where stablished. After processing all the initial part the 3D model was get, the result is shown in Figure 6.1.

Figure 6.1: 3D model quarry 1

As can be seen the 3D model is outstanding, showing an amazing depth and texture, in the Figure 6.2 another angle of the model is shown in order to check the quality from another point of view.

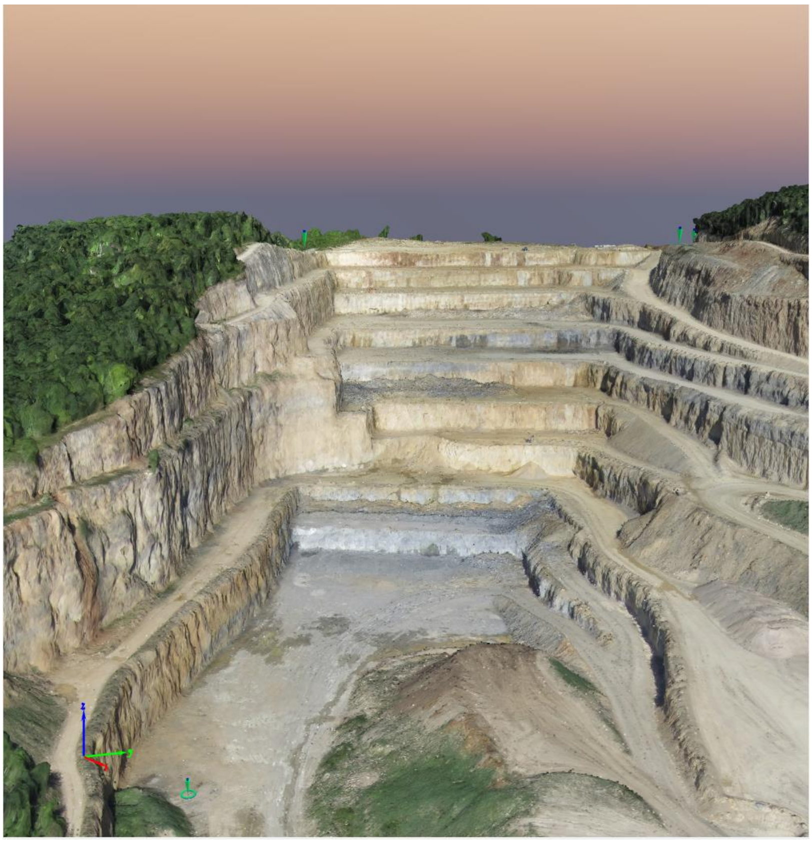

Figure 6.2: 3D model quarry 2

This second perspective of the quarry is in the inside of the hill, the elevation of each cut is perfectly recognized, and as stated before the texture is amazing.

With all the model finished its time to see the otrhomosaic, that , as stated before, is the 2D model of the quarry with all the images stitched together creating a perfect big image with accurate measurements. In Figure 6.3 this orthomosaic is shown.

Figure 6.3: Orthomosaic quarry

It’s possible to see that all the images where rectified and stitched correctly since the image seems like a single image, but when zooming in it can be seen the huge resolution that this image has, in Figure 6.4 a zoom in of the orthomosaic is shown.

Figure 6.4: Zoom in orthomosaic quarry

In the Figure 6.4 is shown a pile of tires that was not distinguishable in Figure 6.3, there it seems just like a black spot in the mid-right of the picture. The resolution is amazing, according to the quality report the average ground sampling distance is 8.83 cm per pixel, which means that one pixel represents 8.83 cm of the image, and this gives a great resolution for the desired work.

Another important output is the DSM (Digital Surface Model) that shows the elevation of the model in each point, being very useful for the designers and constructors since they can know the properties of the terrain. In Figure 6.5 this DSM is shown.

