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Designing a drone based measurement system for outdoor material fields in industrial environment

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Abstract

Drones are a rapidly evolving technology with potential for different surveying and measurement purposes. With various embedded sensors, drones can provide data from their surroundings with a capability to easily reach places that can otherwise be difficult to measure. The ability to perform tasks while flying in the air and being able to do them both quickly and inexpensively is what separates the drones from more traditional measurement methods. It is also what makes the use of drones interesting in industrial environments where there is a need to have more accurate and timely measurement systems to provide information about material use and management.

The objective of this thesis was to research if a drone based measurement system for outdoor material fields in industrial environment is a feasible concept. In this thesis, a drone based measurement system is considered a system, which uses a drone to collect the measurement data by taking photographs and which produces the measurements through measurable 3D models based on the photographs and GPS location data.

This research was conducted with design science research methodology. The system's feasibility was studied by implementing the system as a pilot project in an industrial environment. Prior research related to the use of drones in similar applications was analysed through a structured literature review, from which recommendations for a good system design could be derived. The system was built by applying the local needs to the system alongside with the theoretical recommendations. The completed system was evaluated by comparing the system's performance against traditional measurement methods and by comparing the system against the requirements that it was designed with. From the results of the evaluation, the feasibility of the system could be assessed and recommendations for improving and developing the system in the future described.

The research showed that a drone based measurement system for outdoor material fields is a feasible and practically working concept. The system can produce very accurate and timely results, being capable of replacing more traditional measurement methods. The system is limited by being dependent on good weather conditions and by having lack of automation in some parts of its workflow. The research as a whole was limited by its approach of pilot testing, which could make some of the results not generalizable.

Keywords
drone, drone based measurement system, unmanned aerial system, unmanned aerial vehicle, uas, uav, georeferencing, measurement

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Tiivistelmä

Dronet eli miehittämättömät ilma-alukset ovat nopeasti kehittyvä teknologia, jossa on potentiaalia erilaisiin kartoitus- ja mittaustehtäviin. Moninaisten sulautettujen sensorien avulla dronet voivat tuottaa erilaista dataa ympäristöstään, pystyen helposti yltämään paikkoihin, joita olisi muutoin vaikea mitata. Kyky suorittaa tehtäviä ilmasta käsin, sekä niiden suorittaminen nopeasti ja edullisesti on ominaisuus, joka erottaa dronet muista perinteisemmistä mittausmenetelmistä. Se myös tekee dronejen käytöstä mielenkiintoista teollisissa ympäristöissä, joissa on tarvetta entistä tarkemmille ja oikea-aikaisemmille materiaalien käytöstä ja hallinnasta tietoa tuottaville mittausjärjestelmille.

Tämän pro gradu -tutkielman tavoitteena oli tutkia, onko ulkona sijaitsevia materiaalikenttiä teollisessa ympäristössä mittaava drone-pohjainen mittausjärjestelmä toteuttamiskelpoinen konsepti. Tässä tutkielmassa drone-pohjaisella mittausjärjestelmällä tarkoitetaan järjestelmää, joka käyttää dronea keräämään mittausdataa valokuvia ottamalla ja joka tuottaa mittauksia 3D-malleista, jotka pohjautuvat näihin otettuihin kuviin ja GPS-paikkatietoon.

Tämä tutkimus toteutettiin design science research -metodologialla. Järjestelmän toteuttamiskelpoisuutta tutkittiin toteuttamalla järjestelmä pilottiprojektina teollisessa ympäristössä. Aiempaa dronejen käyttöön liittyvää tutkimusta vastaavissa sovelluksissa analysoitiin strukturoidun kirjallisuuskatsauksen kautta. Sen avulla voitiin johtaa suosituksia hyviä järjestelmänsuunnitteluperiaatteita varten. Järjestelmä rakennettiin soveltamalla järjestelmään paikallisia tarpeita teoreettisten suositusten rinnalla. Valmista järjestelmää arvioitiin vertaamalla järjestelmän suorituskykyä perinteisiä mittausmenetelmiä ja järjestelmän suunnitteluvaiheessa käytettyjä vaatimuksia vasten. Arvioinnin tulosten perusteella järjestelmän käyttökelpoisuutta voitiin tarkastella, sekä antaa ehdotuksia järjestelmän parantamiseen ja kehittämiseen tulevaisuudessa.

Tutkimus osoitti, että ulkona sijaitsevia materiaalikenttiä teollisessa ympäristössä mittaava drone-pohjainen mittausjärjestelmä on toteuttamiskelpoinen ja käytännössä toimiva konsepti. Järjestelmä voi tuottaa hyvin tarkkoja ja oikea-aikaisia tuloksia, ollen kykenevä korvaamaan perinteisempiä mittausmetodeja. Järjestelmää rajoittaa sen riippuvuus hyvistä sääolosuhteista ja automaation puute joissain osissa sen työnkulkua. Tutkimusta kokonaisuutena rajoitti sen pilottitestausta käyttävä lähestymistapa, joka saattaa estää joidenkin tulosten osien yleistämisen.

Abbreviations

ALS	Airborne Laser Scanning
CHMS	Coke Management and Handling System
DGPS	Differential Global Positioning System
GIS	Geographical Information System
GPS	Global Positioning System
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
WGS 84	World Geodetic System 84
WPF	Windows Presentation Foundation

Contents

1. Introduction

Drones, also known as unmanned aerial vehicles (UAV) are aircrafts, which often have sensors such as digital cameras equipped with them. Drones can be either under remote control by a human operator, or they can be working fully or partially autonomously. Drones are a timely and rapidly evolving technology, having their roots in military applications (Ehsani & Maja, 2013; Gago et al., 2015). Lately, drones have been used more and more for civilian purposes such as different kinds of measurement and surveying tasks (Gago et al., 2015). These have not been for hobbyists only as there is a growing interest to use drones professionally in industrial environments. What makes drones interesting for professional use is their defining key characteristic of being able to perform surveying tasks while flying in the air and doing these tasks both quickly and inexpensively which is often difficult to accomplish by other more traditional methods (Tuominen, Balazs, Saari, Polonen, Sarkeala, & Viitala, 2015). The potential applications of working from mid-air alongside with the recent developments of the technology are the main reasons their use is becoming more widespread and should be further studied.

The objective of this master's thesis is to research if a drone based measurement system for outdoor material fields in industrial environment is a feasible concept. In this context, *a drone based system* means a system, which uses a drone to collect the measurement data by taking photographs of the measured targets. *A measurement system for outdoor material fields* means a system capable of calculating different material inventory and management related data such as the materials' volume and location at the material field. The measurement itself is done by creating measurable 3D models from the photographs taken by the drone with the assistance of GPS location data.

The motivation for this thesis comes from the need to understand the capabilities of the drone based measurement technology in more detail. An increasing amount of research related to drone use has been published during the last five years but there are still gaps in knowledge related to how these kinds of systems should be implemented in practice as they have to be customized according to local needs. There is also a need to research how the system would compare against other, more traditional measurement methods used for same purposes. Thus, *the feasibility of the concept* in this thesis means not only if the system is capable of performing its tasks in general but also how well it compares against the traditional measurement systems.

The feasibility of the concept will be studied by implementing a pilot version of the system at SSAB Europe's steel factory's coke plant at the city of Raahe in Finland. The outdoor material fields and the material usage in the factory's coke plant offer good and suitable conditions for the research. Existing measurement system for the materials also exists in the factory, which makes comparing the drone based system's capabilities against the traditional methods possible. If the implementation is successful, the drone based system may have potential to replace or supplement the traditional measurement system.

The thesis begins by defining the research problem and specifying the research questions. The way the research is done by applying design science research methodology is presented.

With the research methodology described, a structured literature review is conducted to understand the existing knowledge related to drones in similar applications. The literature review is based on the bachelor's thesis conducted by the author. With the literature review's findings alongside with the practical business needs from SSAB Europe, requirements for the system can be developed. Then, based on the requirements, the system is implemented in practice. Implementation is done by building the system step by step in smaller cycles. With the implementation done, the system is evaluated by comparing it against the traditional measurement system and by analysing how well it met the designed requirements. Finally, the results are discussed and the research's limitations and related future research areas can be recognized.

2. Research Problem and Methodology

The objective of this thesis is to research the feasibility of a drone based measurement system for outdoor material fields in industrial environment. This objective should be explained in more detail so that explicit research questions to answer it can be created. As stated in the introduction, in this context a drone based system means a system using a drone to collect the measurement data by photographing the measured targets. A measurement system for outdoor material fields means a system capable of calculating material inventory and management related data such as material volume and material location at the material fields. The system is implemented at SSAB Europe's factory which means that both the local business needs and the recommendations from the existing literature will have to be taken into account in the design of the system. The local conditions also set the perspective from which the problem is approached. The implemented system is going to be evaluated by comparing it against both the requirements designed for it and the traditional measurement methods used at the factory. With this kind of implementation and evaluation, the research problem can best be answered by setting the following two research questions:

- How a drone based measurement system for outdoor material fields can be designed?
- What are the benefits and challenges of a drone based measurement system?

The answer to the first question will describe what are the steps needed to create the wanted drone based measurement system. Answering the question will help to understand if there are deviations from the recommendations of the prior research and how the local needs are reflected in the design. The answer to the second question will describe how the system can actually be beneficial when taking the existing measurement system and the business realities into account. It will also tell what the shortcomings of the system are, which is essential to understand from the aspect of a good system design. With these solutions, the initial research problem can be answered and the feasibility of the concept assessed.

2.1 Research method

As this thesis is an empirical research where a new system is built and evaluated, design science research methodology is chosen as the research method to approach this thesis. Design science research is a research methodology where the design problem is understood and solved by building and applying a viable artifact (Hevner, March, Park & Ram, 2004). The artifact can be a construct, a model, a method or an instantiation which helps to understand and address information system related problems. The artifact is in turns developed and then evaluated in order to produce a viable outcome. In this thesis, the drone system concept itself is considered the IT artifact as it is the core issue of this research.

A number of different design science research related frameworks exist which differ in their view on what should be emphasized in the research process and how it should be done in general. The framework to conduct design science research as presented by Hevner et al. (2004) and as shown in Figure 1 is used in this research in an applied manner as it is well suitable for the environment in which the research is done in.

In addition, the seven guidelines proposed by Hevner et al. (2004) are also followed. How these guidelines are met is addressed in Chapter 6.1. How the actual framework is applied to this research is described below.

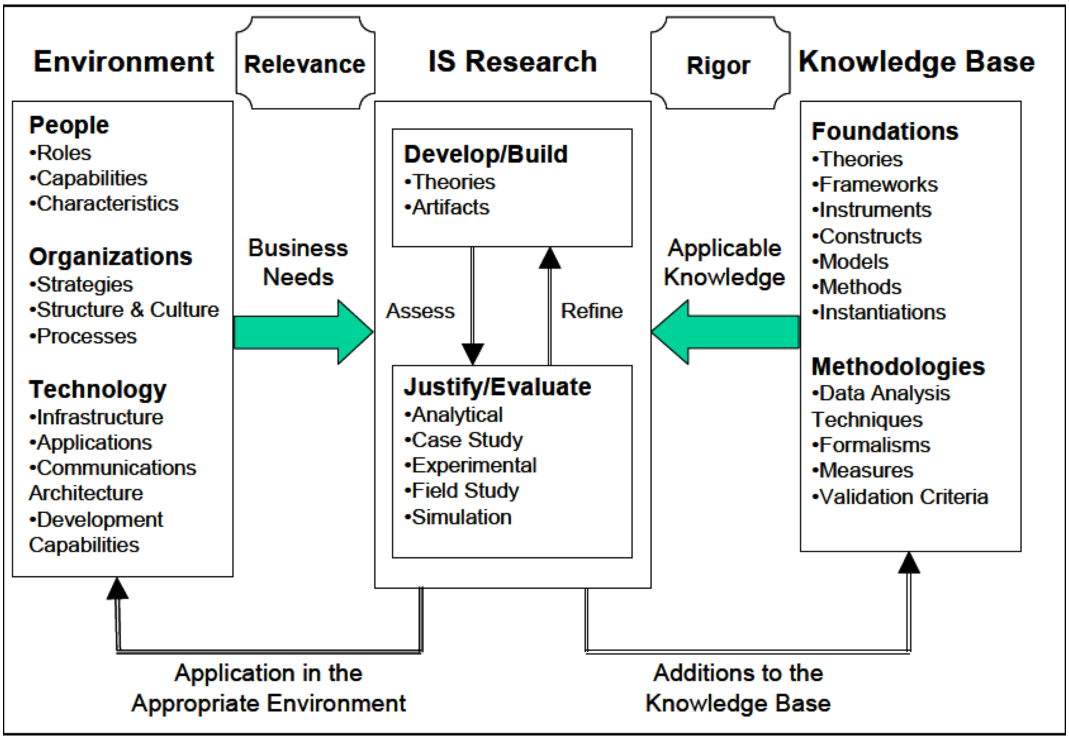

Figure 1. Information Systems Research Framework (Hevner et al., 2004)

The environment of this research is the local setting where the system is implemented. The environment is focused around the organization, which is SSAB Europe and more specifically, their coke plant at the factory in Raahe, where the system is to be used. From the aspect of this research, the goal of the coke plant and in wider perspective the organization is to provide accurate and timely information about the material use in the coke plant. The information is gathered and first-hand used by the development engineers and other personnel working at the coke plant. The relevant material use information, which means the volume and location data of the materials, is gathered by two separate measurement methods, which in this thesis are called *the traditional methods* and which together form *the traditional measurement system*. The information gathered and provided by the traditional measurement system should be done more accurately, more timely and more inexpensively and this creates the need for a change from the company's perspective. In design science research, this need for a change together with the different parts of the organization define the business needs that make the research problem relevant and influence how the artifact is to be built.

The knowledge base of this research is the existing research related to the use of drones in similar applications. It is analysed in the structured literature review that is to be conducted in this thesis. The structured literature review, which is based on the bachelor's thesis conducted by the author, can help to understand what kind of challenges and benefits are related to the use of drones and what kind of concerns are especially important to take into consideration. These recommendations from the literature review are combined into a list of theoretical requirements, which are used to support the drone based system's design. From design science research's perspective, the theoretical requirements provide the applicable knowledge that is used for building the artifact. The method for conducting the structured literature review is described in Chapter 2.2.

The core of the research is the development of the artifact. The development is done as an iterative process in multiple stages. This process includes completion of several cycles, which are needed to develop the complete system. Each cycle has its own objectives to accomplish and they are also evaluated against these objectives. As the system is implemented as a pilot project, the nature of a pilot test is taken into account in the objectives and the system development in general. The main cycles of the research with their objectives and evaluation criteria are following.

Cycle 1: Developing the requirements

The objective is to develop a list of requirements for the system. The requirements are gathered from the theoretical requirements of the structured literature review and from the practical needs of the company. The practical needs are based on the wanted outcome of the drone based system and the performance of the currently used traditional measurement system. The completion of the cycle is evaluated by analysing the validity of the requirements with the professionals from the company.

Cycle 2: Designing the system structure

The objective is to design the structure of the system’s components and the workflow of the system, which means all the activities that are needed for the system’s use. The structure and the workflow are based on the requirements developed in the previous cycle. The completion of the cycle is evaluated by confirming that both the structure and the workflow are in-line with the requirements and the objectives of the thesis.

Cycle 3: Choosing the drone

The objective is to choose a proper drone model to be used in the system. The chosen drone must fulfil the developed requirements and it must be capable of fitting in the system structure and following the workflow. The completion of the cycle is evaluated by confirming the validity of the choice.

Cycle 4: Choosing the software

The objective is to choose proper software to process the data gathered by the drone. The software must fulfil the developed requirements, be capable of fitting in the system structure and following the workflow and be compatible with the chosen drone. Different software choices are compared against each other and the best one is chosen. The completion of the cycle is evaluated by confirming the validity of the choice.

Cycle 5: Testing the system

The objective is to use the system to perform all its features according to the developed workflow and system structure. The components chosen in the previous cycles are used. The completion of the cycle is evaluated by confirming that the system is capable of performing the wanted features.

After the cycles have been completed, the system is evaluated as a whole. This is done by first comparing the system’s performance against the traditional measurement system in a field test. Then, the system is compared against the requirements it was designed with to see how well it achieved them. In a case of having requirements that could not be achieved, the reasoning for that must be analysed and further steps to fix the situation suggested.

With the system's evaluation done, the implications, the limitations and the future research related to the research can be discussed. By reflecting the developed system against the prior drone related research, the research questions can be answered and the initial research problem solved. Like presented in the framework by Hevner et al. (2004), the developed system, which is the created artifact, can be used as a practical solution for the business environment. With the research questions and the research problem solved, the knowledge gained from the research and this thesis as a whole can be used as a contribution to the knowledge base.

2.2 Structured literature review

The structured literature review is approached with the systematic literature review principles presented by Kitchenham and Charters (2007). The principles are used in an applied manner and they are not followed rigorously and because of this, the literature review is called *structured* instead of *systematic*. The systematic literature review principles are not fully followed because in the scope of this thesis there is no need for a full systematic mapping of the existing research. This is because the emphasis and the main objective of this thesis is the actual design and implementation of the system where the literature review serves as a basis to support the decision making in the system's design. The process of how and why the literature review's studies were chosen in a structured manner are presented below.

The search for literature was started by having broad search terms and then gradually narrowing them down to get the most fitting results available. The interest towards wanting to better understand the nature of a drone based measurement system, to avoid common mistakes and to make better choices in the design process were the guiding lines for the way the search was done. As the amount of results was step by step reduced, the final result was a manageable size of literature for the scope of this thesis.

The literature was searched from the reference databases of Scopus and Web of Science. At first, some pilot searches were conducted. As the thesis is based around the drone technology it was the obvious first choice for a search term. Attempting to search with only the term *drone* and its synonyms and abbreviations *Unmanned Aerial Vehicle*, *UAV*, *Unmanned Aerial System* and *UAS* yielded over 30 000 results. One of the problems was that the word drone has a dual meaning, meaning certain types of insects, so some of the results were related to the field of biology. There were also likely wrong results due to the abbreviations used. Even though the synonyms and abbreviations were used in the search phase, only the term drone is used throughout the thesis for the reasons of uniformity and convenience for the readers.

After the false results from drone term's dual meaning were noticed, a need to focus the search on specific areas was recognized. In addition to word drone and its synonyms, two types of terms were added. These were the relevant way of operating wanted from the drone and the application area where the drone should be used. *Estimation*, *mapping* and *measurement* were all seen as fitting descriptions of what was the wanted operating from the drone. These actions were combined with the application areas of *agriculture*, *forestry* and *mining*. Although multiple other areas of using drones existed, these three were chosen as they all share the similar nature of measuring different kind of volumes and observing changes in the targeted areas. Because of these features, they could best answer to questions regarding the designed measurement system. Finally, the search query could be defined as following:

(drone OR UAV OR "Unmanned Aerial Vehicle" OR UAS OR "Unmanned Aerial System" OR "Unmanned Aircraft")
AND
(
(estimat* AND (agricultur* OR forest* OR mining))
OR
(mapping AND (agricultur* OR forest OR mining))
OR
(measur* AND (agricultur* OR forest* OR mining))
)

The query's first part included the term drone and its synonyms and abbreviations. The second part of the query consisted of three options that were separated from each other with the *OR* statement. These three options each had the relevant way of operating and the relevant application area.

With the query ready, the search was targeted towards title, abstract and keywords in Scopus and topic in Web of Science. The search was limited to English results only and to articles, conference papers, journal papers and books. The search was also limited only to publications that were released between 2005-2015 as the interest of this literature review was to focus especially on modern research of the drone technology. The technology has evolved quickly in the recent years and the objective was to design a system capable of potentially performing better than the current solutions utilising the latest technology possible.

The search was also limited by filtering the search towards specific research and subject areas. In Scopus the areas chosen were *Computer Science*, *Engineering*, *Agricultural and Biological Sciences* and *Environmental Science*. In Web of Science the areas chosen were *Agriculture*, *Computer Science*, *Engineering*, *Environmental Sciences Ecology*, *Forestry* and *Mining Mineral Processing*. These were all related to either the system development view point or the application areas where relevant research regarding these systems could be possibly found.

The search on Scopus yielded 331 results and on Web of Science 66 results. After removing duplicates, a total of 384 results could be found.

The results were then refined by reading the papers' titles and including only results which had topics relevant to following questions:

- Does the topic focus on the development of a system using a drone?
- Does the topic focus on creation of 3D models from pictures?
- Does the topic focus on agriculture, forestry or mining?

After this refinement 59 papers were left for study. These papers were reviewed with light reading and finally 23 papers were left for the literature review. These 23 primary studies were seen as the most relevant cases in understanding the drone technology and its applications in the context of this thesis. The primary studies are listed in the references, marked with an asterisk.

3. Prior Research

The prior research related to the use of drone technology for measurement purposes was researched through this structured literature review. The objective of this literature review was to understand the use of drone technology for measurement purposes more in-depth and to use this understanding to support decision making in the design of the drone based measurement system. The results from the literature review could be used to develop a list of theoretical requirements for the system's design. These requirements could provide a good foundation for how the system should be developed and what kind of aspects should be taken into consideration in its implementation. The requirements could then be combined with the more practical needs from the company.

The primary studies researched in this structured literature review consisted of studies where the drone technology was applied to different measurement and surveying tasks in areas of agriculture, forestry and mining. These areas all share the similar need to measure different shapes and volumes and to observe the changes happening in them, which were an important part of the main focus of this thesis. Many other application areas for the drone use, such as security, humanitarian crisis management and archaeology exist (Gademer et al., 2010) but limiting the researched area to the chosen three was seen as the best way to support understanding the measurement and surveying based drone systems in the scope of this thesis.

The structured literature review was arranged so that first the traditional measurement methods and needs for each three application areas were described. The term *traditional* in this context means the type of methods that have been used before adapting the drone based methods. With the traditional methods and needs described, the modern drone based solutions for each area were then presented. From the results of these studies and by comparing the drone based solutions to the traditional methods, the benefits and challenges related to the drone use could be identified. Finally, these benefits and challenges were used to design the theoretical requirements for the drone based system.

3.1 Traditional measurements in agriculture

In agriculture it is necessary to monitor the crops, how they grow and evolve and if there are any unneeded elements such as weeds disturbing their growing process. In Europe, regulations in agriculture have required farmers to keep their land in a good condition (Diaz-Varela, Zarco-Tejada, Angileri & Loudjani, 2014). The good condition means for instance prevention of soil erosion, conservation of soil organic matter and structure, and the maintenance of habitat and landscape features. To reach high quality standards, site-specific management practices are nowadays needed to maintain the land (Comba, Gay, Primicerio & Ricauda Aimonino, 2015).

Many of these needed agricultural measurement tasks have been attempted to be solved with aerial or satellite-based remote sensing (Ehsani & Maja, 2013). Problems with these technologies have been many such as the expensive price, low resolution or simple inconvenience (Ehsani & Maja, 2013). There is also often only a narrow window of opportunity to do these measurements as they are needed in the specific time of the crops' growth. Difficulties in measurements are also related to a need to monitor large areas, which farms typically tend to be (Hernandez, Murcia, Copot & De Keyser, 2015).

When using different kinds of sensors in these vast areas, the measurements are limited by factors such as power supply, calibration procedures, data delays, accessibility issues for installation and maintenance, and also the high costs.

Low resolution of satellite images has limited the precise measurements on a single plant level. For instance, in palm plantations there is a high interest towards efficient inventorying of palm trees on a single tree level (Kattenborn, Sperlich, Bataua & Koch, 2014). These inventories could be used to support documentation, management and certification in different plantation tasks.

Instead of satellites, measurements have been done with remote sensors placed on towers at the crop fields (Gago et al., 2015). Their limitation is their fixed position in the data collection. They can only cover limited area and from a limited point of view. Monitoring vast areas efficiently would require more mobile and transformable methods which could be adjusted according to changing environment and needs.

3.2 Traditional measurements in forestry

In forestry, there is a need to observe how the trees grow, if there are changes to the forests' health from for instance pollution and if there are forest fires and how they are spreading. Hundreds of thousands of hectares of forest are burned every year (Merino, Caballero, Martínez-De-Dios, Maza & Ollero, 2012). This leads not only to the destruction of the forests and their animals but it also has huge social, economic and environmental problems. Forest fighting itself has been traditionally very human labor intensive and dangerous work. The work has been based mainly on visual observations, which are prone to error such as smoke occluding the flames and human inaccuracy in estimating and localizing the fire. Forest fire areas can also be massive in size.

In Finland, airborne laser scanning (ALS) data and digital aerial photography are the most important remote sensing methods in forest inventorying (Tuominen et al., 2015). As the downside of airborne laser scanning, Tuominen et al. (2015) cite several studies (Törmä, 2000; Packalen & Maltamo, 2006, 2007; Waser et al., 2011), according to which the technology is not well suited for estimating tree species composition or dominance. Aerial images are said to be the best-suited for the inventorying purposes as Tuominen et al. (2015) cite Maltamo et al. (2006) and Tuominen and Haapanen (2011).

In addition to airborne methods, forests can be measured with ground-based methods (Paneque-Gálvez, McCall, Napoletano, Wich & Koh, 2014). This has been traditionally done with ground surveys, using measurement units like diameter at breast height, tree height, percentage of canopy cover, number of trees and tree species. The problems related to ground-based surveying have been their limitation on being done on very small areas and being costly, time-consuming and tedious. They are also problematic with logistical challenges related to the environment, like safety and access to the specific sites (Paneque-Gálvez et al., 2014).

3.3 Traditional measurements in mining

In mining, there is a need to measure sizes of different kind of material mounds, monitor the status of quarry walls (Chen, Li, Chang, Sofia & Tarolli, 2015) and for instance survey the radiation level in uranium mines (Martin, Payton, Fardoulis, Richards & Scott, 2015). Other processes that need monitoring are for instance pollution, erosion, subsidence and the effects of continued mining on a specific area (Chen et al., 2015). Mining companies are especially interested to regularly calculate the amount of mass extracted and stocked in the mine (Shahbazi, Sohn, Théau & Menard, 2015).

Chen et al. (2015) emphasized the significance of open-pit mining, citing Martín-Duque et al. (2010), according to whom open-pit mining has ecological effects on the land, affecting vegetation, soil, bedrock and landforms. These can eventually change surface hydrology, groundwater levels and flow paths, as Chen et al. (2015) cite Osterkamp and Joseph (2000) and Nicolau and Asensio (2000). Open-pit mines and quarries are also the most dangerous industrial sector, causing a number of injuries and accidents (Chen et al., 2015). These dangers could be partly understood as being a result from lacking measurement capabilities. Chen et al. (2015) cite several studies (Slatton et al., 2007; Roering et al., 2013; Westoby et al., 2012; Fonstad et al., 2013; Javernick et al., 2014; Micheletti et al., 2014; Prosdocimi et al., 2015), according to which LIDAR and Structure from Motion photogrammetry have been used as technologies during the last decade as survey technologies. Yet, despite the benefits of using these technologies, there is a need for fast, accurate and low-cost investigation methods in the mining industry. New surveying methods are for instance needed to monitor the shapes of the mines. From the shapes, possible erosion and the failing of the mines' slopes can be predicted (Chen et al., 2015).

Another kind of measurement need in mining is the surveying of legacy uranium mines (Martin et al., 2015). Because of the dangers of the radiation to living beings, surveying these mines has been done from afar. Surveys have been done with light-weight aircrafts with altitudes from 56 to over 200 meters (Martin et al., 2015). The challenges with these surveys have been the lack of spatial resolution, high price and need for well-trained pilots. There is a need for accurate, cheap and relatively easily usable technology to counter these challenges.

The number of studies related to mining in this structured literature review was relatively low when compared to the studies concerning agriculture and forestry. Chen et al. (2015) mention in their study that at the time of their paper in 2015, there are still only a few publications related to mining industry with the use of drones.

3.4 Modern drone based measurements in agriculture

In agriculture there are several different challenges to resolve with the drones. According to Ehsani and Maja (2013), there have been only a few actual uses of drones in agriculture, despite having immense potential. The reasoning for the lack of drone use was said to be for example too expensive pricing, low resolution or simple inconveniency. These arguments seemed to emphasize the rapid development of the technology in the last couple of years, as the issues of pricing and resolution seemed to have been resolved according to other studies (Comba et al., 2015; Gademer et al., 2010; Peña et al., 2013). Many studies concerning drone use in agriculture have also been published during the last two years, after the paper by Ehsani and Maja (2013).

Plenty of different applications were recognized as having potential with drones in agriculture. These were crop scouting, pest distribution mapping, crop loss assessment, bare soil imagery, irrigation and drainage planning, yield estimation and monitoring, inventory management, diagnosis of herbicide injury in crops, selection of plants for further breeding, sampling of plant pathogens in the air, efficient use of chemicals and pesticides, safety and security, automation and navigation of ground vehicles and academic and extension education (Ehsani & Maja, 2013). As a conclusion from this list of possible drone applications, Ehsani and Maja (2013) considered precision agriculture in general as the largest future commercial use of drones. Some of these before mentioned applications were then actually realized in the other primary studies.

Weed detection was a common interest which was solved with drone based surveying (Borra-Serrano, Peña, Torres-Sánchez, Mesas-Carrascosa & López-Granados, 2015; Comba et al., 2015; Rasmussen, Nielsen, Garcia-Ruiz, Christensen & Streibig, 2013). In one primary study, a drone could be successfully used to detect single weeds from the altitude of 30 meters (Borra-Serrano et al., 2015). With the gathered data, herbicide could be spread on specific locations instead of the whole farm area which has been the more traditional method. This so called site-specific weed management helped to reduce not only the need for the amount of herbicide but also the time consumed for spreading it around the farm. It also made following the European agricultural regulations (Diaz-Varela et al., 2014) easier. In another study, the drone based weed detection on a vineyard was reported to have 95 % correct detection rate (Comba et al., 2015). This already very high accuracy could be further increased with more work towards it. Minor errors in the detection were related to disturbances in some of the pictures that were taken by the drone. In a third weed detection related study, a 100 % correct detection rate was achieved (Peña, Torres-Sánchez, de Castro, Kelly & López-Granados, 2013). In this study, the accuracy of weed detection in a Spanish maize field was evaluated by comparing the drone imagery to photographs taken on-ground. Only very minor errors were noticed due to some of the weeds being located in the corners of the pictures taken, making spotting them slightly problematic. The tasks performed with the drone were very complex as the general appearance of both weeds and crop plants were very similar and the natural crop fields had changing conditions that had to be taken into account.

3.5 Modern drone based measurements in forestry

In forestry, the interest with drones was mainly related to monitoring tree competition, growth and morphological plasticity (Gatziolis, Lienard, Vogs & Strigul, 2015) and surveying forest fires and their recovery (Merino et al., 2012).

With drones, trees could be measured on a single tree level (Gatziolis et al., 2015; Torres-Sánchez et al., 2015). Camera equipped drones were used to take pictures from the forest and the pictures were processed into 3D models. These models were then used for multiple purposes such as effective tree growth monitoring over time (Gatziolis et al., 2015). One study stated that the measurement of single trees from a forest was at 97% accuracy (Torres-Sánchez et al., 2015). This included using drones to take pictures of the forest from the altitudes of 50 meters and 100 meters. The difference in altitude only had minimal effects on the accuracy of the results, making varying picture taking methods possible. The pictures taken with the drone from 100 meters only had minor errors causing blurry areas in the 3D model created from the pictures. This was assumed to have happened due to low color contrast between the trees and the surrounding area. Despite the minor errors, taking the pictures from higher altitudes was recommended as it significantly reduced the time needed both for collecting images and processing them as 3D model in dedicated processing software (Torres-Sánchez et al., 2015). The processing software needed to create the models can also be very resource demanding, making having a powerful computer dedicated for the processing tasks a benefit, as it can also drastically reduce the processing time (Torres-Sánchez et al., 2015).

Despite being accurate on a single tree level, there were doubts about the drone based technology when used to survey larger forests (Lisein, Pierrot-Deseilligny, Bonnet & Lejeune, 2013; Tuominen et al., 2015; Zahawi, Dandois, Holl, Nadwodny, Reid & Ellis, 2015). Drones could be used to successfully measure tree canopy in forests, but it was done by using a LIDAR laser scanner in addition to normal digital camera. Using camera-equipped drones was suggested as being more of a complement than replacement for LIDAR laser scanning (Lisein et al., 2013). The camera equipped drones were stated as being a reasonable and a well suited method for doing forest inventorying but still not being a match for the traditional methods.

Conventional aerial imaging was suggested being more efficient on large scale image acquisition (Tuominen et al., 2015). In a context of tropical forest monitoring, camera equipped drones were stated to have a need for a supporting technology for the measurements, and that the drones could not replace traditional ground-based surveys (Zahawi et al., 2015). It was concluded that the camera equipped drone measurement has potential for monitoring forest structural evolutions and forest planning but there is still a lot of room for improvement in the technology (Lisein et al., 2013).

Contrary to the doubts for a large scale forest measurement, combating forest fires was suggested as a potential application area for the drones (Merino et al., 2012). The drone based technology was stated as being highly useful, as it can overcome the shortcomings that are traditionally faced in the very human labor intensive and dangerous forest fire fighting work. With drones, views from areas that are difficult to reach to due fire could be easily reached. Using multiple drones at the same time was suggested to make forest fire fighting efforts even more useful (Merino et al., 2012).

3.6 Modern drone based measurements in mining

In mining the drones were used for two types of tasks: surveying topography and using specific sensors to detect radioactivity. In one study, an open-pit mine was mapped with the drone with the objective of establishing a basis for automatic mine mapping at a given time (Chen et al., 2015). Using the drone was successful and topographic measurements could be made from a georeferenced 3D model created from the drone's pictures. Despite not using the results for later analysis in the study itself, different uses for the data were recognized (Chen et al., 2015). These were tracking the changes in the mine happening over time and being able to follow several processes in the area typical for the open-pit mines, such as pollution, erosion and subsidence. Using drones for this kind of mapping studies was suggested as being a powerful tool to support decision making in mining (Chen et al., 2015).

In another open-pit mine measurement study the objective was to perform extensive testing for all the drone based system's aspects (Shahbazi et al., 2015). The measurement capabilities were tested by mapping an open-pit gravel mine as the open-pit mine's characteristics were stated as being a challenging environment for 3D modeling and there being a need for a drone based system in mining industry. In-house software was developed for using the drone and processing its results. Multiple aspects of the system had to be taken into consideration to properly test the system, such as camera offline calibration, platform calibration, system integration, flight and fieldwork planning, data acquisition and photogrammetric processing and application. The study was successful and the created system was being able to produce accurate measurement results. It was proposed as being usable in various geological applications (Shahbazi et al., 2015).

In addition to camera based measurements, mines can be mapped with drones equipped with gamma radiation mapping unit sensors too (Martin et al., 2015). In the study, a legacy uranium mine was mapped with the drone. The mapping was successful and a radiation map could be created from the mine. Despite not having a camera in this study, it was stated that a LIDAR laser scanner could be used in future to generate 3D maps of the mines to improve the drone's usability. Although not mentioned in the paper, the reason for not considering a digital camera might have been due to camera's possible fragility when being exposed to gamma radiation.

3.7 Benefits of drones in measurement tasks

Among the primary studies a lot of commonalities could be found from the benefits that the researchers had from their results. Benefits were either directly mentioned or they could be interpreted indirectly when comparing their results to the situation before deploying the drone based solution. These benefits were usually tightly coupled to the recent development of the drone technology itself and the advantages it has provided.

The inexpensiveness of the drone technology was perhaps the most important benefit of drones. The prices of drones have rapidly dropped in the recent years as the technology has developed on multiple different sectors such as automatics and embedded processing (Gademer et al., 2010). Because of the low prices, drones have become available for a wider range of audience and it has made purchasing drones for research purposes more compelling.

Previously to have the surveying done with either satellites or airplanes, people needing the surveying such as farmers were dependent on other people and factors they could not have influence on. Now, they are free to time their surveying tasks as they please as they can control the surveying themselves with the drones (Gademer et al., 2010).

Despite relying on digital cameras, the drones have made very accurate results possible. This is due to both the development of digital cameras and the low altitude that drones can operate from (Gago et al., 2015). Many of the primary studies highlighted this accuracy of drone based mapping. The camera-equipped drone usually managed to produce all the results from its surveying tasks that were wanted from it (Diaz-Varela et al., 2014; Peña et al., 2013; Torres-Sánchez et al., 2015). The accuracy was compared to being as good as the traditional and more expensive LIDAR mapping (Diaz-Varela et al., 2014; Zarco-Tejada et al., 2014).

One benefit from using the drones was the reduction of human labor in different fields such as forest fighting (Merino et al., 2012). As the need for manual human work reduced it also had effects such as reducing the risks of accidents, reducing uncertainty and having long time monetary savings.

Overall, the introduction of drones has significant reduction in costs when considering all the other benefits. These are both direct and indirect and mainly focus around factors such as saving of time, opportunity cost against traditional methods, reduces in cost of work, and the improvement of the results' accuracy.

3.8 Challenges of drones in measurement tasks

Despite having clear overall beneficial advantages, the drone use still faces problems and difficulties. The challenges were often related to technical shortcomings or to very situational problems related to the papers' case studies and the environment they were operating in.

The effects of wind on drone were mentioned in several of the primary studies (Borra-Serrano et al., 2015; Gatziolis et al., 2015; Kattenborn et al., 2014; Martin et al., 2015; Merino et al., 2012). Especially on higher altitudes the wind may cause unwanted movement of the drone. This movement may then cause the camera or other sensor that is used to take inaccurate photos or other measurements (Primicerio et al., 2012). According to Katteborn et al. (2014), the wind and gusts even caused a relatively high amount of mission errors in their case study. Some of the drones may have gimbals or gyroscopes to attempt to counter the effect of the wind but their effectiveness is limited. Other weather conditions affecting the drone were unfavorable sun illuminations such as sun facing camera exposures or the lack of light during dusk (Gatziolis et al., 2015). Using image enhancements was suggested to counter the problems resulting from illuminations. Despite sunlight being a challenging factor, in some cases the disparities in light can actually improve the surveying as they emphasize feature edges.