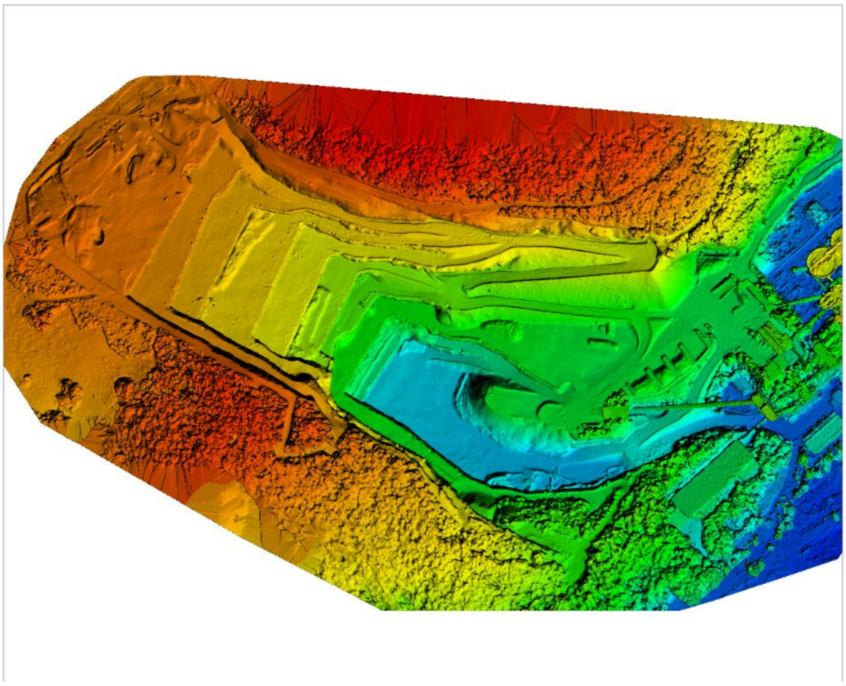

Figure 6.5: DSM of the quarry

This Figure shows the different elevations and useful information, but this should be complemented with the contour lines, for this case the Figure 6.6 will show the contour lines overlapping the orthomosaic for better understanding but if desired it is possible to see the contour lines alone.

Figure 6.6: Contour lines Quarry

With this contour lines the architect and constructor are able to know the exact elevation of each part of the terrain with a 10 meters step.

The next step is dedicated to acknowledge of the geographic position of the quarry, this is made by overlapping the orthomosaic to a google map to see where is located. In Figure 6.7 this overlapping is shown.

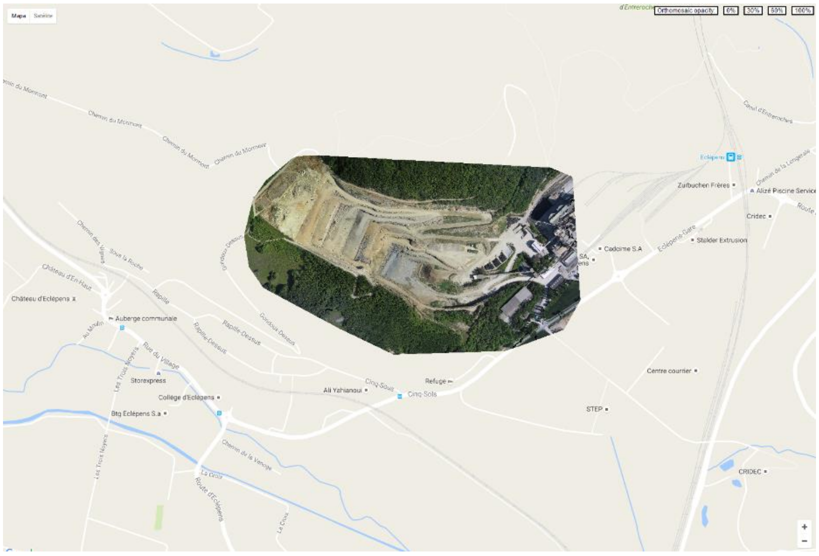

Figure 6.7: Geographic position quarry

Since this is a google map it is possible to zoom in and out to check and verify its location, and as shown in Figure 6.8 is also possible to recognize the image with the satellite map to see the surrounding and possible complications, It's also possible to change the opacity of the orthomosaic to compare it with the map structure.

Figure 6.8: Satellite map and orthomosaic quarry

The last part of the project after having everything recognized and knowing the different elevation and location is to do the desired measurements and analyzing them for getting a useful value for the construction or comparison with the original plan.