Related to the need for emphasized features in surveying, there were problems with monitoring areas, which have a lot of similar looking areas such as some of the crop farms (Borra-Serrano et al., 2015). It was also noted that complex landscape patterns and diverse vegetation may also make the remote sensing difficult (Diaz-Varela et al., 2014). Setting specific ground control points in the monitored area was suggested as a way to make the remote sensing easier in these challenging environments. These ground control points can be detected from multiple pictures taken by the drone and the photos can then be connected accurately to each other to create a 3D model. Setting the ground control points in the area is still a task that requires extra work, especially if the monitored area is not always in the same place. Newer studies had a GPS receiver embedded to their drone (Gago et al., 2015; Gatziolis et al., 2015), which made the ground control points usually unneeded. With the GPS coordinates attached to the metadata of the photos or other surveyed data taken by the drone, the photos could be easily combined together for the creation of 3D models. This difference in methods, using GPS instead of ground control points is an example of how quickly the drone technology has improved in the last years. Having this small part of the drone surveying automated is a part of the bigger picture where the drone technology as a whole can automate huge amount of laborious work.

Despite having improved during the latest years, the battery technology is still a limiting factor in the drone use (Borra-Serrano et al., 2015; Martin et al., 2015); Merino et al., 2012; Primicerio et al., 2012). The sensors and the drones themselves having become lighter and smaller has helped to resolve this issue (Gago et al., 2015). The downside of having short battery time is that it limits the size of the area that can be monitored during one flight. Because of this, multiple flights may be needed, which results in extra steps of changing or recharging batteries and returning the drone to the starting point between flights. According to Merino et al. (2012), higher endurance of drones is needed to perform forest fire monitoring tasks that they were interested in. Merino et al. (2012) suggested that for their needs these more endurable drones would be possible to be developed as they have been used similarly in defense and security applications. Lack of endurance was also mentioned as the reason that traditional measuring methods are likely to preserve as a more efficient method when surveying larger forest areas (Tuominen et al., 2015).

Many of the primary studies used commercial off-the-shelf drones in their case studies. Ehsani and Maja (2013) went as far as calling these commercial low-cost drones “hobby-grade hardware” and warned of them being prone to software bugs and interference. These sorts of issues didn’t realize themselves in any of the primary studies although the risk of either faulty software or hardware causing destructive accidents was mentioned (Rasmussen et al., 2013). Software bugs are especially important to take into notice if the software is used to calculate or measure important tasks that are used for decision making with for instance financial or safety related consequences.

Drone based technologies should be more user-friendly and available for all types of end-users (Gago et al., 2015; Primicerio et al., 2012). Even though the drones themselves and the software used to process their data were usually commercial products, they required technical knowledge to properly set them up and use (Rasmussen et al., 2013; Zahawi et al., 2015). The technical skills needed to control the drone may not be a quick skill to master for everyone. Especially if the drone has no automatic landing or take-off capability, basic piloting skills for those tasks are needed. Those skills are also important as a back-up in a case that automatic piloting is disturbed or it fails (Zahawi et al., 2015). Zahawi et al. (2015) suggested that users should also understand the drone in mechanical aspects as the technical support may not be available when needed. If the drone breaks, the initial low costs may rise substantially if the drone cannot be repaired. Drone processing programs have a need for more automation through better workflows and they are being rapidly improved by software developers (Paneque-Gálvez et al., 2014).

Need for an on-ground operator with a visual contact for the drone was seen as a limiting factor (Hernandez et al., 2013). It was considered especially important for the drone's actions such as taking off, landing, collision avoidance and path-planning. Collisions could happen for instance due to power lines, cell phone masts or other drones (Paneque-Gálvez et al., 2014). Lately, as the GPS being incorporated in drones have become more general, some of these issues have been resolved as GPS allows more planning and more independence for the drone. Still, more autonomy and automation for drones is a wanted feature in general (Primicerio et al., 2012). In the case of having a missing communication link, not having enough bandwidth available or having a high number of drones present at the same time, the drone should be able to survive on its own (Merino et al., 2012). As an alternative or a supplement to independence, having a complex control center of significant amount of people when having multiple drones operating at the same time was proposed (Merino et al., 2012).

Although the drop in prices has made the drones more available, funding is still an issue that should be considered (Córcoles, Ortega, Hernandez & Moreno, 2013; Paneque-Gálvez et al., 2014). One possibility would be to share the expenses of the drone between people in the same local industry, such as farmers in agriculture (Córcoles et al., 2013). As the technology quickly improves this could potentially force the users to continuously upgrade their drones to new better versions. The benefits of having a better drone against the costs should be evaluated.

Being a novel technology, using the drones in an area with other people can cause social and ethical issues. People may not understand the reasoning for drone's use and may consider it for instance as a toy or they may think that they are being video recorded which they might not like. Possible privacy violations are an issue that should be considered when using the drone (Paneque-Gálvez et al., 2014). In general, understanding the surrounding environment and its restrictions is a factor that should be taken into account. Paneque-Gálvez et al. (2014) focused on drone use in tropical forests and mentioned that in their environment, drone users should be wary of actors that could potentially threaten the users. These threats could be for instance illegal actors such as illegal loggers, poachers or drug producers.

As another downside of the fast development, the legislation is not always able to stay up to date with the technology and regulations can be ambiguous towards the drone use (Paneque-Gálvez et al., 2014). Changing the legislation may be needed to make the drone use more viable (Tuominen et al., 2015). As the legislation can be different in each country it can potentially complicate the creation of standards for drones. Restrictions to drones could be related to their size, speed or frequency of remote controller for instance.

3.9 Requirements derived from the literature

The results with the structured literature review with the identified benefits and challenges were pieced together into a set of requirements that could provide the basis for a good drone based measurement system design. The system should meet the benefits and advantages that were noted in the literature and it should also attempt to counter the challenges that were commonly faced when using the drones. Some of the requirements were mentioned directly in the analyzed primary studies but some were the author's own interpretation. For instance, Ehsani and Maja (2013) warned of drones being prone to software bugs. This was interpreted as a requirement L-R15, according to which the drone's firmware should have regular updates in order to fix these potential bugs.

In the requirements, which are listed in Table 1, the term *system* refers to the entirety of the designed system including the used hardware, software, the processes related to them and their use. *Drone* refers to the used drone equipment and *software* to the application that was used to process the photographs and other data provided by the drone. The requirements should be adapted according to used case as not all of them might be applicable in all situations.

Table 1. The requirements from the literature.

Requirement ID	Requirement description
L-R1	The system should be inexpensive (Gademer et al., 2010).
L-R2	The system's use should be able to be timed whenever the user wishes (Gademer et al., 2010).
L-R3	The system should produce as accurate results as LIDAR (Zarco-Tejada et al., 2014).
L-R4	The system should reduce the need for manual human labor (Merino et al., 2012).
L-R5	The system should reduce time needed for measurement tasks (Gademer et al., 2010; Merino et al., 2012).
L-R6	The movement and photographing of the drone should be unhindered by wind (Borra-Serrano et al., 2015; Gatziolis et al., 2015; Kattenborn et al., 2014; Martin et al., 2015; Merino et al., 2012; Primicerio et al., 2012).
L-R7	Sun illumination should not hamper the photographing of the drone (Gatziolis et al., 2015).
L-R8	Lack of sunlight should not hamper the photographing of the drone (Gatziolis et al., 2015).
L-R9	Repeating patterns and colors on the ground should not prevent the creation and analysis of 3D models used in measurement tasks (Borra-Serrano et al., 2015).
L-R10	Complex landscape patterns should not prevent the creation and processing of 3D models used in measurement tasks (Diaz-Varela et al., 2014).
L-R11	Ground control points should be used in the measured area for improved measurement results (Gago et al., 2015).
L-R12	The drone should have a GPS receiver embedded to it for improved measurement results (Gago et al., 2015; Gatziolis et al., 2015).
L-R13	The drone should have a battery that can endure for the duration of the whole flight use (Borra-Serrano et al., 2015; Martin et al., 2015; Merino et al., 2012; Primicerio et al., 2012).
L-R14	The drone should have a backup battery that can be changed when needed (Gago et al., 2015).

L-R15	The drone should have upgradable firmware in case of software bugs (Ehsani & Maja, 2013).
L-R16	The software should have regular updates in case of software bugs (Ehsani & Maja, 2013; Rasmussen et al., 2013).
L-R17	The use of system should require minimal amount of technical knowledge (Gago et al., 2015; Primicerio et al., 2012; Rasmussen et al., 2013; Zahawi et al., 2015).
L-R18	The drone should be able to fly as automatically as possible (Primicerio et al., 2012).
L-R19	The drone should be repairable through warranty or purchasable spare parts (Zahawi et al., 2015).
L-R20	The drone should be controllable without visual contact (Hernandez et al., 2013).
L-R21	The drone should be able to safely land in case the remote controller malfunctions (Merino et al., 2012).
L-R22	Multiple drones should be able to operate and collaborate simultaneously (Merino et al., 2012).
L-R23	The drone should be upgradable to new features to minimize the need to buy new models (Córcoles et al., 2013; Paneque-Gálvez et al., 2014).
L-R24	The drone should be used so that it does not cause any risk or harm to people (Paneque-Gálvez et al., 2014).
L-R25	The drone should avoid taking pictures of bystanders moving in the targeted area (Paneque-Gálvez et al., 2014).
L-R26	The system should be adapted to work within local regulations and legislation (Paneque-Gálvez et al., 2014; Tuominen et al., 2015).

4. Design

With the support of the theoretical requirements created in the structured literature review, the development of the system could begin. This meant implementing the system as a pilot project. The system was developed iteratively in cycles in the way the design process was described in Chapter 2.1.

4.1 Developing the requirements

Requirements for the system were designed to provide the basis for how the system should be built and to which the implemented pilot system should be compared against during the evaluation. The requirements consisted of two parts. First, there were requirements that were derived from the existing research that was analyzed in the structured literature review. Secondly, there were the requirements provided by the company, which were based on the goals and objectives of the pilot project. These were then combined to constitute the final requirements for the system.

The company's requirements were gathered by designing them with development engineers working at the company. They were working with the maintenance and development of the coke plant and the different information systems used to support the coke plant's functions and had thus a good understanding of what was needed from the designed system. The requirements were created by first taking a look at the current situation of how the measurement tasks are done without the drone technology. These methods were then compared against the wanted outcome with the drone. The research was also treated as a project with practical needs. As the aim was to prove the feasibility of the technology, the requirements also included different threshold values and minimum qualities that the project had to meet in order to be beneficial in practice. In short, the wanted outcome was that the system should be able to produce accurate results inexpensively and on a regular basis, while operating as automatically as possible.

4.1.1 Existing measurement methods and company requirements

The interest of this thesis was towards the measurement of outdoor material fields in general. For the implemented pilot project, the coal field belonging to the coke plant of the factory was chosen as the examined target area. This was due to practical reasons as the people working with this project were also working at the coke plant. Because the pilot focused on the coal field, the requirements of the system were designed by taking the coke plant's needs into account. Despite the focus, the coke plant's field faces the same needs and limitations as the other material fields in the factory area and thus the knowledge learned from the results could be well utilized in other locations for similar measurement purposes.

The coal field consists of vast mounds made of different coal types, which are the target of different measurement tasks. The coal types are used in a coal blend, which is used for the coke making process. As there are different types of coal with differing qualities, it is important that they will not get mixed before they are actually used for the coal blend.

Before being processed, the coal is stored in the coal field. There it is measured in different ways and at various stages in the coal's "life cycle", meaning the time between the moment when it is brought to the factory area and the moment when it is processed in the coke plant. These different measurement methods are described below.

First, the mass of the coal is weighed when it is unloaded from the ships delivering the coal to the factory's harbor. The measured coal is then delivered by trucks to the material field in the factory area. After the coal has been placed on the material field for storage and later use, it is eventually transferred by loader vehicles moving in the material field to be used in the coke plant. To move the coal to the coke plant, it is dropped in the receiving container by the loaders (Fig. 2). Beneath these containers are conveyor belts which have scales used for measuring the amount of coal used. The time it takes for a whole coal mound to be used from the material field varies a lot, and it could take several months, depending on the coal types needed for the coal blend. After being transferred to the coke plant, the amount of coal used is measured for the last time when it is used for the coal blend and the coke making process.

Figure 2. A loader vehicle delivering coal to a container where the coal's mass is measured.

When the coal is stored in the material field as separate coal mounds, the shapes of the mounds, which are also called geometries, are measured. This is done by having a person walk alongside the edges of the coal mounds while carrying a backpack equipped with a GPS receiver (Fig. 3). The GPS coordinates of the edges of the coal mounds are recorded as the walking person's position and then transferred to a database for later use. To correct the errors happening with the normal GPS, the backpack has a radio receiving DGPS (Differential GPS) signal from the factory area. The other components of the backpack solution are a tablet PC which is used for turning the GPS recording on and off, a controller which can be used to change settings related to the GPS receiver and a battery which powers up the system. This geometry measurement process is done when the coal first arrives in the field and then occasionally when the coal has been used and the mounds have reduced in size. The problems related to this method are the need for somebody to actually walk around the area and having occasional problems with the signals. These tasks always take some time as the material field is in a separate area from the coke plant's office and the material field itself is a large area as are the coal mounds positioned there. There is usually a traffic in the area too as the trucks and loader vehicles are moving around, which has to be taken into account when moving in the area.

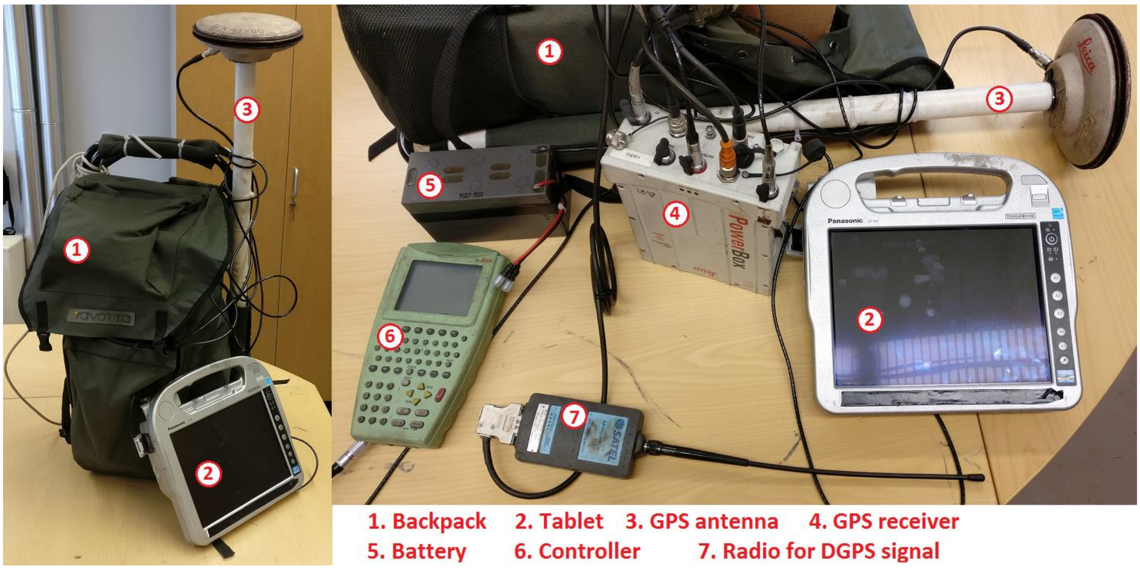

Figure 3. GPS equipped backpack and its components. Packed on the left and unpacked on the right.

After the GPS positions of the measured mounds are transferred to a database, they are used in CHMS (Coke Handling Management System) program to visualize the locations of the mounds on a map and to mark them with different information regarding the mounds such as the coal's quality, mass and if they are being currently used for the coke making process. The visualized coal mound locations are an important part of a daily coal use and the coal field management.

Alongside with these more frequent methods, the coal in the material field is also measured four times a year by an external contractor with LIDAR based laser mapping. LIDAR (Light detection and ranging) is a laser based technology, which measures distances by calculating time it takes for an emitted laser to travel to the targeted object. This can be used for surveying purposes by creating very accurate 3D point clouds from the laser distance data.

At the factory, the contractor conducting the LIDAR mapping uses a Riegl VZ-400 type laser scanner model (Fig. 4). The scanner is positioned on a tripod and moved around the measured area by carrying it by foot. The scanner is capable of mapping details at the distance of approximately 600 meters. Depending on the shape and size of the measured target, the amount of used positions needed for mapping varies. To cover a whole coal mound, it can be enough to map the target from three different positions around it to get all the angles covered. There is a possibility to use GPS with the LIDAR but in these tasks it has been determined unnecessary as the GPS does not have enough accuracy to improve the scanning. The scanned results are processed in Riegl RiSCAN Pro program and created as a point cloud from which calculations can be made. Results from calculations include volume of the coal mounds, which can be used for inventory and management purposes.

Figure 4. LIDAR scanner positioned on a tripod is used to measure the coal mounds.

Although using LIDAR based mapping is accurate, it is also expensive and having the measurement done every three months is a very long time span as the coal mounds' positions and sizes are changing all the time as they are used for the coke making process. There is a need to have both cheaper and more often usable complementary methods to perform these measurements and that is what the drone based system could have potential for.

As a conclusion from the current situation, there are mainly three different sorts of measurement data gathered:

- The mass which is calculated at various points of the coal's life cycle.
- The location and shape of a coal mound which are measured at the beginning and occasionally during the coal's life cycle.
- The volume which is calculated approximately four times a year

It was recognized that with the drone it could be possible to get all these three types of measurements done. The location, the shape and the volume could be obtained by proper software processing the drone's data and getting them was an objective for the project. The coal's mass could be obtained too by dividing the volume of the coal with the theoretical density of the coal. However, the results would be highly inaccurate as the actual density varies a lot. The change in density generally happens when the loader vehicle builds the coal mound. The coal mounds are often built into two layers which means that when the first layer is built, the loader vehicle has to drive over the first layer to create the second one. This causes the lower layer to become thicker. As the material fields are outdoors, they are also exposed to rain which heavily alters the density. Hence the calculation of mass was left out from the objectives of the pilot project. It could still be useful in the future for other material fields, which store solid material with fixed density.

Having recognized the current situation and its shortcomings, several requirements could be created for the system. Discussing more about the system and its wanted features with the company's professionals also yielded more detailed requirements. It was required that the system should be both cheaper and faster to use than the current methods while also being capable of creating as accurate and as applicable results. The system should also be able to be used on a regular basis. Despite being first implemented at the coke plant, the design of the system should take into notice the need to possibly expand the system around the factory area.

The local regulations, which had to be taken into account, were investigated in order to see if additional requirements were needed. It was discovered that a new regulation concerning drone use in Finland came into effect on 9.10.2015. According to Trafi, the Finnish Transport Safety Agency, all drone flights, which are used for professional purposes have to be logged for 3 years (Trafi, 2015). In this case, the term professional does not only mean direct monetary gain and the use of the drone based system at the company was seen as belonging to the professional classification. Because of this, the logging feature was added as a mandatory aspect of the system.

It was noted that like in the requirements from the literature that were designed earlier, the requirements should focus on the three main aspects of the system: the system as a whole, the drone that would be used to gather the data, and the software that would be used to process the data. Each of them had their own functional and qualitative needs that would have to be fulfilled in order for the system to succeed. Both the practical needs from the company and the regulatory aspects were finally pieced together into the company requirements listed in Table 2.

Table 2. The company requirements.

Requirement ID	**Requirement description**
C-R1	The system should produce 3D models from measured targets in common formats
C-R2	The system should be able to calculate volumes from measured targets
C-R3	The system should be able to present the measured target's shape and location on a georeferenced map
C-R4	The system should store logs from the flights
C-R5	The system should use a drone equipped with a digital camera
C-R6	The system should use a drone equipped with a GPS receiver in order to produce the measured target's location and to improve the measurement results
C-R7	The system should use a drone with a minimum of 15 minutes flight time
C-R8	The system should stay within a 20 000 € budget and have maintenance costs lower than LIDAR based solution
C-R9	Volume measurements done by the system should be as close as possible to the measurements done by LIDAR
C-R10	Shape and location measurement done by the system should produce as accurate results as the GPS equipped backpack method
C-R11	The system should use a drone capable of flying at the altitude of at least 30 meters
C-R12	The system should reduce time needed for measurement tasks when compared to existing methods
C-R13	The system should reduce the need for manual human labor when compared to existing methods
C-R14	The system should be usable for measurement tasks on at least a weekly basis
C-R15	The measurement process as a whole should have a 24 hour completion time, including data gathering and processing
C-R16	The system should be able to be integrated to company's Coke Handling and Management System (CHMS)
C-R17	The system should be transferable around the factory area
C-R18	The system should use a drone with at least 500 m transmission distance
C-R19	The system should use a drone with a partial autopilot support
C-R20	The system should be usable during winter in below-zero temperatures
C-R21	The system should not be dependent on the model of drone used
C-R22	The system should be able to be used with minimal training by people with technical background
C-R23	The system should use both drone and processing software with sufficient customer and technical support available
C-R24	The system should comply with local regulations and legislation
C-R25	In a case of regulations restricting the drone use, a plan to keep the system working should be implemented
C-R26	The measurement data and material should be consistent and verifiable for a decided time span
C-R27	The data should be backed up on a file server

4.1.2 Final requirements

After developing the company related requirements, they could be combined with the requirements from the literature into the final requirements as shown in Table 3. The requirements were listed in an approximated order of importance.

For the final requirements, the overlapping or very similar requirements from the literature and the company were merged and the requirements not seen as relevant in the project were left out. Some of the main rationales for the final requirements that were seen to be essential to describe are following.

The 3D models, volume calculation, shape and location were the results that were needed for the measurement. They were the main functions that the system had to be able to produce. The flight logs were needed to fulfill the local legislation, which requires storing the main details about all the drone flights for three years. The different threshold values such as budget, maintenance costs, flight height and marginal error were decided by the company in order for the system to be beneficial in practice when considering the financial factors, existing methods and the environment of the material fields.

Some of the requirements were left out from the final requirements. Since the system had to have a support for GPS, the need for ground control points was left out. Being able to fly as automatically as possible was refined as a need for a partial autopilot though the automatic flying was seen as a thing to consider in the future. Even though the requirement for being able to fly the drone without visual contact would be a good feature, it was left out due to being against the local regulations concerning the drones. The support for multiple drones operating and collaborating simultaneously was also a good feature but it was seen as something beyond this project and as a thing to be considered in the future.

Table 3. Final requirements.

Requirement ID	Requirement description
R1	The system should produce 3D models from measured targets in common formats
R2	The system should be able to calculate volumes from measured targets
R3	The system should be able to present the measured target's shape and location on a georeferenced map
R4	The system should store logs from the flights
R5	The system should use a drone equipped with a digital camera
R6	The system should use a drone equipped with a GPS receiver in order to produce the measured target's location and to improve the measurement results
R7	The system should use a drone with a minimum of 15 minutes flight time
R8	The system should stay within a 20 000 € budget and have maintenance costs lower than LIDAR based solution
R9	Volume measurements done by the system should be as close as possible to the measurements done by LIDAR
R10	Shape and location measurement done by the system should produce as accurate results as the GPS equipped backpack method
R11	The system should use a drone capable of flying at the altitude of at least 30 meters

R12	The system should reduce time needed for measurement tasks when compared to existing methods
R13	The system should reduce the need for manual human labor when compared to existing methods
R14	The system’s use should be able to be timed whenever the user wishes, with measurement tasks being doable on at least a weekly basis
R15	The measurement process as a whole should have a 24 hour completion time, including data gathering and processing
R16	The system should be able to be integrated to the company’s Coke Handling and Management System (CHMS)
R17	The system should be transferable around the factory area
R18	The system should use a drone with at least 500 meter transmission distance
R19	The system should use a drone with at least a partial autopilot support
R20	The system should use a drone with changeable battery
R21	The system should be usable during winter in below-zero temperatures
R22	The system should be usable during windy weather, having drone’s movement and photographing unhindered by the wind
R23	Sun illumination should not hamper the photographing of the drone
R24	Lack of sunlight should not hamper the photographing of the drone
R25	Repeating patterns and colors on the ground should not prevent the creation and processing of 3D models used for the measurement tasks
R26	Complex landscape patterns should not prevent the creation and analysis of 3D models used in measurement tasks
R27	The system should not be dependent on the model of drone used
R28	The system should be able to be used with minimal training by people with technical background
R29	The drone should have upgradable firmware in case of software bugs
R30	The software should have regular updates in case of software bugs
R31	The system should use both drone and processing software with sufficient customer and technical support available
R32	The drone should be repairable through warranty or purchasable spare parts
R33	The drone should be upgradable to new features to minimize the need to buy new models
R34	The drone should be able to safely land in case the remote controller malfunctions
R35	The system should comply with local regulations and legislation
R36	In a case of regulations restricting the drone use, a plan to keep the system working should be implemented
R37	The measurement data and material should be consistent and verifiable for a decided time span
R38	The data should be backed up on a file server
R39	The drone should be used so that it does not cause any risk or harm to people
R40	The drone should avoid taking pictures of bystanders moving in the targeted area

The final requirements were verified with the professionals from the company. The requirements were evaluated as being acceptable and valid in the scope of the pilot project. The cycle could be completed and the created requirements used to support the decisions for designing the system structure.

4.2 Designing the system structure

With the requirements properly developed, the structure of the system had to be designed. This included designing how the different components related to each other. It also meant designing the workflow for the system's use.

The structure of the system was dependent on four main components that had been recognized from the literature and from the practical needs. These were the drone, the processing software, a workstation and a logbook. A proper drone model was to be used for getting the measurement data by taking photographs. Applicable software was to be used for processing the drone's data into 3D models and creating the actual measurements. A dedicated workstation PC to process the drone's data with the chosen software was needed too. In addition, as the need for logging the flight information was discovered in the development of the requirements, developing a logbook application was decided to be a part of the system structure's design. Finally, an existing Microsoft SQL database running on the company's server could be used to store the data. This structure of the system is presented in Figure 5.

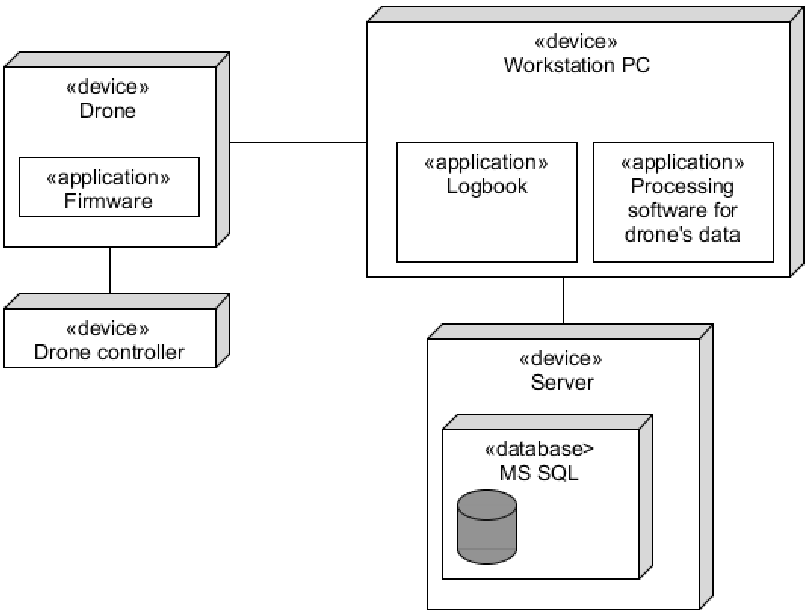

Figure 5. Deployment diagram describing the system structure.

The workflow to describe how the system would be used was designed. Figure 6 illustrates the ideal workflow expected from the working system with all the components in place. As described in the figure, the workflow begins with the planning of the flight. This means mostly the tasks of deciding on which material mounds should be measured, scheduling the time the flight is done and determining if there are any special concerns that should be taken into account. Then, if the weather permits, the drone can be flown over the material field and the wanted pictures taken. If the weather conditions are not good enough, the flight has to be rescheduled.

When the flight can be carried out and the pictures taken, the outcome is the set of pictures, which are the raw data for the measurement. The pictures are transferred to a workstation PC, from which two different tasks can be done simultaneously. First, the information concerning the flight can be logged and then, the pictures can be processed in a creation of a 3D model. From the 3D model, the volume and shape of the target can be measured. These three outcomes of flight log, volume and shape can then all be saved to a database to be used in inventory and material management purposes.

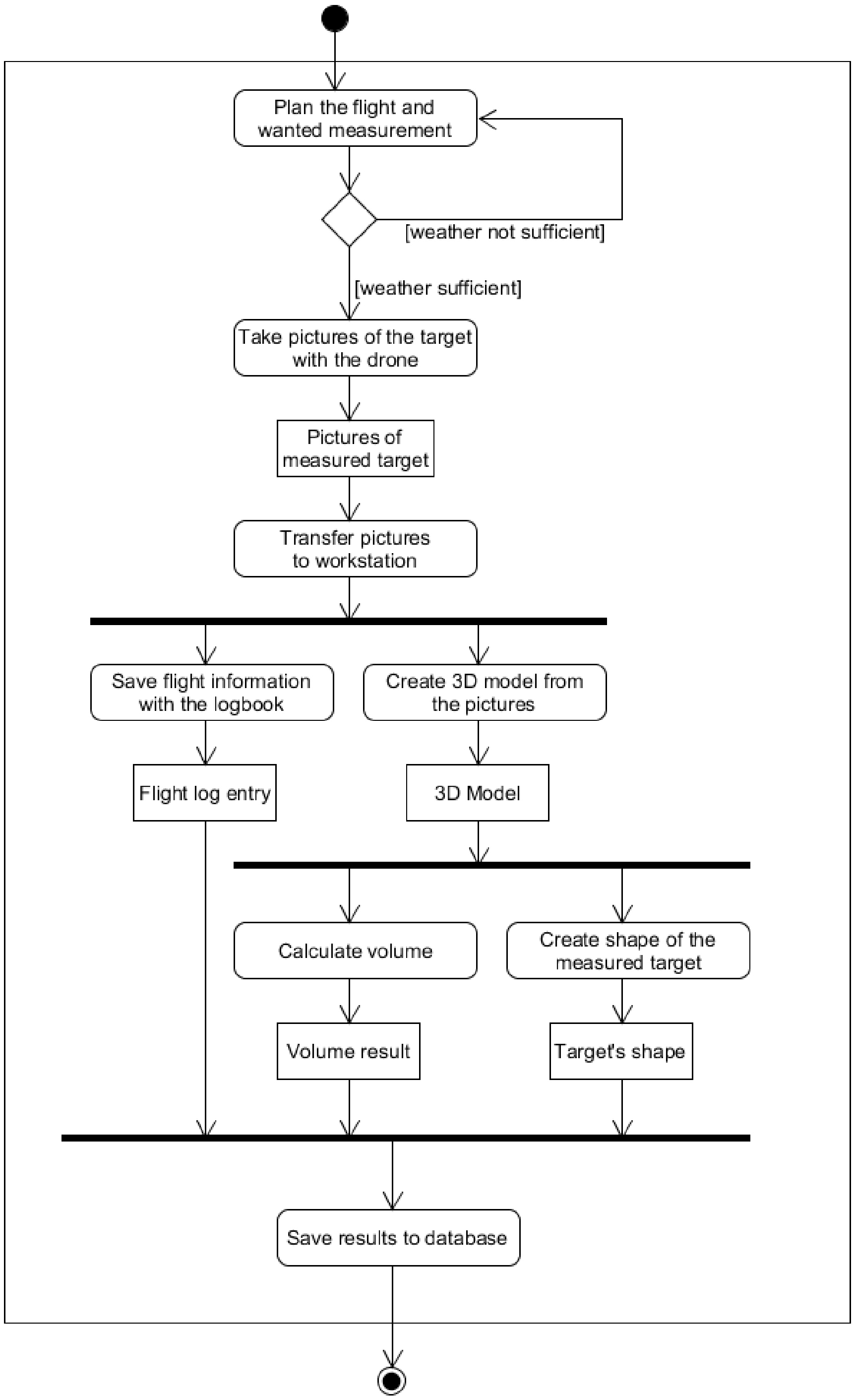

Figure 6. Activity diagram describing the system's workflow.

Both the structure and the workflow were estimated to be in line with the requirements and they could make the system work in practice. It was noted that the later cycles could possibly alter either the structure or the workflow and there might be a need to eventually revise them.

4.2.1 Developing the logbook

According to regulation by Trafi, the Finnish Transport Safety Agency, the information regarding all the drone flights, where the drone is used for professional purposes, must be stored for 3 years (Trafi, 2015). This made the flight logging a mandatory part of the system.

The information needed for each flight has to include the date and time of the flight, the place where the flight took place, who was the pilot of the drone, what kind of drone model was used, was the flight done within visual line of sight (VLOS) or beyond visual line of sight (BVLOS), description for the nature of the flight and a mention if a possible lookout person for the drone was part of the flight mission.

Writing down all this information after each flight was seen as a rather laborious task. The system, of which the flight log was part of, was required to have good degree automation with reduced manual work. For this purpose, a logbook application was developed.

When the system is being continuously used in the same area, like the coke plant in this project, most of the information regarding the flight stays the same between the flights. It is usually just the date and time and possibly the pilot that keep changing. This was taken into account when developing the logbook which was implemented as a C# based WPF (Windows Presentation Foundation) application.

The application, which consists of views for adding a new flight log and searching the existing ones, was developed to have prefilled values for the mostly constant information (Fig. 7). In the optimal situation, the user has to add only the time of the flight in order for the log to be complete. Adding the time of the flight can be done either by typing the time manually or preferably more automatically by selecting the folder where the pictures taken by the drone are located. How the latter option works is that the application goes through the metadata of all the pictures in the folder and checks the timestamps of when the pictures were taken. The oldest and newest pictures' timestamps are then saved as the timespan of when the flight occurred. Alongside with the timestamps, the GPS locations of these pictures are stored as extra data to improve the accuracy of where the flight took place.

The idea behind the more automatic approach for getting the timestamps is that the flight logging can be conveniently combined with the task of transferring the drone's pictures for processing. As the person operating the drone connects the drone to a computer to transfer the pictures from the flight, he transfers the pictures to a predetermined directory from which the processing is done with the processing software. By opening the logbook, the user can select the same directory as the source for flight's timestamps and in this way it is possible to save the flight information with only as few as three mouse clicks.

Figure 7. The logbook application with the default view for adding a new flight log entry.

In addition to adding new log entries, the application also provides a view where all the existing flight records are shown in a table. The view is only meant for browsing the existing records but if the system is kept in development in the future, it would be possible to be expanded to have features for comparing and analyzing the flight records.

With the logbook successfully implemented, it could fit both in the designed system structure and workflow and make moving into the next cycle possible.

4.3 Choosing the drone

With the system structure and workflow planned, the next cycle was the choosing of the drone model to be used. The choice for the model was based on multiple requirements and factors. Still, as this was only a pilot test, there was no need to spend a lot of time on the decision making process for the drone equipment; it just had to be good enough to meet the requirements and be capable of performing the tasks wanted from it.

As could be understood from the structured literature review, the technology around the drones has rapidly advanced in the last couple of years and so the model that was chosen could already be outdated on some levels when the pilot test was over. This was one factor for making the decision quickly and getting a drone that was relatively cheap but still well performing.

The drone needed to have a digital camera equipped with. As mentioned in the structured literature review, drones can also be equipped with for instance LIDAR laser scanners or even radiation mapping units to perform different measurement tasks of their surroundings. Still, using a camera based solution instead of LIDAR was an interest of this thesis in order to test the technology's potential. Cameras are a lot cheaper than LIDAR and the inexpensiveness was one of the project's key aspects. As digital cameras nowadays are capable of megapixel level of resolution, it is possible to use them for these kinds of high accuracy tasks. Use of normal cameras also has the benefit of producing images, which are easily understandable and decipherable to human eye. LIDAR can produce point clouds with colors but it is still often more convenient to handle normal photos that are familiar from everyday life. Using the drone for taking photos could potentially have other uses too besides the wanted measurement tasks.

Another factor to be taken into consideration was a GPS receiver included with the drone. GPS coordinates would be needed to produce the shape and location data of the measured targets, which was one of the requirements from the company. With a GPS receiver, measurement tasks with the software could potentially be faster and more accurate too. The system itself being as automatic and easy to use as possible was stated as one of the requirements. Without GPS metadata attached to the pictures, pictures taken with the drone would have to be aligned together manually by recognizing ground control points in the pictures. More than that, the ground control points themselves would have to be set up in the measured terrain before the drone's flight, becoming extra laborious if the measured area keeps changing or the control points cannot be left in the area permanently.

The GPS receiver could also make using a predefined flight route possible if the drone itself had a support for it. This could make the measurement faster as the drone could be sent to take pictures automatically without having someone piloting it manually. This aligned well with the requirements of reduced manual work, more automation and a capability of using an autopilot.

Having a gimbal with the drone's camera was seen as an advantage as it would make taking high quality pictures easier. Balancing the camera with a gimbal could let the drone fly at a higher speed and make faster turns. It could also help keeping the camera steady in a case of windy weather.

Weather was also a factor; the drone should be able to fly in a temperature of at least a couple of degrees minus Celsius so that it could be used during winter at the company's factory. As the factory is located close to the sea, the weather can often get both windy and cold. Besides the gimbal, it would also be useful if the drone could resist wind by having strong enough motors to keep itself steady.

Yet another wanted feature was to have as long flight time as possible for the drone. The material fields, including the coal field of the pilot project are large areas where a long flight time is a clear benefit. Not having to recharge or change the drone's battery and perform multiple flights would obviously save time aligning well with the requirements of reduced time and labour.