As explained in the Photogrammetry software chapter, Pix4D allows the user to measure distances, areas and volumes so that's going to be tested know, first the distance, in Figure 6.9

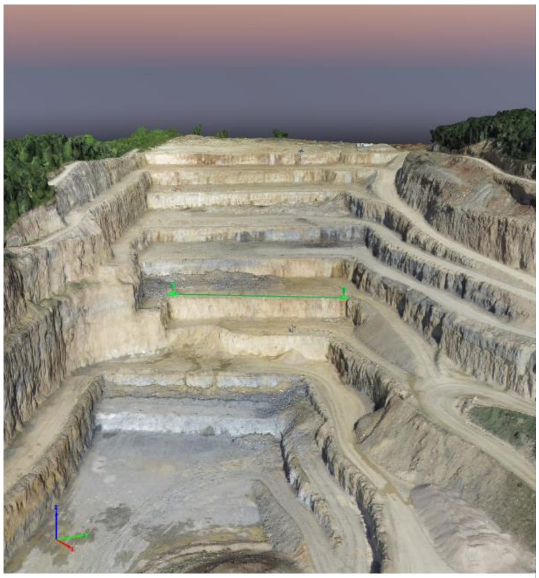

Figure 6.9: Measurement Quarry

The green line represents the desired measurement, this can be done in any place, and this was selected just as an example. In Figure 6.10 the result of the measurement is shown.

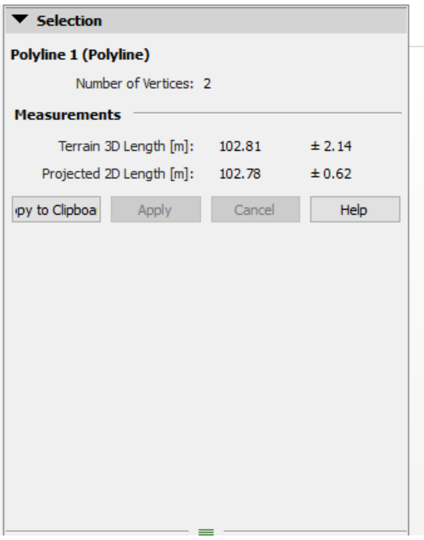

Figure 6.10: Measurement result Quarry

As it can be seen in Figure 6.10 the measurement is of 102.78 with a maximum error of plus or minus 0.62 meters, so the result is really amazing with a low error, as stated before, to minimize the error more pictures should be taken.

After having the distance measurement and compare it to the design the next step is to do an area measurement to check the same.

The area to be measured is shown in Figure 6.11.

Figure 6.11: Area measurement Quarry

The green selection is the area to be measured, is an empty space use to store materials, the resulted measurement is shown in Figure 6.12

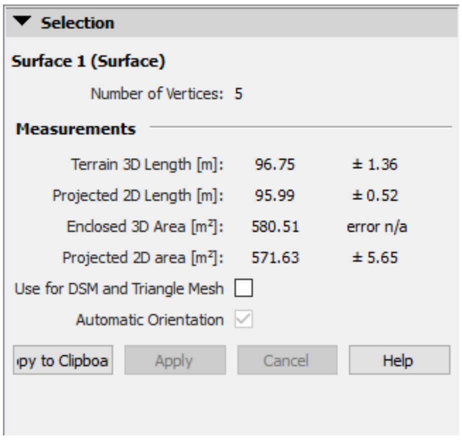

Figure 6.12: Area measurement result Quarry

In the Figure 6.12 it can be seen that the area is 571.63 square meters with an error of more or less 5.65 square meters, this is less than 1% off error which means the result is reliable and is of high quality, as before this value can be reduced taking more pictures.

The las output that can be measured is the volume, this is highly useful since the inventory and the stockpile can be measured and the constructor can know exactly how much material does he has and if he needs to order more.

In the Figure 6.13 a stockpile is measured.