After defining the demanded features for the drone and looking at some of the options, a drone model called DJI Phantom 3 Advanced (Fig. 8) was proposed to be used in the project. It fulfilled the requirements well and had an active online support for troubleshooting, including an official discussion forum dedicated to this specific model with more than 11000 threads (DJI Forum, n.d.). Despite being outside of the project's scope, the manufacturer supported users to develop their own software to control the drone with their software development kit (DJI Developer, n.d.). This could be used to enhance the drone's functionality in the future. The drone was also for sale from one of the specific vendors that were preferred to be used to conform to the company rules. Finally, the model also had positive reviews (Engadget, 2015; Gizmodo, 2015), which further supported the decision.

DJI Phantom 3 Advanced was thus decided to be acquired for the pilot project. Decision to buy it was also a rather lucky one as an alternative which was considered, DJI Inspire 1 model from the same manufacturer, was temporarily banned in Finland by the Finnish Communications Regulatory Authority due to not fulfilling technical requirements in legislation regarding the frequencies in which the drones can operate in (Viestintävirasto, 2015).

Figure 8. DJI Phantom 3 Advanced drone and the remote controller with an Apple iPad.

The main features corresponding to the requirements could be read from the manufacturer's product description (DJI, n.d.). Phantom 3 Advanced had a GPS support, integrated gimbal, 23 minutes flight time, 12,4 megapixel resolution camera, up to 3,5 km transmission distance and capability to operate even in -20 degrees Celsius when a battery heater was attached. The remote controller also had a support for various iOS and Android compatible devices, which could be used for setting predefined flight routes and to provide live video feed from the drone. All these features lined up nicely with the requirements set up for the drone. More in detail look at the different drone models was decided to be taken if the thesis and the project included were successful and there was an interest to continue researching the drone technology for measurement purposes.

In addition to the drone itself, some other components were needed to make using it feasible. A tablet was needed to be used with the controller for running the drone's mobile application to get a live feed from the drone. Apple iPad was purchased for this purpose (Fig. 8), though it could also be used to support other tasks too at the coke plant's office. An extra battery was acquired to make longer flight sessions possible. 16 GB SD memory card was bought to be used to save and transfer the pictures between the drone and the workstation. A case to carry and store the drone was obtained (Fig. 9). With the case, the drone could be easily moved around the factory area according to measurement needs. Battery heater purchasable from the drone's manufacturer was not yet acquired but getting one was deemed possible if the project was to succeed.

Figure 9. A case to carry and store the drone was one of the additional acquisitions.

The choice was evaluated as being in line with the requirements and the system structure. The chosen drone could also support the system's workflow. This made the cycle complete and possible to move in to the next step of choosing the proper processing software.

4.4 Choosing the software

For processing the data gathered by the drone specialized software had to be used. The software had to be in line with the requirements, system structure and workflow and be compatible with the chosen drone model. For the software's features, it had to be capable of creating 3D models from photographs, have a support for including GPS coordinates in the models, have the ability to export the models' coordinates from the software and be capable of accurately calculating volumes from the models.

In the process of looking for applicable programs, two good alternatives were found that fit these purposes: Agisoft Photoscan and Pix4D Mapper Pro. Other similar programs exist too but in the scope of the pilot project it was deemed enough to focus on these two.

Photoscan is a program intended for photogrammetric processing of digital images and generation of 3D spatial data in GIS (Geographical Information System) applications and for measurement and visual effect production in general (Agisoft, n.d.). Pix4D Mapper Pro is a program dedicated especially for drone based mapping created from images (Pix4D, n.d.).

Both programs are relatively expensive and as the project had to stay within a budget, a decision to buy either of them had to be made. Finding out which one to use was decided by trying out the programs with free trial editions. Trial editions offered access to most of the functionality of the full software for a limited time. The programs were compared by trying out their volume calculation capabilities and accuracy in a practical test.

The accuracy of volume measurement calculation was done by taking photographs with the chosen DJI Phantom 3 Advanced drone and then processing these pictures with both of the candidate software. For the test, a standard shipping container (Fig. 10) was placed on flat ground in an open area. The shipping container was chosen for the test as it has straight lines and its actual size can be easily verified. The container had a verified volume of 88,11 m^3. This was a bit more than the official container size as the container was slightly above the ground due to some rocks under it. The volume measurement results from both programs could be compared to this verified size of the container.

Figure 10. Container which was photographed by the drone in an attempt to determine software accuracy.

To test the drone’s and candidate programs’ capabilities, multiple flights from different altitudes were done. Flights were done from the altitudes of 15 meters, 30 meters and 45 meters. 20 photos were taken during each flight, making sure the container was covered from every angle. In the actual coal field, the drone has to fly at the altitude of at least 30 meters due to lighting poles limiting the flying in the area. In other locations the altitude might vary if the system is to be used for other measurement tasks in the future.

Flying was done by having the drone fly around the container in a circle, facing the camera towards the container all the time. This was the recommended way of doing the picture capturing process when dealing with a single object of a rather small size (Agisoft, n.d.).

The pictures were transferred to a computer where both Photoscan and Pix4D Mapper Pro were installed. With both programs, 3D models were created from pictures from each altitude. Pictures that were taken with the drone had 12-megapixel accuracy, were in JPEG-format and had GPS coordinates of the drone's location in WGS84 projection saved in the metadata of the picture.

In both programs the model creation consisted of similar phases: aligning the pictures according to their position, creating a point cloud and a more detailed 3D model. Measuring the volume of the container required separating the container from the background. The separation was done by hand by marking the edges of the container. Having separated the container's model from the background, the software had to interpolate the missing ground under the container. Finally, from this separated and completed model (Fig. 11) both programs could calculate the model's volume.

Figure 11. 3D model of the container which was separated from the surroundings in order to calculate its volume.

With both of the tested programs, multiple measurements were done by trying out different settings and combinations of pictures. The results from measurements were following. With Agisoft Photoscan, the volume results were within a range of 88,00 m^3 - 92,50 m^3. With Pix4D Mapper Pro, the volume results were within a range of 87,31 m^3 - 96,63 m^3. Despite the variance, the accuracy of both programs was surprisingly good. Photoscan's results were slightly closer to the actual size of 88,11 m^3 but the level of accuracy obtained from both programs was seen as sufficient for the system's needs and both programs could fulfill the requirements of the pilot project. The variance in results could be due to possibility of not having good enough pictures covering the target or having used some sub-optimal settings in the processing phase. Having to mark the measured area by hand also had a chance of causing inaccuracy. Because of the very accurate results, they could not be used as a reason to pick either of the programs. Some other aspects of the programs were studied.

Pix4D Mapper Pro was considered to have more user friendly and simplified user interface whereas the Photoscan was more complicated and required more from the user. Even though the automaticity and agility of the system were seen as requirements, the software itself was to be used by development engineers with a technical background so the user interface was not considered as a problem.

Photoscan supported Python scripts for automating the projects. It also had a support for creating processing work lists with which you could predetermine the wanted processes and their settings and complete the processing with a single action. Pix4D Mapper also had a support for batch scripts for automation but these were limited to owners of Enterprise Server License which could not be obtained in the scope of this project. Photoscan's Python script support was deemed as a great benefit as it could potentially increase the automation level of the system greatly by potentially integrating its functionality to other systems used in the company.

Either of the programs would have likely been a sufficient choice. In the scope of the pilot project the support for automated workflows and Python scripting was seen as a good reason to pick Photoscan. The scripting support is a great feature especially considering future developments of the system and the objective of aiming for as automated system as possible. If the system is seen as a success, the used software can be reconsidered in the future, as the system is not supposed to be dependent on any of its components.

As Photoscan was chosen, a license for Photoscan's Professional version was then acquired. To use the software, a dedicated workstation PC was also bought. According to the recommendations from Agisoft, the workstation was supplied with a significant amount of RAM (64 GB) that was needed when a lot pictures were used, and a well performing GPU (Nvidia GeForce GTX 980) and a CPU (Intel Core i7-5930K) to fasten the process of model creation.

The chosen software was evaluated as being in line with all the prior cycles and being able to fulfill the needs that were required from it. With the software acquired, the research could move into a cycle where the system was tested in practice.

4.5 Testing the system

With all the components in place and both the system's structure and workflow designed, the system was tested in practice. This included completing the workflow with the system and evaluating how well the system could follow it. The system and its workflow were tested multiple times in order to notice any potential deviations and other issues related to them. Deviations were possible as the system structure and the workflow were planned before acquisition of all the components and before actually testing the system in practice. If deviations were recognized, revising parts of the structure and the workflow were needed. The performance of the system was not yet evaluated as it was part of the evaluation of the whole system, which is presented in Chapter 5.

Testing the workflow began by planning the flight. This included scheduling the flight and deciding which the measured targets were. With the flight scheduled, the drone was used for taking pictures of the measured targets, which were coal mounds in the coke plant's coal field. It was noted during the multiple flights that were conducted that the pictures did not have to be taken from some absolute predetermined positions or angles and good results were possible even with varying methods. Still, the best results were seen by taking pictures of the target by facing the drone's camera straight down, flying in a grid-like pattern and having as good overlap of the target as possible. Then, to properly record the shapes of the walls of the coal mound, it was recommended to fly around the target in a circle, taking pictures by facing the camera downward in around 45 degree angle. For the flight to be completed, it had to be confirmed that enough pictures were taken. This should be reflected in the revised workflow. Also, the revised system structure should take into account the Apple iPad tablet which was running the drone manufacturer's mobile application and used with the controller during the flight.

With the pictures taken, they were transferred to the workstation PC used for the processing. An SD card was used as a method to transfer the pictures from the drone to the PC. This transfer method should be reflected in the revised system structure.

With the pictures transferred to the PC, two concurrent activities began: logging the flight and processing the data for measurements.

The flight information was logged successfully. The logbook's described actions in the workflow should be expanded by adding that the flight information is first attempted to be filled automatically by reading the pictures' metadata, after which the user is given an opportunity to confirm the information.

Processing the data for measurements began by importing the pictures into Photoscan. After this, the measurement process required several tasks: aligning of the pictures and creation of point cloud, dense cloud and mesh. Aligning the pictures meant positioning the pictures according to the coordinates that the pictures were taken from. The location data for each picture was saved in their metadata. Aligning the pictures resulted in a sparse point cloud. From this sparse point cloud, a more detailed dense cloud was processed. This was the most resource heavy part of the process, and depending on the wanted quality and the number of used pictures, it might take several hours of processing. Both the GPU and all the cores of the CPU were used to support the calculation for the dense cloud creation. With the dense cloud generated, a polygonal mesh was created. This gave the model an intact and more detailed surface. Missing parts of the model were interpolated according to surrounding points in the model. All these processing tasks were automated by loading a predefined task list, which was an XML file defining the wanted processing actions with specific settings. The outcome with the created mesh was a 3D model of both the coal mound and its surrounding area that the drone had photographed. All the phases of model creation are presented in Appendix A.

To be able to measure the target, it had to be separated from its surroundings. This was done by marking the borders of the mound by hand by using a cropping tool in the software. After marking the borders, the cropped mound was cut from the surroundings and the result was the 3D model of the mound (Fig. 12). As the mound had to be cropped by hand, it could lead to slight variance in the final results. Unlike in the case of the container measured during the choosing of the software, it is challenging to accurately recognize the point where the mound ends and the ground begins. This is due to similar coloring of both the mounds and the ground and the way of mounds being gently sloping near their edges. Because of this, the target may have to be cropped multiple times in order to get accurate results. This should also be stated in the revised workflow.

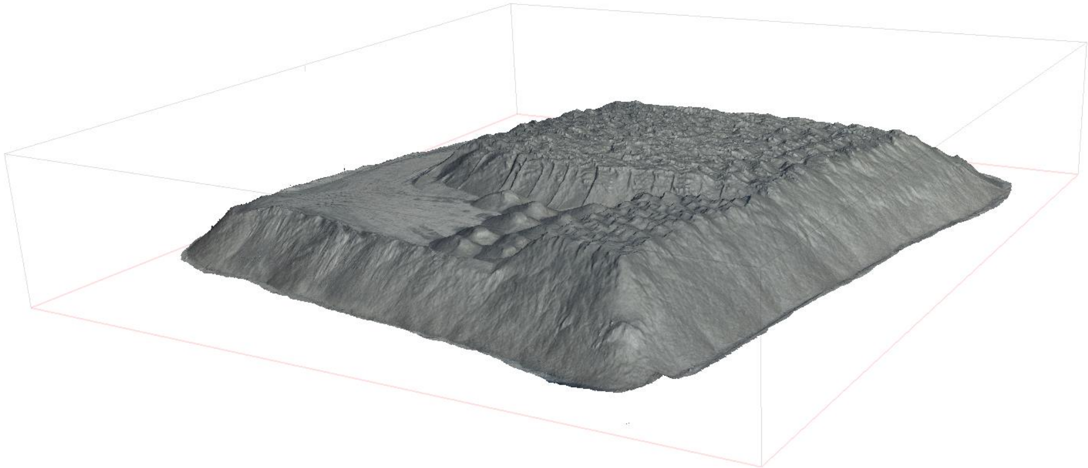

Figure 12. 3D model cropped from its surroundings.

From the ready 3D model, the two different measurement tasks started. First, the volume was measured. As the underneath of the mound did not have any texture, a straight layer had to be created for the volume calculation to be possible. This was done with close holes –feature, which connected the edges of the mound's bottom with a straight layer. Finally, a calculate volume -feature was used which presented the mound's volume in cubic meters (Fig. 13). The volume results were then saved into a database.

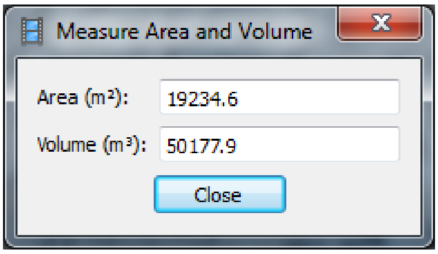

Figure 13. Volume of the mound, which was one of the wanted outcomes.

Measuring the target's shape and location required steps similar to the cropping of the model. The wanted shape was created with a tool for drawing points around the model (Fig. 14). These points were then connected with lines and they could be exported out of the program as a shapefile (.shp) which included the GPS location data.

Figure 14. White dots could be placed around the model by hand to form a uniform polyline (red), representing the model's shape and location.

As a final step for the shape measurement, a C# based application to parse the coordinates from the shapefile (Fig. 15) had to be developed. The shapefile can be treated as a text file where each border coordinate is placed in its own row, making parsing them a relatively straightforward process. The coordinates were then saved into a database for a future use in the material management program CHMS.

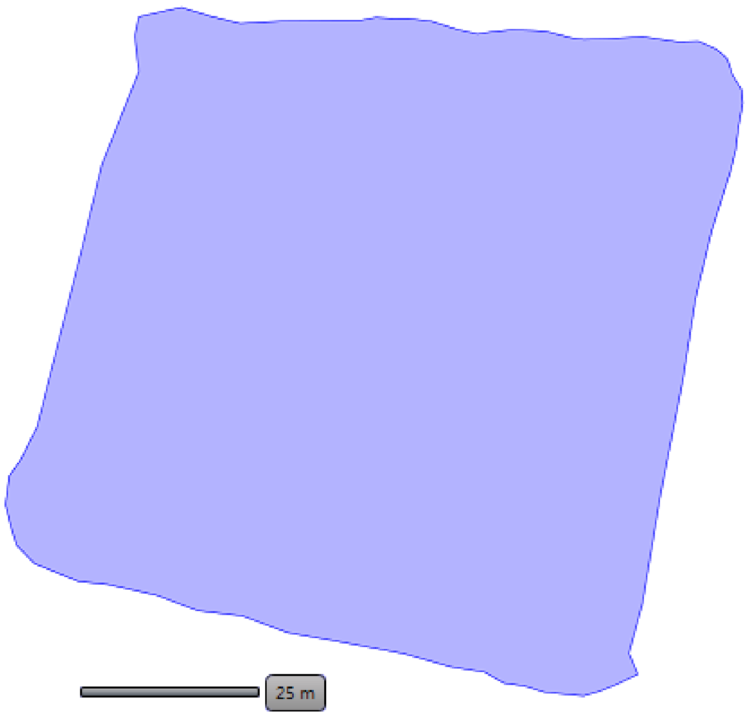

Figure 15. Shape of the mound visualized from the border coordinates. Shape and location was the second wanted outcome.

With the workflow completed, a revised version of the system structure and workflow was created. Using the system in practice showed that the system's use required additional steps in order to produce the wanted outcome. A revised structure of the system with the added details could be shown in Figure 16. A revised workflow of the system could be described in an activity diagram as shown in Figure 17. The revised workflow shows that many of the steps in the system's workflow need checks to see if the step has been successful or if it should be done again. This makes the system more reliable but it also has a chance to cause potential problems if the checks keep looping multiple times, causing the process to slow down.

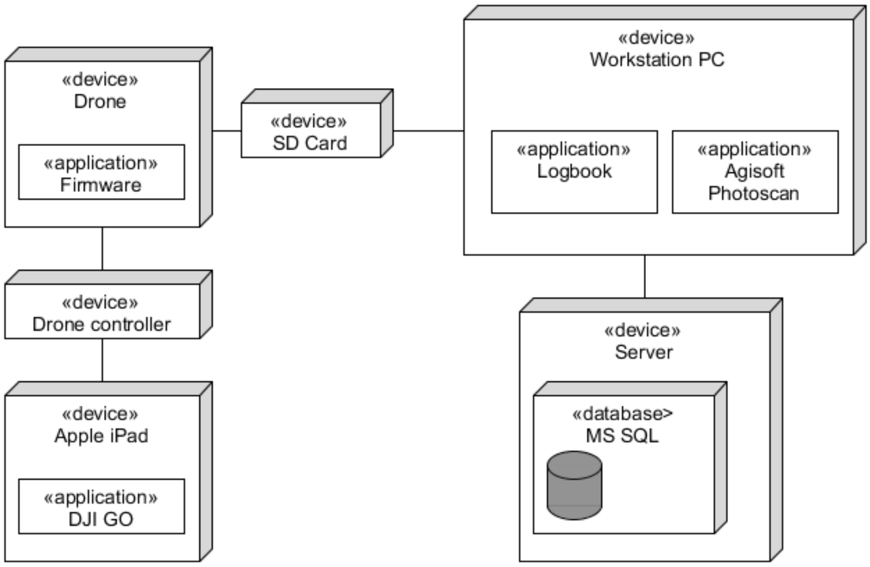

Figure 16. Revised structure of the system.

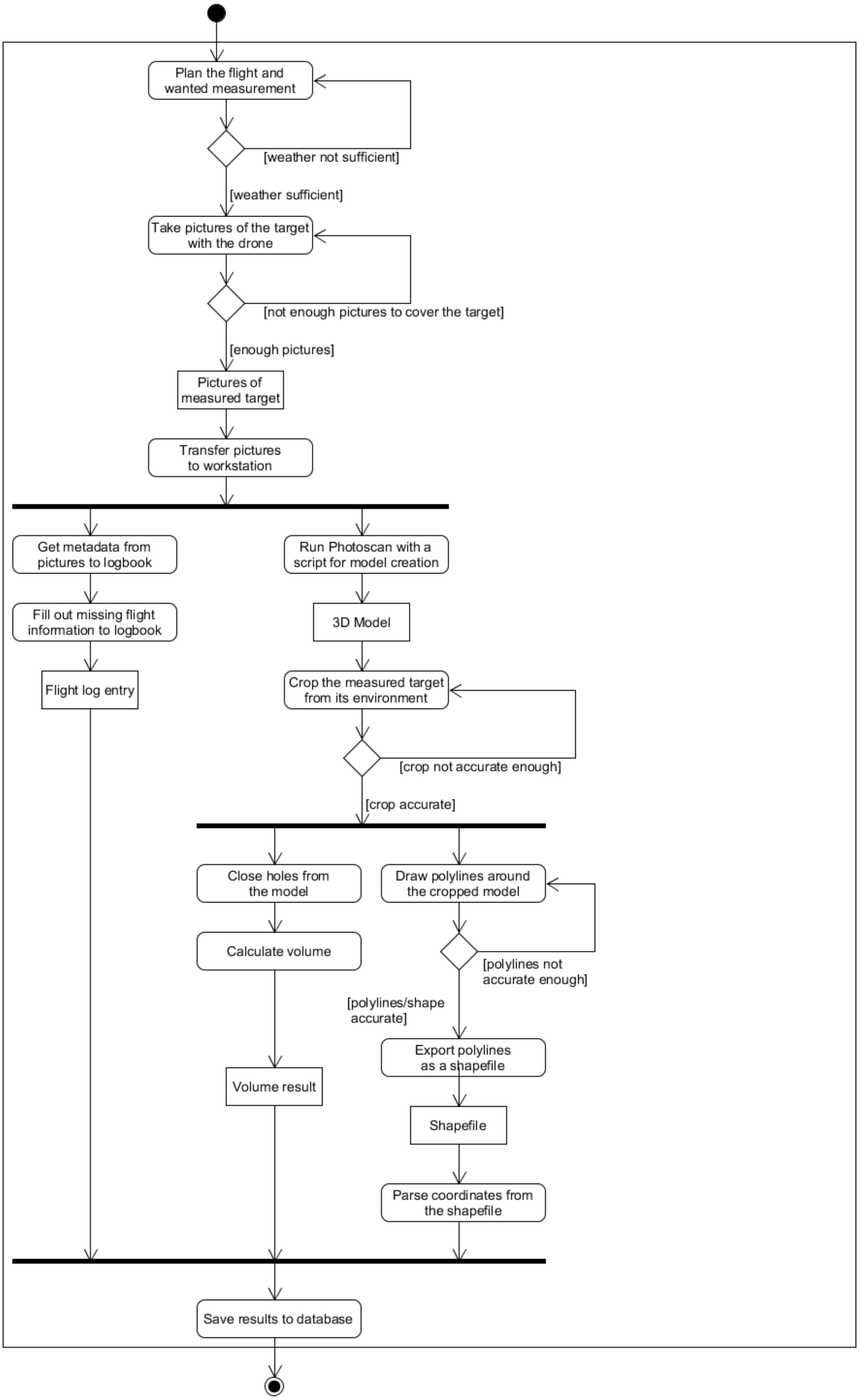

Figure 17. Revised workflow of the system.

With the system used in practice and its use and structure revised, the cycle could be completed and the system was ready to be evaluated as a whole.

5. Evaluation

As the design was completed, the implemented system could be evaluated. The smaller cycles completed in the design had been assessed as successful but a more rigorous and comprehensive evaluation for the whole system was needed.

The evaluation was done in two stages. First, the system's performance was compared against the traditional measurement system. Secondly, the system was compared against the requirements that it was designed with. The results from the evaluation could be used to understand how the system should be improved in future.

5.1 Comparison against the traditional measurement system

The system's performance was compared against the traditional measurement system by testing the system's measurement capabilities in practice. The testing included the system's main features of volume calculation and the shape and location measurement. The volume calculation was compared against LIDAR based solution and the measurement of coal mounds' shape and location was compared against the GPS equipped backpack method.

5.1.1 Volume measurement performance

The volume calculation part of the test was done at the material field of the factory's blast furnace. The test took place at the blast furnace instead of coke plant due to practical reasons as the external contractor conducting the LIDAR mapping was scanning the blast furnace's outdoor area there. Also, the personnel working at the blast furnace were interested in the drone's measurement capabilities. The test could thus provide beneficial information for both the blast furnace and the coke plant. The blast furnace's material field had coal mounds similar to ones located at the coke plant's field, making the measurement task and its results wholly comparable to measurements performed at the coke plant.

The target coal mound was around 24 meters by 13 meters in size, being smaller than coal mounds usually and requiring thus more accuracy. The mound was placed on a flat ground in an open area (Fig. 18). It was scanned first by LIDAR and then photographed with the drone.

Figure 18. Photograph of the mound that was measured.

The contractor scanned the coal mound with LIDAR by positioning the scanner on three different angles around the area. The scanned data was imported into RiSCAN Pro program in which a point cloud could be created. Then the target mound could be separated from the surroundings and its volume measured. The contractor reported the results and they could be compared against the drone.

With the drone, the coal mound was photographed from different angles by flying around it. With the pictures taken, they were then transferred to a computer and imported into Photoscan. The 3D model (Fig. 19) from the pictures was created in a similar way as described in Chapter 4.5.

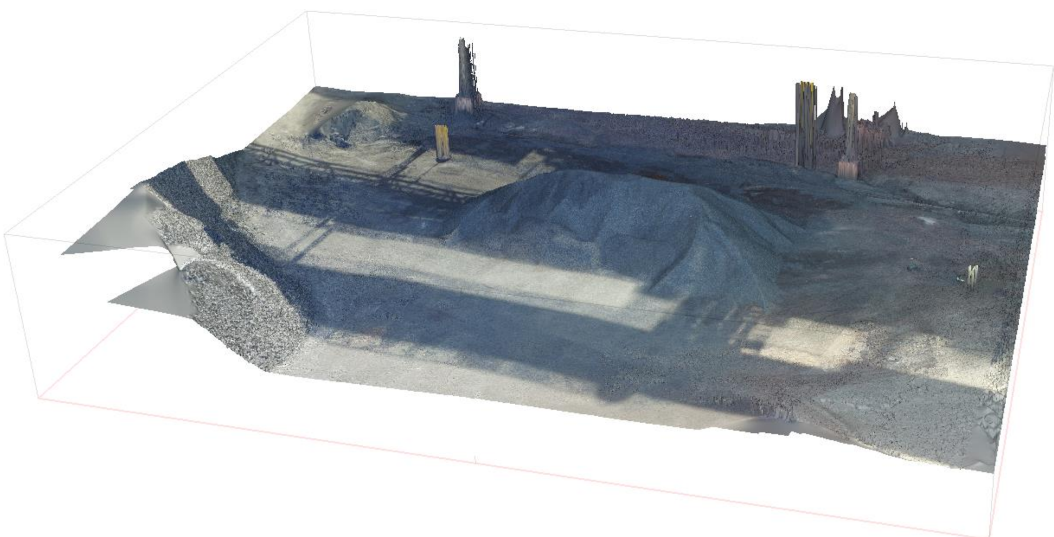

Figure 19. Model of the coal mound and its surroundings.

Like mentioned in Chapter 4.5 and the revised workflow, cropping the measured target from its surroundings (Fig. 20) may cause some variance in the results. To ensure more accurate results, the cropping and calculation phase was repeated 10 times. After this, the measurements were done and they could be compared to the LIDAR based solution.

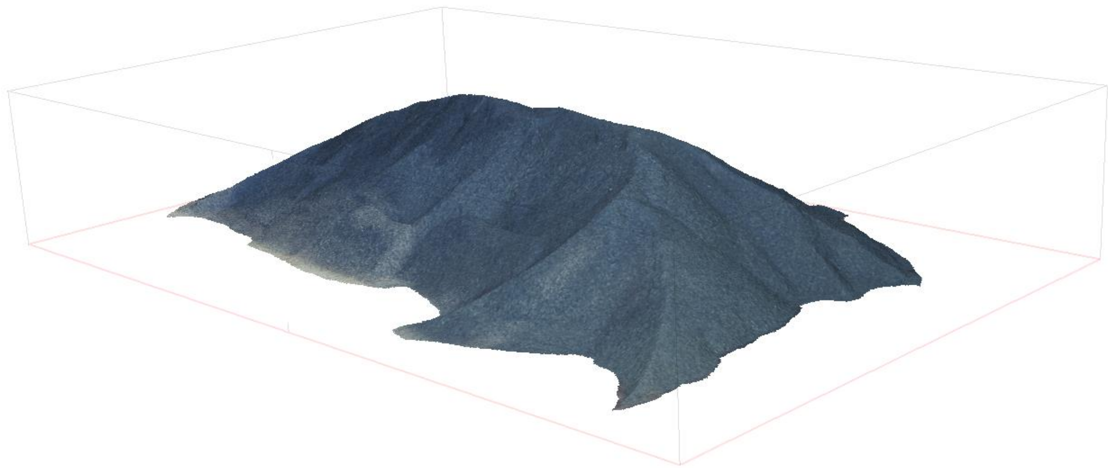

Figure 20. 3D model of the mound cropped from environment and ready for volume calculation.

According to the LIDAR based solution, the volume of the target mound was 380 m^3. With the drone based system, the average volume of the 10 measurements was 374,89 m^3. The root-mean-square error of these 10 drone based measurements was 1,82 m^3. The bias of the average results from the drone based system against the LIDAR based solution was -5,12 m^3. The reason for the drone based measurements to have given smaller result than with the LIDAR was likely because the LIDAR could take the shape of the ground level into consideration. The drone based solution simply draws a smooth line to connect the borders of the targeted mound. There is also the dependence on how the user decides to crop the mound from its surroundings. Still, considering the size of the error when compared to the size of the mound, the results were considered excellent and within acceptable range.

5.1.2 Shape and location measurement performance

Having determined the volume measurement accuracy, the system's capability to produce the coal mounds' shape and location was tested at the coke plant's material field. A coal mound's shape was first mapped traditionally by walking around it with the GPS equipped backpack of which functionality was described in Chapter 4.1.1. The shape mapping in the traditional way was carried out normally except for slight problems that were caused by pools of water around the mound. It had rained a lot earlier and the water had yet dried. Because of this the person carrying the GPS backpack had to walk around the pools, resulting in slight errors in the measured shape. The errors had to be corrected afterwards by hand in CHMS program where the shapes were placed in. The correction could be done with a tool in CHMS by removing some of the recorded GPS location points and interpolating the shape between existing points. Alongside with the original recorded coordinates, the corrected coordinates were saved in a database storing the shapes of all the currently existing coal mounds.

With the traditional measurement done, the drone was flown over the mound, taking photographs around it and creating them into a 3D model in the same way as in the volume measurement process. After the mound had been cropped from its surroundings, the mound's shape was created with the polyline tool of which functionality was described in Chapter 4.5. The resulting shapefile was exported out of the program to be compared against the traditional system's measurements.

To compare the shapes from traditional method and the new system, a C# based WPF application was developed, where shapefiles could be visualized on a georeferenced map. First, the shapes presented on the map were compared against the model of the measured mound (Fig. 21). The actual shape of the mound seemed to be very accurate with the drone based system. The shape created by the drone had a lot more details whereas the traditional method which had less recorded GPS positions had more straight lines and interpolation. At the upper left corner of the traditional method's shape (red), a position where the correction to the shape was made in CHMS due to person walking around a pool of water can be seen. The corner of the mound has not been recorded in the shape as the removed points have been interpolated as a straight line.

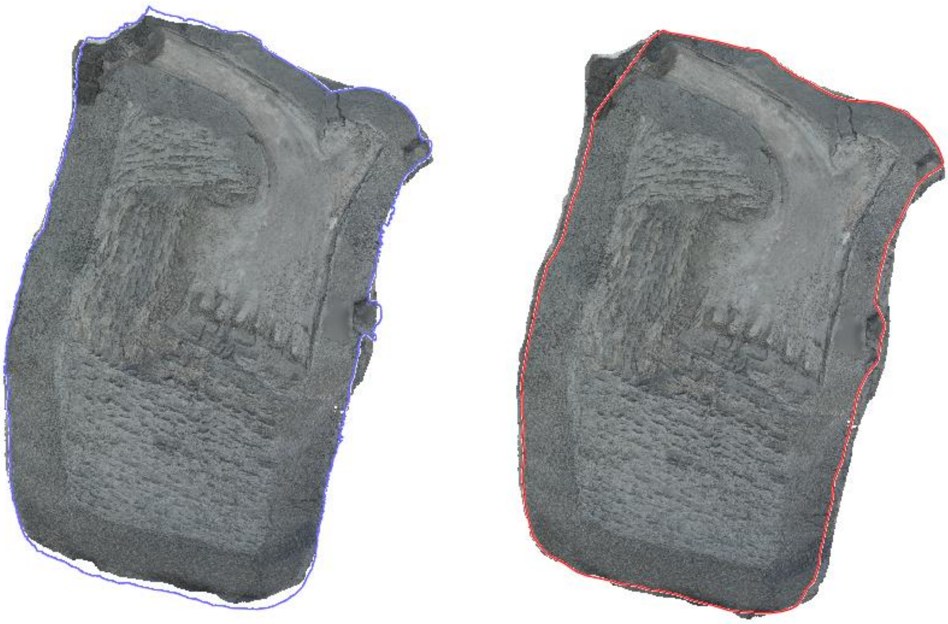

Figure 21. Shapes created by the drone based system (blue) and the traditional system (red) projected over the 3D model of the mound.

To compare the accuracy of the positioning of the shape, the shapes from both methods were shown in their actual position on a map, making them appear on top of each other (Fig. 22). As shown in the figure, the drone based system's shape's location (blue) was differing by around 5 meters horizontally when compared to the traditional method (red). The traditional method utilizes the DGPS to improve the GPS accuracy whereas the drone is reliant on normal GPS making it more prone to error. The amount of error should have some level of correction when all the photographs are combined and GPS position recalculated but it seemed to be not enough.

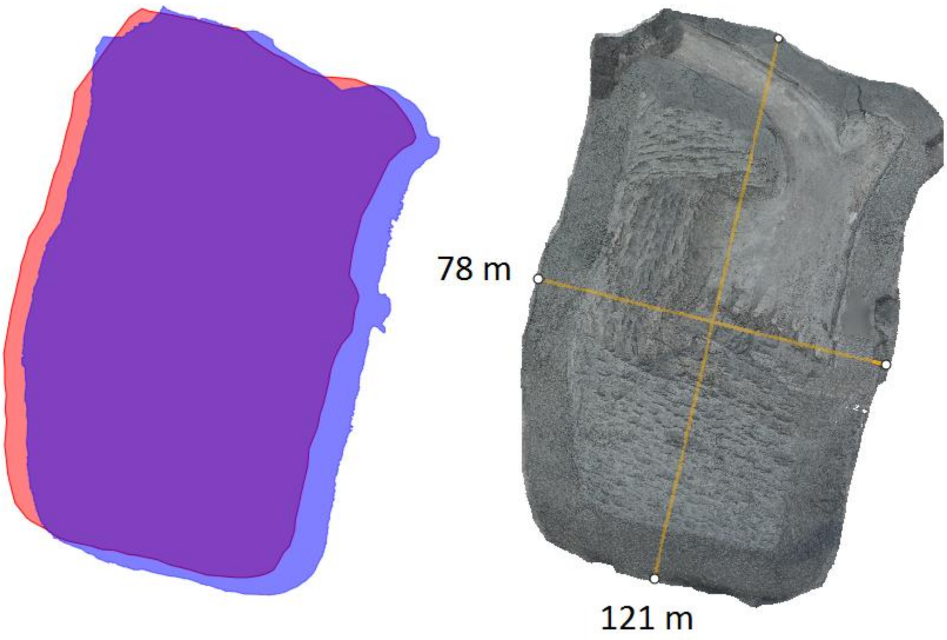

Figure 22. Relative locations of the shapes created by the drone based system (blue) and the traditional system (red), with the mound's 3D model and size on the right.

The inaccuracy of the location created by the drone based system was not acceptable, so it was investigated further to find out if there was a way to improve it. Some more shape measurements were done with both the traditional and the drone based system. From these measurements it was noted that the mounds' position created by the drone based system was always incorrect in a similar way by being in a wrong position by around 2 to 5 meters towards east. It was difficult to say what caused this error which had a clear pattern. It was speculated that it was likely because of the natural error of the GPS which the drone system used and Photoscan not being able to correct the error even with a huge number of pictures.

In an attempt to solve this error, it was thought that the accuracy could perhaps be improved by setting a couple of predefined ground control points in the area and then optimizing the created model with these correct GPS locations. The points were recorded with the traditional method's GPS equipped backpack which utilizes the DGPS correction signal. For the recording, the backpack was carried to the corners and the centers of the sides of a coal mound. The serial port sending the location coordinates was listened to with the open-source terminal emulator PuTTY and from there the coordinates were copied into a text file.

Before using the ground control points for the drone's optimization, the points were visualized on the map application created for shape visualization earlier to check that the recorded points were correct. This led to a surprising result. As seen on Figure 23, the recorded points aligned correctly with the drone based system's shape, not the traditional system's shape as was expected. This lead to a realization that it was actually the new drone based system, which had been providing correct location data all along. Even though the corner points were recorded with the same backpack used for shape measurement, there was one notable difference, which was suspected to be the cause of error in the traditional system. Normally, the backpack uses the factory area's own internal coordinate system. The coordinates are later on changed to WGS84 projection programmatically when they are saved to a database. For the recording of the control points, the GPS receiver's settings were changed with the controller (Fig. 3) to directly use WGS84 projection instead of factory coordinates. This was done so that the coordinates could be conveniently used straight in the shape visualization application without the extra step of converting them from one format to another. Because the coordinate positions originally recorded in WGS84 projection are so different from the ones recorded with the factory's projection, it means that there must be some kind of arithmetic error in the conversion of factory coordinates into the WGS84 projection. This would also explain the way how the mistakenly located shapes were always following a clear pattern. Recording the corner points of a mound with the DGPS was later repeated for another mound to verify the finding and the results were similar. The small differences in locations between the drone and the DGPS shown in the southern edge of Figure 23 are likely due to conveyors near the mound, which was located on the field's southernmost part. The conveyors, which are used to transfer the coal out from the coal field, have a lot of metal in them, which may cause some disrupt in the GPS signal. This means that the shape shown by the drone (blue) in Figure 23 is actually more accurate than the points (black) recorded by DGPS utilizing backpack method.

Finding the error in the traditional system was an interesting discovery, which not only proved the accuracy of the drone based system, but also revealed a significant bug in the traditional system. CHMS currently uses the factory area's coordinates for visualizing the coal mound locations so no actual damage has been done. Still, the converted WGS84 coordinates stored in the database, which were used in this project were planned to be used in the future. Thus discovering this error in time was a great finding, and it may have helped to prevent problems in future coal field's management. The bug was reported to the external software company developing and maintaining the program.