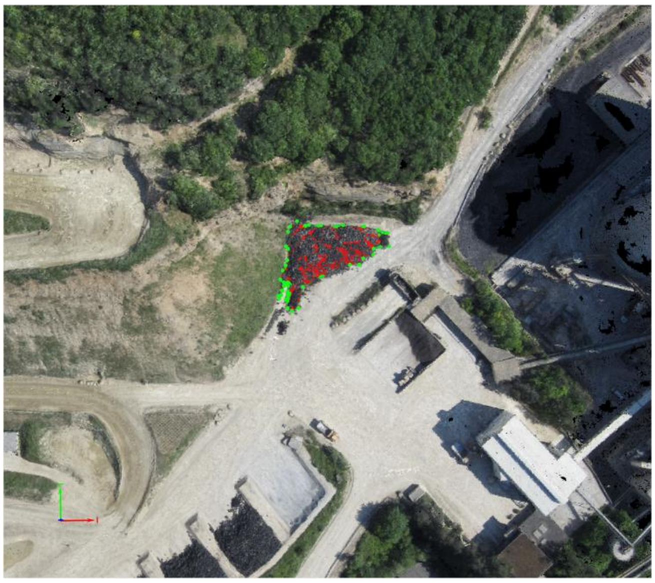
Figure 6.13: Volume measurement Quarry

The green-red area is a stockpile that should be measured in order to know if there is enough or if it's necessary to order more, the volume of this stockpile is shown in Figure 6.14

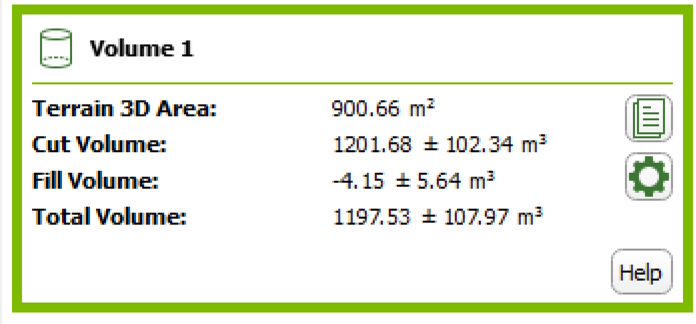

Figure 6.14:Area measurement result quarry

The measured volume is of 1197.53 cubic meters with an error of 107.97 cubic meters, it's a really good result that allow the constructor to make decisions related to this stockpile.

As seen in this example the outputs of the Pix4D mapper pro help vastly the construction company with all the desired models and results, all for simplify their lives.

6.2 Cadastre

This dataset was taken from Pix4D. [44]. The images where taken in Switzerland with the drone swinglet CAM of senseFly which has an RGB camera Canon IXUS 120IS with 12 mega pixels. During the flight 70 pictures where taken and 12 ground control points where stablished. After processing all the initial part the 3D model was get, the result is shown in Figure 6.15.

Figure 6.15: 3D model cadastre 1

It can be seen in the image that the reconstructed model is of high quality and allows to see all the structures in a perfect way, maybe it can be better if another flight was made with an oblique camera angle just to get a high detail of the facades of the constructions. In Figure 6.16 another angle of the model is shown.

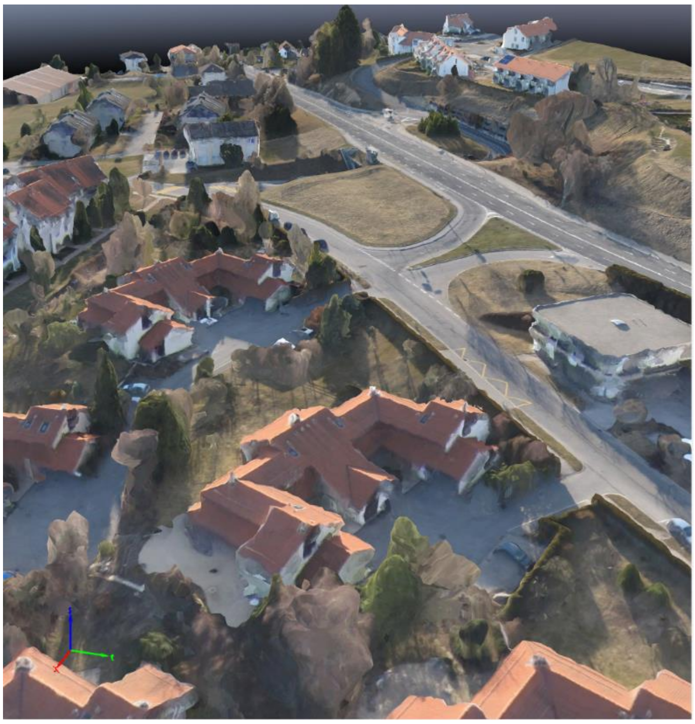

Figure 6.16: 3D model cadastre 2

As mentioned before, the model is quite good with the problem of the low resolution in the facades but the texture of the road and the grass is outstanding

With all the model finished its time to see the otrhomosaic, that, as stated before, is the 2D model of the cadastre with all the images stitched together creating a perfect big image with accurate measurements, this is the most important output for this case since the model is not as useful as the location of the houses and routes with the correct location and measurements. In Figure 6.17 this orthomosaic is shown.