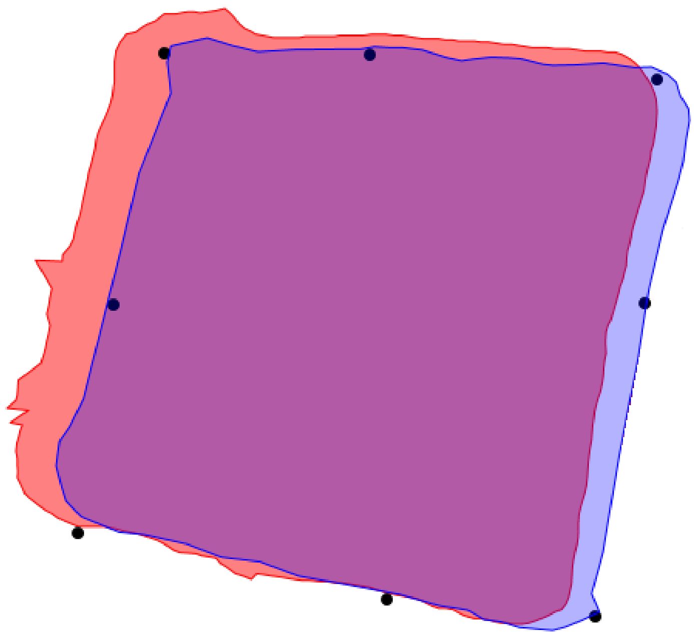

Figure 23. Shape from the drone based system (blue) and the traditional system (red) with black dots representing locations of ground control points recorded with DGPS.

With the source of error found, it could be estimated that the drone based system was capable of providing more accurate results than the traditional measurement system. As both the performance in volume and shape and location measurements were evaluated, the system could then be further evaluated by comparing it against the requirements.

5.2 Comparison against the requirements

The system was evaluated by analyzing how it corresponded to the requirements that were engineered before the implementation of the pilot. Each of the requirements were marked as a status of having been achieved, having been partially achieved or having not been achieved (Table 4). Each requirement had a thorough examination for the causes of the requirement's status and what would have to be done in order to improve it.

Table 4. Status of the evaluated requirements.

Requirement ID: Status (Achieved (A)/Partially achieved (P)/Not achieved (N))									
R1: A	R2: A	R3: A	R4: A	R5: A	R6: A	R7: P	R8: A	R9: A	R10: A
R11: A	R12: P	R13: P	R14: A	R15: A	R16: P	R17: A	R18: A	R19: A	R20: A
R21: P	R22: P	R23: P	R24: P	R25: P	R26: P	R27: A	R28: A	R29: A	R30: A
R31: A	R32: A	R33: P	R34: A	R35: A	R36: A	R37: P	R38: P	R39: A	R40: P

R1: The system should produce 3D models from measured targets in common formats
Status: Achieved
Evaluation: The system was capable of producing 3D models from pictures taken by the drone. Being able to create the 3D model was essential part of the process to get the measurements done. Having enough pictures to cover the target area from all directions was deemed enough to produce the complete model.

R2: The system should be able to calculate volumes from measured targets
Status: Achieved
Evaluation: The system was capable of calculating volumes from the targets. Volume calculation required a working georeferenced 3D model which was available as R1 was achieved. Small variance in the volume calculation results was happening due to need to crop the measured target from its surroundings manually.

R3: The system should be able to present the measured target's shape and location on a georeferenced map
Status: Achieved
Evaluation: The system was capable of presenting both the targets' shape and location accurately on a georeferenced map. Shape and location measurement required a working georeferenced 3D model which was available as R1 was achieved.

R4: The system should store logs from the flights
Status: Achieved
Evaluation: The system was capable of storing the flight logs with the logbook application which was developed a part of the system. The logging process was made as automatic as possible and the logs were stored into a database.

R5: The system should use a drone equipped with a digital camera
Status: Achieved
Evaluation: The system used a digital camera equipped drone as a means to take pictures for the 3D model creation.

R6: The system should use a drone equipped with a GPS receiver in order to produce the measured target's location and to improve the measurement results
Status: Achieved
Evaluation: The system used a drone with a GPS receiver. GPS coordinates were successfully used to generate the measured target's location. Photoscan used the GPS coordinates embedded into pictures' metadata to improve the accuracy of the generated 3D model and to make the volume calculation and shape and location measurement possible.

R7: The system should use a drone with a minimum of 15 minutes flight time
Status: Partially achieved
Evaluation: The system used a drone with more than the minimum of 15 minutes flight time. Phantom 3 Advanced was capable of around 20-23 minutes flight time in plus zero temperatures. Flight time during below-zero temperatures in winter was not recorded. The battery endurance might be significantly reduced during winter.

R8: The system should stay within a 20 000 € budget and have maintenance costs lower than LIDAR based solution
Status: Achieved
Evaluation: The components for the system cost around 6000 €. The labor costs were not included in the budget. The maintenance costs for the system were considered minimal and less than LIDAR solution even in the situation of having to replace all the components as the LIDAR's costs were around 24000 € a year. In the optimal situation the only costs would be the time it takes a person to operate the drone and process the results, meaning a maximum of a couple of hours per measurement which might be done once a week.

R9: Volume measurements done by the system should be as close as possible to the measurements done by LIDAR
Status: Achieved
Evaluation: The system was capable of producing volume results with a bias of -5,12 m^3 when compared to LIDAR. The root-mean-square error within 10 different measurements was only 1,82 m^3. Considering the size of the target mound (380 m^3), the results were considered very close to the wanted accuracy level and they could be used at the factory for inventory purposes.

R10: Shape and location measurement done by the system should produce as accurate results as the GPS equipped backpack method
Status: Achieved
Evaluation: The system was capable of producing shapes with the accuracy similar to the traditional method. The system was outperforming the traditional method in cases where physical restraints were limiting the traditional method's accuracy like the pool of water in the shape and location measurement performance test. Producing the shapes' location was as accurate as with the traditional method, with the drone based system clearly outperforming the traditional system when taking the traditional system's coordinate conversion error into account.

R11: The system should use a drone capable of flying at the altitude of at least 30 meters
Status: Achieved
Evaluation: The system used a drone with capability of flying at the minimum of 30 meters altitude. Some of the flights were done in the altitude of 45 meters with a successful performance of the flight, picture taking and 3D model creation. The

requirement of 30 meters was not seen as mandatory in the end as it would be rather easy to control the drone around the light poles located in the material field.

R12: The system should reduce time needed for measurement tasks when compared to existing methods
Status: Achieved
Evaluation: The time needed for volume calculation was reduced when compared to the LIDAR based solution as the measurement could be timed as wanted without being dependent on the contractor. The time needed for shape and location measurement was seen as a slightly faster or equal to the GPS equipped backpack method. Time needed depended mostly on the amount of time the drone flight itself required, which could further be quickened with autopilot.

R13: The system should reduce the need for manual human labor when compared to existing methods
Status: Achieved
Evaluation: The manual labor needed for the volume calculation was either similar or reduced slightly, depending on the size of the measured targets, as there was no need to walk around the material field like with the LIDAR based solution. The processing of data for both methods was rather similar. Even though from the company's point of view, the amount of labor increased as the volume calculation was no longer done by the contractor but by the company's own employees, it was offset by the reduction in time and money. The manual labor needed for shape and location measurement was also either similar or reduced slightly, depending on the size of the measured targets as there was no longer need for walking around the material field. The need to perform some manual operations in the data processing phase was seen as more laborious than with the traditional system.

R14: The system's use should be able to be timed whenever the user wishes, with measurement tasks being doable on at least a weekly basis
Status: Achieved
Evaluation: The system's use can be timed as the users want, assuming the weather permits it and the frequency of a weekly basis is doable for the users of the system.

R15: The measurement process as a whole should have a 24 hour completion time, including data gathering and processing
Status: Achieved
Evaluation: The system is capable of less than a 24 hour completion time with the 3D model creation process taking the longest time, usually less than 3 hours with the dedicated workstation.

R16: The system should be able to be integrated to company's Coke Handling and Management System (CHMS)
Status: Achieved
Evaluation: The system outputs the measured targets' shape and location as a coordinate data that can be stored in a database. It can potentially be used as a data source for CHMS but it is not implemented at the moment.

R17: The system should be transferable around the factory area
Status: Achieved
Evaluation: The system can be transferred and used in other similar material fields. The system's components are not tied to a place but they might need slight optimization depending on local circumstances.

R18: The system should use a drone with at least 500 meter transmission distance
Status: Achieved
Evaluation: The drone can be controlled at more than 500 meter transmission distance but the local regulations demand a visual line of sight towards the drone, limiting the maximum distance.

R19: The system should use a drone with at least a partial autopilot support
Status: Achieved
Evaluation: The drone's flight path can be predefined with the controller's application but controlling it manually was seen as a more reliable way to get the pictures from wanted angles and positions. Using the system for a longer time might make the use of autopilot more convenient. The drone also has a support for autopilot landing in cases of lack of signal and a low battery.

R20: The system should use a drone with changeable battery
Status: Achieved
Evaluation: The drone's battery can be changed and it was done during the flights to double the time the drone could operate.

R21: The system should be usable during winter in below-zero temperatures
Status: Partially achieved
Evaluation: The system could be used in below-zero temperatures if it was equipped with a separate battery heater pack from the drone's manufacturer. This was not done during the pilot project.

R22: The system should be usable during windy weather, having drone's movement and photographing unhindered by the wind
Status: Partially achieved
Evaluation: The system can be used in slight wind but the drone might take some error in its positioning and photographing. The drone was not attempted to be used in a strong wind due to risk of breaking the device.

R23: Sun illumination should not hamper the photographing of the drone
Status: Partially achieved
Evaluation: The sun illumination did not hamper the drone as pictures were taken by facing the camera downwards. Possible polarizing lens could be purchased for the drone if the sun illumination would be seen as a problem in some situation.

R24: Lack of sunlight should not hamper the photographing of the drone
Status: Partially achieved
Evaluation: Shadows did not seem to hamper the drone's functioning and was likely partly because additional pictures were taken from multiple angles, making recognizing shapes easier. The drone was not tested in a time when sun was not up as it was mainly used during normal working hours. Problems could rise during winter when the sun in Finland can be up for only a few hours and the system's use could then be limited. The material fields have 30 meters high lighting poles in the area which can help to counter the lack of light. Further testing during winter is still needed.

R25: Repeating patterns and colors on the ground should not prevent the creation and processing of 3D models used for the measurement tasks
Status: Partially achieved
Evaluation: The coal mounds and other material mounds are usually very monochromatic, making them to have repeating patterns all over them. Still, it did not have any effect on the automatic creation of the 3D models from the pictures. This was

likely because of the multiple angles for the pictures used and the GPS coordinates helping the program recognize the correct location of shapes of the area. The repeating patterns caused problems in the cropping phase, when the target mound had to be manually separated from its environment. Because the coal mounds tend to be gently sloping near their edges and the ground can be rather similarly colored as the mound, it can be sometimes challenging to recognize the point where the mound ends and the surrounding ground begins. Being able to automatically separate the mound by setting the ground level's height as a reference level would be the best solution.

R26: Complex landscape patterns should not prevent the creation and analysis of 3D models used in measurement tasks
Status: Partially achieved
Evaluation: The coal mounds and other material mounds can have rather complex shapes and small details in them but as could be noted from the volume calculation's results when compared to the LIDAR based solution, the complexity did not have an effect on them. The complexity only caused problems in the cropping phase when the user had to be precise on selecting where the mound's border was. Like with the issue with monochromatic texture in R25, being able to separate the mound with a preset reference level would help with the issue.

R27: The system should not be dependent on the model of drone used
Status: Achieved
Evaluation: The system was not dependent on the drone used as the drone did not have features unique to that model that would be mandatory for the system to operate. The wanted features of a GPS receiver, a digital camera and others could be found from other drone models too.

R28: The system should be able to be used with minimal training by people with technical background
Status: Achieved
Evaluation: The system's workflow was reported in detail making its use fast to learn. A document listing the steps needed in the used applications was also created. Altering and developing the system, its components and workflow should be relatively easy by having a technical background.

R29: The drone should have upgradable firmware in case of software bugs
Status: Achieved
Evaluation: The manufacturer of the drone released multiple updates during the development of the system (DJI, 2016). As a newer drone model has already been released, it is difficult to say how long there will be firmware releases for the used older model.

R30: The software should have regular updates in case of software bugs
Status: Achieved
Evaluation: The developer of the used processing software has released multiple updates during the development of the system (Agisoft, 2016).

R31: The system should use both a drone model and processing software with sufficient customer and technical support available
Status: Achieved
Evaluation: Both the drone and the software have active official discussion forums and a customer support for answering questions regarding their products. The customer support of software developer was consulted during the project to ask details about the features of their product.

R32: The drone should be repairable through warranty or purchasable spare parts
Status: Achieved
Evaluation: The drone has a limited warranty.

R33: The drone should be upgradable to new features to minimize the need to buy new models
Status: Partially achieved
Evaluation: The drone can be upgraded with features such as a battery heater and a polarizing lens but more advanced features are likely not going to be upgradable as the manufacturer has already released a new drone model.

R34: The drone should be able to safely land in case the remote controller malfunctions
Status: Achieved
Evaluation: The drone has a feature to land in case the signal is lost from the controller.

R35: The system should comply with local regulations and legislation
Status: Achieved
Evaluation: Local regulations and legislation were taken into account in the development of the system. The logbook application is used to log the flight information and the drone is used within the allowed frames, such as flying in the allowed heights, keeping an eye contact at the drone and having a capability to land the drone like mentioned in R34.

R36: In a case of regulations restricting the drone use, a plan to keep the system working should be implemented
Status: Achieved
Evaluation: The traditional methods can still be used as a backup in a case the drone can no longer be used in a wanted way.

R37: The measurement data and material should be consistent and verifiable for a decided time span
Status: Partially achieved
Evaluation: All the measurement data and material is currently stored. Limiting the amount of stored data in the future can be considered.

R38: The data should be backed up on a file server
Status: Partially achieved
Evaluation: The measurement material is not backed up. The measurement results are stored in a database with backup mechanisms.

R39: The drone should be used so that it does not cause any risk or harm to people
Status: Achieved
Evaluation: The drone is not flown over people, it is kept in visual contact at all times, it is used only during decent weather and it will land in case the remote control connection is lost (R34).

R40: The drone should avoid taking pictures of bystanders moving in the targeted area
Status: Partially achieved
Evaluation: The drone is used in a restricted area with only few people moving there. The pictures are taken from the measured material mounds and they are not taken if there are people in the target area as it may interfere with the model creation process.

The majority of the requirements were fully met and the rest of the requirements were achieved at least partially. None of the requirements had a status of not having been achieved at all. Therefore, the results were considered excellent. The reason for the system having met the requirements as well as it did is likely due to requirements having been planned realistically. The requirements such as support for multiple drones working simultaneously and full autopilot capability were not reasonable in the scope of the project and were thus purposefully left out.

6. Discussion

The objective of this research was to find out if a drone based measurement system for outdoor material fields in industrial environment is a feasible concept. This research problem was studied by approaching it with design science research methodology. The methodology was applied by building the system as a pilot version and evaluating it in a rigorous manner. The development of the system was divided into cycles and the development process was done iteratively. The completed pilot version of the system was evaluated with a practical performance test against the traditional measurement system and with an analytic comparison against the requirements that the system was designed with. The results of the evaluation provided excellent and well usable results. With them, the two research questions that were set up in the beginning of the thesis could be addressed. This included reflecting the results of the implemented system against the prior drone related research which was studied in the structured literature review. Both research questions are answered and discussed below.

The first research question of this thesis was: *How a drone based measurement system for outdoor material fields can be designed?* A drone based measurement system can be designed by following the steps used in this research. The design begins by first planning the requirements according to both theoretical recommendations and practical needs. The theoretical requirements can be gathered by analyzing existing research where similar drone based solutions have been implemented. The prior research supports understanding of the drone technology used in similar applications and it highlights features of the system that should be particularly paid attention to. Like in the implemented pilot, the practical requirements can vary according to local needs and the system should be customized according to them. When the requirements are in place, the system's structure and workflow can be designed. They should follow the guidelines from the requirements and make sure that all the wanted features can be accomplished. When both the structure and the workflow are ready, the components that are needed to construct the system can be acquired. After this, the system is ready to be used. The system should be tested by using the system is practice. This ensures the measurement capabilities and general operability of the system. When enough practical testing has been done, the system can be evaluated as a whole. The evaluation is used to determine how well the system met the requirements it was designed with. Finally, if any shortcomings were found with the evaluation, the system can be revised accordingly. With these steps, the system can be successfully designed as was proved with pilot.

The second research question of this thesis was: *What are the benefits and challenges of a drone based measurement system?* Both benefits and challenges could be recognized by analyzing the results of the system and by comparing the results to the recommendations from the existing drone related literature.

The benefits of the system were many. The system could perform the measurement tasks more accurately, more affordably and more quickly than the traditional system. With its measurement capabilities, the system could support the factory's processes and decision making in inventory and material management purposes.

According to prior research, a successful drone based system should be able to produce results with a desired accuracy (Diaz-Varela et al., 2014; Peña et al., 2013; Torres-Sánchez et al., 2015). It should be even as accurate as a LIDAR based system (Diaz-

Varela et al., 2014; Zarco-Tejada et al., 2014). The system did meet the LIDAR based system's accuracy with an accepted marginal error in the volume measurement. In shape and location measurement, the system surpassed the traditional system in both shape's and location's accuracy.

Another important feature of the drone based systems is the inexpensiveness of the technology, which has made them more accessible (Gademer et al., 2010). It is also one of the reasons this project was initiated. The implemented system was able to be created and maintained with components with a reasonable cost. It was clearly cheaper than the existing system which was using LIDAR.

In addition to reduced direct costs, drones are supposed to save resources by making the timing and controlling different surveying tasks easier than with traditional methods (Gademer et al., 2010). The system managed to meet this expectation. With the new system, the volume calculation was no longer dependent on an external contractor. In general, the system could be used as often as wanted without a need to plan the measurement a long time beforehand. Measurements could be done even if there were traffic at the measured material field, which could otherwise limit ground based measurements. The movability of the drone also made it convenient to control the way the measurements were done.

As another way to save expenses and as one of the main reasoning for adapting the drone use is the potential to reduce manual human labor (Merino et al., 2012). The system managed to reduce human labor in the measurement tasks that it was used for. There was no longer a need to walk around the huge material fields as the measurements could be performed from a single spot. This saved time that the measurement tasks needed as a whole. By having to no longer move in the material fields by foot, there is also a reduced chance of accidents with the traffic in the area.

An important benefit of the system was that it was not dependent on the type of the components used. They could be replaced with better ones with different features if needed. This made expanding and customizing the system possible according to local needs. The technology on which the system was built could possibly be used for other purposes besides measurement tasks too. Ease of use made learning to operate the system relatively effortless.

Although the system was a success, there were still several challenges related to it. This was mainly due to two factors: the general novelty of the technology and the nature of a pilot project, which is merely meant to prove the potential of the studied system.