Figure 6.17: Orthomosaic cadastre

In the Figure it is possible to appreciate the high quality orthomosaic, with all the detailed structure and the correct rectification of the images, but at this distance it's impossible to see the true quality of the output, in order to get a bigger understanding it is important to do a zoom at a certain point, in Figure 6.17 this zoom is shown.

Figure 6.18: Zoomed orthomosaic cadastre

The image shows the amazing resolution that this orthomosaic has, it's possible to see the detail in the roofs and in the cars, according to the quality report the average ground sampling distance is 5.1 cm per pixel, that is an amazing resolution since allows to see a full detail of things without getting distorted or pixelated images.

As in the quarry it's possible to get the DSM and the contour lines but for the purpose of this model is not useful since it's an already constructed are, the idea of this design is to detect the measurements of the houses and the correct geographical positioning, that's why the next step is to geolocate the orthomosaic in a google map. In Figure 6.19 the google map and orthomosaic overlap is shown.

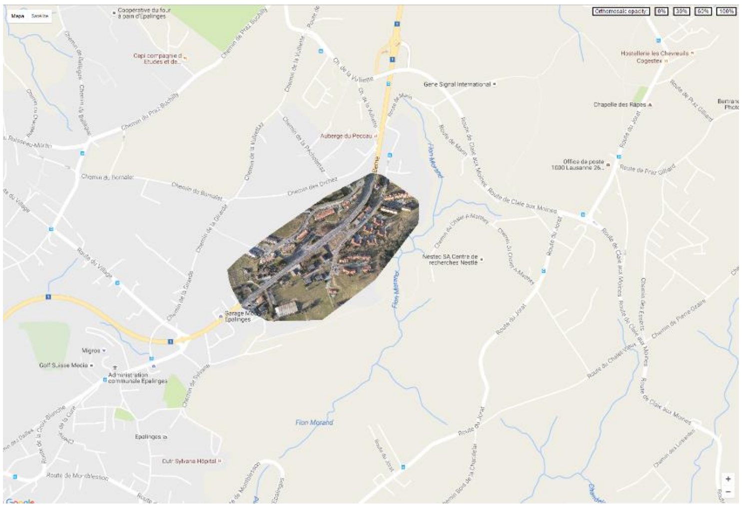

Figure 6.19: Google maps and orthomosaic cadastre

In the Figure can be observed that the road that crosses the village is totally aligned with road in google maps, this means that the orthomosaic was perfectly geolocated. As stated in the quarry sometimes it's useful to have the orthomosaic in top of a satellite map in order to understand the complete region and that's why in Figure 6.20 this is shown.

Figure 6.20: Satellite google maps and orthomosaic cadastre

The image has almost disappeared because of the high quality and perfect alignment of the orthomosaic, every single detail match perfect between the satellite image and the orthomosaic generated with Pix4D, this demonstrate that this method is reliable and accurate.

The next step is to do some measurements, in this case the volume data is not important and useless because, as stated before, this model is just used to know positioning and mapping, there's not stockpiles so the only measures that will be done are distance and area, that may be useful for the comparison with the design. In the Figure 6.21 the distance measured area will be shown.

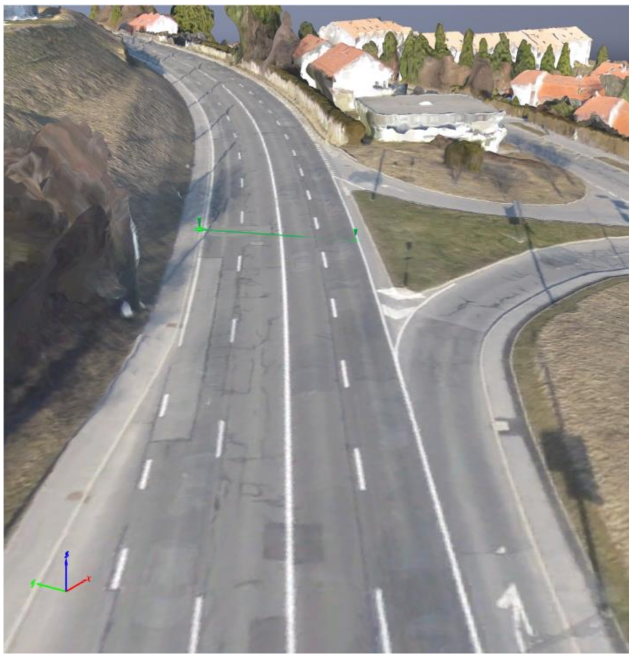

Figure 6.21: Measurement cadastre

The green line represents the distance to be measured, in this case a 4 lane highway, a highway lane width is about 3.1 to 3.2 meters so the four lane highway should measure between 12.4 and 12.8 meters, now to verify the real measurement it's possible to check the value in the Figure 6.22

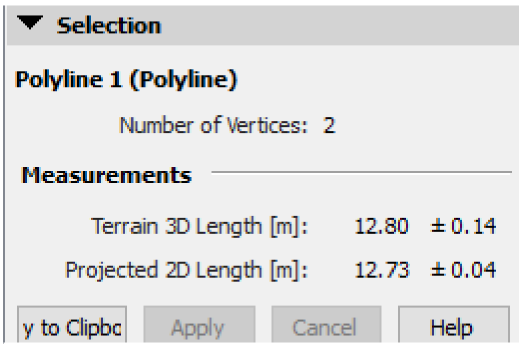

Figure 6.22: Measurement result cadastre

The measurement as seen in Figure 6.22 is of 12.73 meters with an error of plus or minus 0.04 meters, this according to a real value of a street is correct, and suitable, and so the distance measurement have been tested and approved.

The next challenge is the area measurement, in the Figure 6.23 the area to be measured is displayed.

Figure 6.23: Area measurement cadstre

The area to be measured is a parking lot space, normally this spaces measure 2.2 meters wide and 4.8 meters long which gives an area of 10.56 square meters, now to verify this value the figure 6.24 show the measurement of the model.

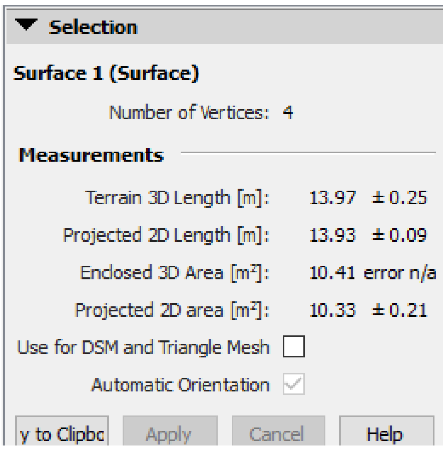

Figure 6.24: Area measurement result cadastre

The area of the measured parking space is of 10.33 square meters with an error of more or less 0.21 meters, which means the measured value fits in the real value so the test was approved and is possible to say that all the measurements with the Pix4D and a good dataset means amazing models with highly accurate measurements.

6.3 Highway

This test was developed in association with SIPAL S.p.A using the IDS drone IA-3 colibri, which has an RPG camera with 16 megapixels APS-C sensor and an 18mm f/2.8 lens.

The images where taken during the construction of the Pedemontana veneta highway build by the company INC S.p.A, an associated company of SIPAL S.p.A. This flight was made with oblique camera angle and is not taking pictures but high quality video, uses a different methodology with respect to the others since this was a test done before all the practice and theory developed during this dissertation, in Figure 6.25 one image of the video is shown just to check the quality of the vide and the way it was captured.

Figure 6.25: Image of the highway

The Figure shows the highway in its construction stage, the flight was done at an altitude of 39 meters with a speed of 4.2 meters per second. After doing all the flight and getting the video the next step is to create the 3D model in order to do the analysis of the as-build as-planned method. The 3D model of the highway is shown in Figure 6.26.