Different weather conditions are a prevalent problem for drone use (Borra-Serrano et al., 2015; Gatziolis et al., 2015; Kattenborn et al., 2014; Martin et al., 2015; Merino et al., 2012). Strong wind can disrupt the drone's flight, making the photos taken inaccurate and preventing the measurement from taking place (Primicerio et al., 2012). The effect of strong wind on the drone was not tested in the pilot but it is likely that the wind may prevent performing the measurement process with the system. There is really not an easy solution to counter the wind's effect unless more powerful drones are developed. Other weather effects possibly having an effect on the drone are rain and below-zero temperatures. During rain, the drone cannot be used as the water would get inside the drone's casing. Below-zero temperatures' effects were not properly tested but it is possible to counter them by using a battery heater and by covering the air conditioning holes which should make using the drone possible even in -20 Celsius temperatures. Luckily, as there is currently no need for daily measurements for taking place, these extreme weather conditions are not that significant of a problem. The measurement can be rescheduled to be done at a more appropriate time so the risk of not being able to perform enough measurements is rather small.

Long term effects such as the endurance of the drone hardware itself could not be tested in the scope of the pilot project. For instance, there tends to be some fine-grained coal dust in the coke plant’s area which might have some unwanted effects on the drone’s hardware. For this and other risks of the drone breaking up, a backup hardware would be needed. Seagulls and other birds were seen flying over the coal field too, making it a real possibility that they would attack the drone and make it fall.

Although measurements were done, seeing if the results are constant has still a bit of uncertainty. Especially concerning the volume measurement, it is difficult to say how accurate the drone based system would be if there were slightly different circumstances such as uneven ground in the measured area. Different kinds of materials were not measured either, though it should not make much of a difference in the measurement process.

Short battery life is considered a challenge in drone use in general (Borra-Serrano et al., 2015; Martin et al., 2015; Merino et al., 2012; Primicerio et al., 2012). In this system it was not that much of a problem as the battery life was enough to get a single survey done. Still, better battery endurance would be needed to optimize the system and to increase the potential application areas that the system could be used for.

Legislation is a potential challenge (Paneque-Gálvez et al., 2014; Tuominen et al., 2015). Like mentioned during the pilot, a new local legislation in Finland came into effect in 2015, which concerns the drone use. But as the technology is new, there can be still be more changes coming, which may make the use of system difficult or impossible. Because of this, alternative solutions for measurement should be kept in mind and the traditional systems should be kept as a backup.

Lack of proper autopilot is a limiting factor for drones, with more automation needed in general (Primicerio et al., 2012). With the system, the need to manually pilot the drone is a step requiring manual work which takes unnecessary time. Automating the flight route and the taking of the pictures is a feature that should be done in the future. The technology makes it possible and it mostly requires enough practice make it provide constant and usable results. Lack of automation was also a problem in the used software as the user has to manually crop the measured area. It is fast to do but from the aspect of automation it is still an unneeded step. Automating it could hopefully be possible on at least some level.

With both of the research questions answered, the research problem could be solved. The explicit answer to the research problem is that a drone based measurement system for outdoor material fields in industrial environment is a feasible concept. Although the concept is working and successful, it should be noted that it is very dependent on the context that was implemented in. Because of this, it might not be possible to generalize all of the results. This and other limitations of the study are discussed in Chapter 6.2. Also, as the implemented system was only a pilot project, a lot potential ways to develop the concept exist. These possibilities are discussed in Chapter 6.3. How the research as a whole met the guidelines it was following is evaluated in Chapter 6.1.

6.1 Evaluation of the design science research guidelines

The framework and the seven guidelines presented by Hevner et al. (2004) were applied for the research method of this thesis. How the seven guidelines for the whole research were met is described below.

Guideline 1: Design as an Artifact

In this thesis, the artifact that was produced was the drone based measurement system. The system itself was viable and working, being capable of producing the wanted measurement results in a new and improved manner.

Guideline 2: Problem Relevance

The research problem was relevant as there was a need to both understand the drone technology more in-depth and a need to improve the existing measurement methods. Designing and implementing the drone based measurement system was a solution for these needs.

Guideline 3: Design Evaluation

The evaluation of the artifact was done rigorously in two ways: by comparing the system's performance against the existing methods and by analyzing how well the requirements that the system was designed with were achieved.

Guideline 4: Research Contributions

The contributions of this research are the design of the drone based measurement system and the proof of its feasibility in the implemented system's context which is the industrial environment.

Guideline 5: Research Rigor

The research was conducted rigorously by using design science research methodology. The guidelines and framework presented by Hevner et al. (2004) were applied. Existing published literature in similar drone based applications was used as a knowledge basis for the research. The system's design, implementation and evaluation were all planned and executed in detail.

Guideline 6: Design as a Search Process

Both the knowledge base from the existing literature from similar applications and the relevant and practical business needs from the company were used in the research process. Different design choices were weighed in the system's design and the ones fitting best the needs of the pilot project were chosen.

Guideline 7: Communication of Research

The thesis was written in such a way that all the technical decisions were described in detail. The financial and practical benefits of the system were also well explained.

6.2 Limitations

The research was mostly limited by the decision to approach the research problem through a pilot project. As the nature of a pilot project is experimenting and focused on a specific case, it might have a somewhat narrow view on the focused research area. Even though the results were a success and proved the feasibility of the concept, it is difficult to say how much they could be generalized. With a different setting, the results could have been very different.

Some of the weaknesses of the pilot were described in the discussion of the challenges of the design. The pilot could not take all the deviations into consideration, such as the impact of unfavorable weather conditions. Also, the long term effects of the system could not be researched. The sample sizes in the volume measurement against the LIDAR based system were small and the constant results of the system over time could not be confirmed.

Not much time was spent on research towards which components to use. For instance, dozens of different programs exist for the purpose of creating 3D models from pictures. Some of them might have completely different approach for measurement tasks and more automatic workflows.

The evaluation of the requirements was done qualitatively but a more systematic approach to evaluation might have given more accurate and beneficial results. For instance, the evaluated requirements could have each been given a ranking concerning priority and significance.

As the structured literature review was done prior to completion of the pilot, it might not have been the perfect match regarding its content when compared to the implemented system. With different search terms and with different sources, the material might have been somewhat different as could have the requirements derived from the literature. During the writing of the literature review it was not yet perfectly clear what the implemented system was going to turn out to be like.

6.3 Future research

Multiple ways to develop the concept in the future were discovered. These were either direct improvements to the current system or ideas to advance the drone based concept into new directions.

Getting the autopilot working is the most important objective to make the drone more automated. Alternatively, just getting a lot more practice in the piloting of the drone could make the data gathering a faster process. The material field could be divided into a predetermined number of sectors of which the drone could photograph maybe one or two sectors at a time. Getting this sort of autopilot working correctly would require some trial and error to make sure it produces enough usable material for the model creation. When the coal mounds are brought to the material field, their positions might vary slightly from the previous mounds' locations, making having a coal mound cross the predetermined "sector" possible and thus being partially left outside of the pictures. This should be taken into consideration when performing the flights.

More practice should be done in the winter conditions as they are a natural part of the Finnish seasons. Getting a battery heater and following the tips provided by the drone manufacturer such as covering the air conditioning holes in the drone, should be used.

Small tests with VR (Virtual Reality) goggles were done to fly the drone from a first person view. Using the first person view with VR goggles could be useful for general surveying tasks in places that are difficult to reach normally, such as roofs or tall building walls. With the goggles, taking pictures from wanted angles could also be easier as it can sometimes be difficult to detect which direction the drone is facing, especially when it is far away from the pilot's position.

Possibility of using the gathered georeferenced data for augmented reality applications was pondered on. VR goggles or just phones' screens with camera's video feed could be used to present information regarding the coal field when moving in the area. For instance, the shape or model of the mound could be presented virtually on the coal field. This could be useful for detecting changes happening in the mounds' sizes. Key information such as size and type of coal could be presented "hovering" in the air over the actual coal mounds.

It should be investigated if exceptions to the local regulations would be possible as the drone is used exclusively in a private area of the factory. This could reduce some of the limitations placed on the drone.

The system could be expanded to be used in the other areas of the factory. For the expansion, possible special needs of the other areas should be taken into account and the system should then be customized accordingly. If the measured target is solid material or it otherwise has a constant density, then the volume calculation can be especially useful for inventory purposes as the mass of the material can be easily calculated from the volume.

It should be studied if getting additional drones to be used at the same time could be beneficial. As one battery is not enough for a drone to cover the whole material field, using multiple drones could make covering the whole field possible at once. Especially if the autopilot feature is properly implemented, having for instance two or three drones perform the measurement simultaneously could in the long run save both time and money.

Optimizing the used components should be researched. As the pilot settled for components that were just "good enough" there could a possibility to significantly improve the performance of the system by getting the optimal components. This includes further developing the implemented logbook application to better support the flight logging and possibly analyzing the previous flights. As a part of optimizing the components, an eye should be kept on what kind of new features are released for the drones as new models are continuously released. As there are a lot different programs for creating 3D models from pictures, they should be investigated more closely to determine if some of them would make more automated workflows possible. Finally, as the price of the LIDAR technology is also becoming less expensive, it should be evaluated if going back to the LIDAR based technology could be a feasible solution in a long term, for instance in a form of a LIDAR equipped drone.

7. Conclusion

The purpose of this thesis was to research if a drone based measurement system is a feasible concept. The research was done with the design science research methodology. Following the methodology's guidelines, the concept's feasibility was tested by implementing the system as a practical pilot project. The pilot was based on the requirements, which were developed as instructions for a good system design. These requirements were derived from the recommendations of the analyzed drone related literature as well as from the practical needs of the company where the system was developed. The pilot included planning the wanted system structure and workflow, acquiring the needed components, testing the system in practice and evaluating it rigorously. The evaluation was done by comparing the system's performance against the traditional measurement system and by analyzing how well the system met the requirements that it was designed with.

The results showed that the drone based measurement system is both a feasible and a working concept. Using the system makes it possible to reduce costs and manual labor, to get accurate and timely measurement data, and to support material inventory and management processes in an industrial environment. Understanding the still evolving drone related technology offers a variety of possibilities for different kind of survey and measurement tasks. The system and its capabilities could be applied to a multitude of different uses and its potential should be continued to be studied in the future.

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Note: Primary studies used in the literature review are marked with an asterisk.

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Appendix A. 3D model creation phases

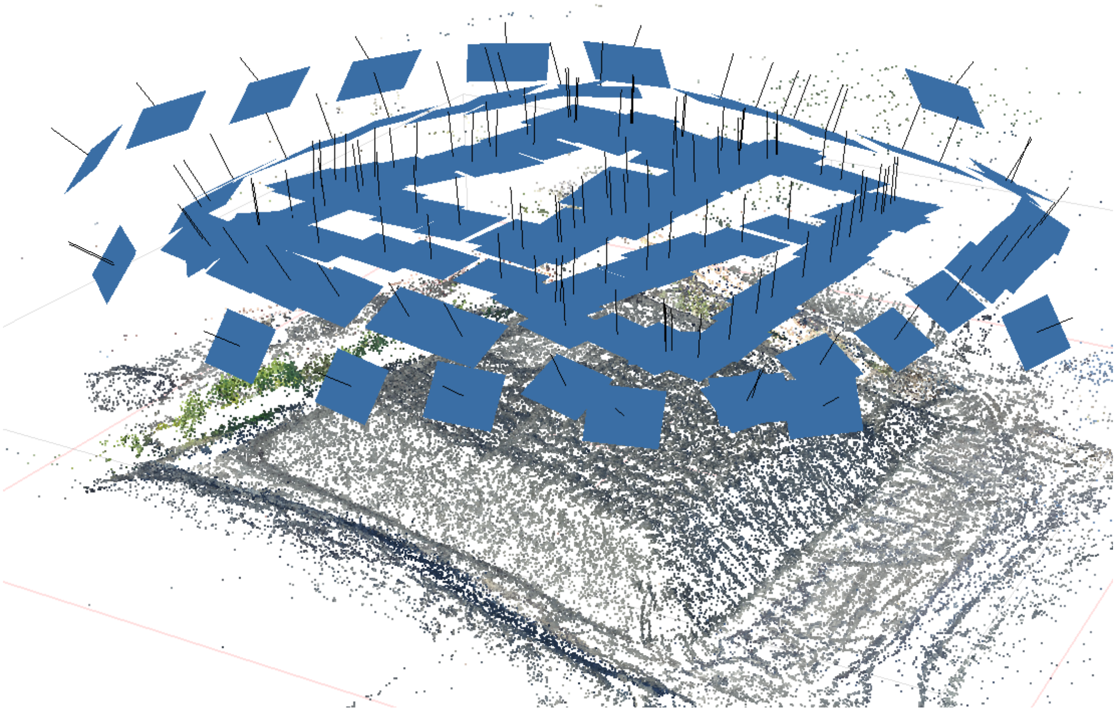

Figure A1. Point cloud with blue squares representing positions of cameras.

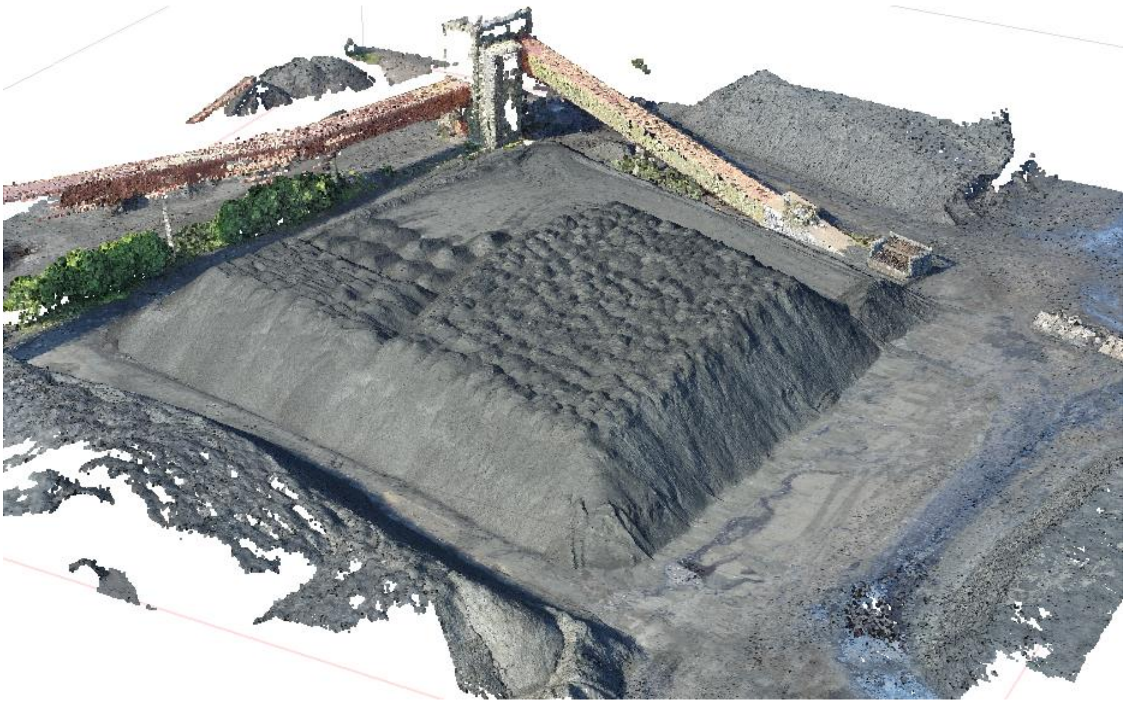

Figure A2. Dense point cloud.

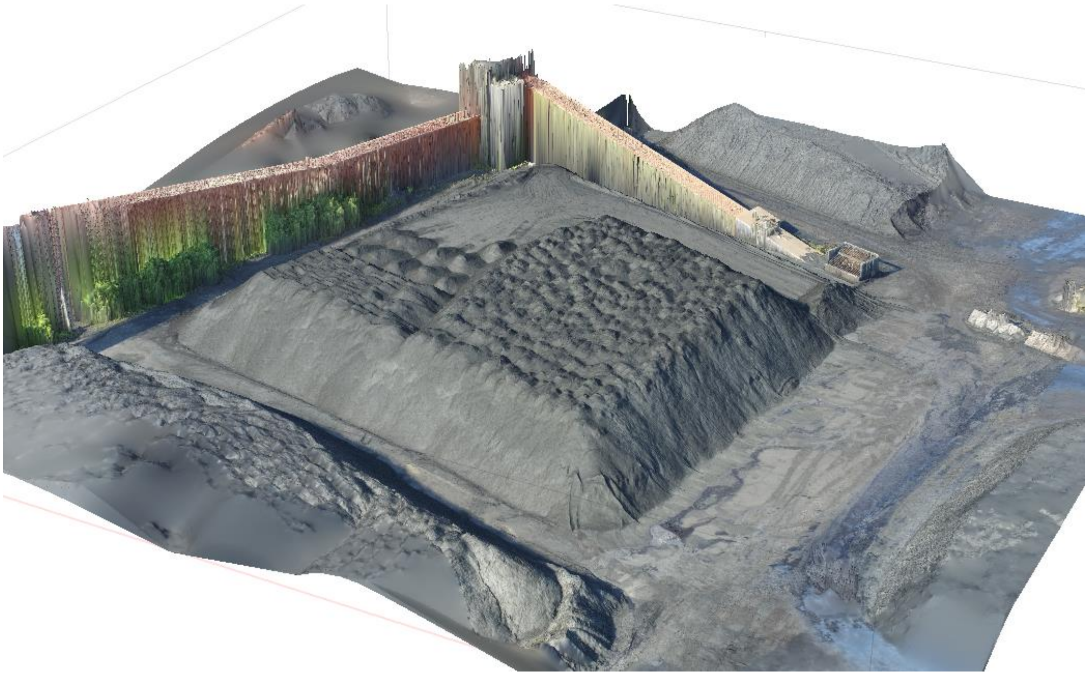

Figure A3. Mesh with more detailed surface and with missing parts interpolated.

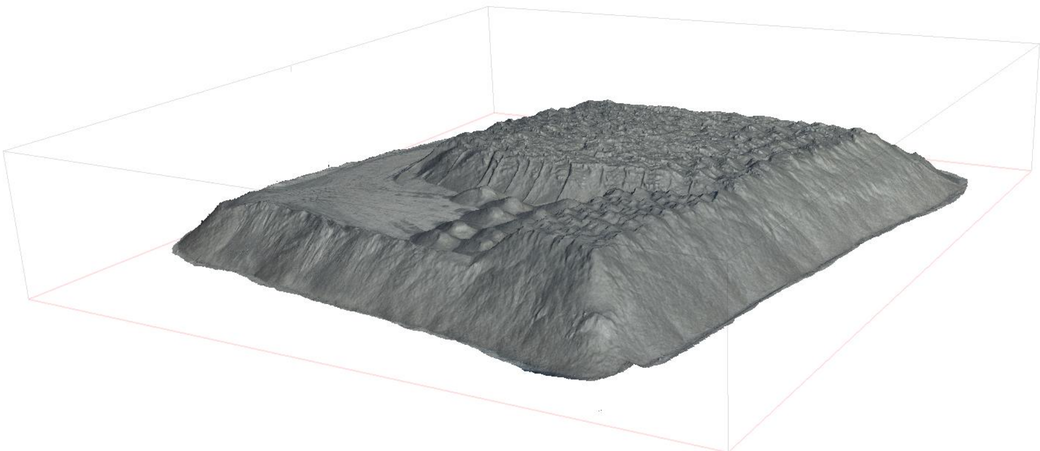

Figure A4. Measurable model cropped from its environment.