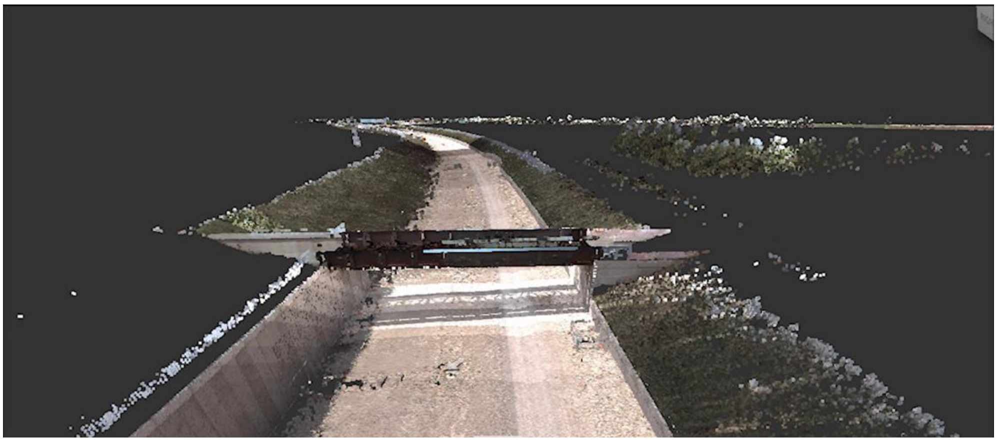

Figure 6.26: 3D model of the highway

It can be seen that the model is not perfect and the quality is nothing similar to the previous ones and that is because the resolution is always better when the model is made by pictures than the model made with video, although the quality is not perfect the model can be recognized perfectly and some measurements can be done with it, also as the construction company works with SIPAL S.p.A some notes about the design can be superimposed in the same model as shown in Figure 6.27.

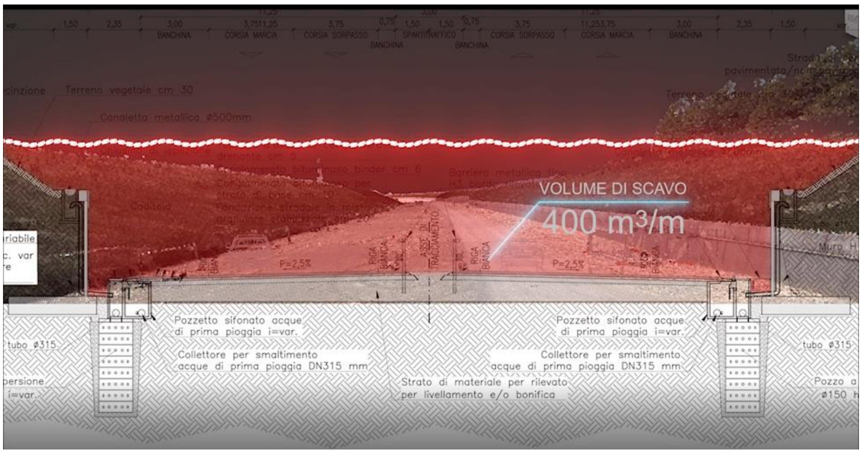

Figure 6.27: Data superimposed in the model, highway

All the read area shows where originally was ground and compare it to the excavation saying that there were 400 cubic meters of digging for the highway. In the lower part of the image a gray bar is shown, this are some notes related to the construction like the cockpit siphon for the storm water construction and some important data about the asphalt.

It can be seen that also with a mid-quality model a lot of data can be extracted, the advantage of this kind of model is the low processing times and resources consumption, if the desired output values does not need to be perfect this mid-quality model may be sufficient for doing the work.

6.4 Relation with Construction

After doing all the tests and analyzing them it is clear how all this can be related to the construction site monitoring.

First of all the 3D model allows to see in a real way how the process of the work is, one of the biggest advantage of this model is tan it can be opened in any 3D modelling software so the designer can do a superposition of the designed BIM with the actual structure to recognize the status and the possible errors, this is called as-plan as-build, it permits the designer and architecture check the actual status of the construction and do a direct comparison with the previously modeled. The new technics of modelling called 4D that have a time schedule connected directly to the 3D model so it’s possible to know in a certain amount of time, what should be the status of the construction. With this 2 tools the designer can see if the construction is on time or if something should be changed in order to adjust the time schedule.

Also another helpful tool is the digital surface model and the contour lines since the architect should know the morphology of the terrain in order to know if the terrain should be flattened or just to know how it is to work with it, the Pix4D also allows to import volume measurements so during the construction stage a previous measurement can be compared with the actual one and know the progress in the earthwork, which is useful to know how the excavation or fill in is and check the status of the work.

The orthomosaic is another really useful output since, as explained before, has real measurements and is just an image, so the designer can compare it directly to the construction plans, comparing plans in 2D is a quite easy task because all the lines in the plan should align with the lines in the real orthomosaic with can be helpful to analyze the as-plan as-build concept and to check if all the walls and columns are placed correctly and with the desired angle.

The last but not least useful output is the orthomosaic in google maps since this helps to analyze and check the surroundings of the construction site which allows to know the conditions of the soil and possible humidity, if the surroundings are pure forest maybe the design will change or if a main highway cross in front maybe the windows should be sound proof, is just useful information for the designer.

As shown in this chapter the models made with drones are really useful for the construction site monitoring in any stage of the construction and in any kind of construction.

7 Conclusions and future developments

In this chapter conclusions about the developed work are evaluated. It is assessed if the UAV system gives satisfying results for the construction site monitoring in terms of reliability of the results, low cost of the system and time consumption. If is satisfactory should be decided which is the best software for photogrammetry and path planning, but first the best type of drone should be selected since this is a very important decision of the project. After all this a future development on the construction site monitoring is given.

7.1 Conclusions

After doing all the tests and checking all the possibilities it is possible to state with confidence that a UAV system is fully capable of monitor and verify a construction site within every stage of the construction since the results show a really small error when taking measurements and a highly accurate model of the reconstructed area allowing the constructor and designer simplify their work with good information and accurate comparisons between the designed model and the actual built structure which give them a full knowledge of what is going on in the field.

The first thing to verify is the best type of drone for the construction site monitoring, in order to give this answer a basic analysis should be done: how is the structure to be monitored, here normally are just two options, a long and big construction site or a small one just for one building. In the first case there are 2 suitable options of drones, a fixed wing or a multirotor, their characteristics where stated before, but the option that gives more precise and manageable images is the multirotor since is more resistant to wind and can be controlled easily, the fixed wing is more vulnerable to the weather conditions causing a probable mistaken in the image acquisition. In the small construction site the only suitable option is the multirotor since the maneuverability is higher. Definitively the best drone for monitor construction sites is a multirotor.

Now that the drone type is selected the flight planning software should be chosen, in order to check the best one is important to see the stability of the flight plan to avoid collisions and risky situations, also is important to verify the ease of use of the software and the drone compatibility. After testing 4 different software in full detail two of them stand out for their good performance and capability: Pix4D capture and Mission Planner, in this case is worthless to select one since they are totally different and can be used in different situations, the Pix4D capture can be used with a small amount of drones but the flight is very stable and the pictures are well geolocated and homogeneous. The Mission Planner is not so easy to use but allows to do polygon flight as desired and can control a huge amount of drones. The selection of the software is totally dependable of the type of flight and the used drone, both are outstanding software.

After selecting the drone type and the flight planner software is time to select the best photogrammetry software, there were tested 6 software but after a deep analysis just two options where reliable and good enough, the Pix4D mapper pro and the agisoft Photo Scan, both are amazing software but the ease of use and the autonomous process gives Pix4D mapper pro a huge advantage since it is really easy to use, it has all the desired outputs and is almost totally automatic. This software was designed specifically for drones so the geolocation of the images and the outputs are great and useful for almost all the available applications for drones, and since it’s more or less new is always in development with periodical updates and new updates.

In conclusion, the drones are a highly reliable system for monitoring construction sites but with the help of the flight planners Pix4d Capture and Mission Planner and with the help of the Pix4D mapper pro photogrammetry software.

7.2 Future development

This project, as stated previously, was made in collaboration with the company Sipal S.p.A, the company is going to continue with this project with the association of the Puglia region. The near future of this project is to monitor a construction site in Puglia and to continue developing and investigating new methods for monitoring any kind of construction site, each time more autonomous and reliable.

During this 4 years project the company will start will real life tests of the monitoring allowing them to know if all the results of this dissertation are correct and if not verify what is the correction to do in order to get a better model or a fully autonomous model development.

One thing that is slowing down this research field and thus the development is the local normativity since the law prohibit to do a remote flight without the presence of a certified pilot near the plane, if someday this law changes it will allow to do a whole system for monitoring more than one construction site being in the home office, just having the drone in location without needing a pilot nearby.

Hopefully in a short term future the monitoring and process could be totally automatic with the help of some python code that will automatically process the images after the acquisition and also planning a periodic flight plan in order to check the construction periodically without the direct dependence of the company.

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