The usage of unmanned aerial vehicles and their prospects in Archaeology

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Abstract

Unmanned aerial vehicles (UAVs) are a recent addition to the archaeologist's arsenal of tools. They are capable of traveling in the air and reaching places that a human cannot. They are however not used in many places over the world. This thesis' purpose is to illuminate the positive and negative aspects of how UAVs can be used in archaeology, in order to generate interest in the utilization. Their ability to acquire images that encompasses large and small areas is its main and most frequently used attribute. By using two case studies, the attributes of UAV's are put forward. The conclusiveness of data procured by UAVs and how it is possible to use this information in further studies are shown in these case studies. We see that the UAVs differ in abilities, and the result is often dependent of the quality of the available tools and gear.

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Introduction

Since the beginning of the last century, aerial archaeology has been a compliment to the field of archaeology. Thanks to latest developments in technology we no longer need large airplanes to be able to perform aerial archaeology; instead we now have small compact aircrafts capable of performing the same feats. I felt there was a need to highlight these small aerial vehicles, and how they affect archaeology.

In this work I will discuss the introduction and use of drones in the investigation of archaeological sites, with the intent of starting a discussion comparing the strengths and weaknesses of these new tools. Moreover I aim to showcase the capabilities and possibilities of using drones in archaeological investigations. By performing a comparative and qualitative study of a drone's qualities, and continue with a discourse and comparative analysis I will be able to bring out the answers I seek. By performing two case studies I will showcase the strengths and possibilities of the drone, to maximize its potential and conclude how conclusive the acquired data is. I hope to be able to illuminate the reader of what sort of data the drone can acquire and how the information can be used in further studies. The study is organized in a way so that focus on the visualization aspect of UAVs will build up an understanding of the method, prior to the case studies where the UAV's abilities are showcased. First is a methodological discussion followed by several chapters where the aspects of the practice are explained. It will shift into a theoretical discussion where the visual aspects are discussed, explained and how they affect archaeology. The reader will then be knowledgeable of what aspects one must be aware of when performing aerial acquisitions. As such, the case studies are after the theoretical discussions, followed by a conclusion.

1. Methodological discussion

1.1. Literature

This thesis encompasses several scientific fields, such as Aerial Archaeology, Aerial Photography, Color Spectrums, Unmanned Aerial Vehicles and Remote Sensing. To get the most complete overview I have used literary sources for most of the theoretical chapters, several of these sources are however not up to date on the technical aspects. This encompasses all of the fields and is due to the constant development of technology, I cross reference my sources with information available on internet and on scientific journals. In specific I used the literature suggested on the Aerial Archaeology Research Group (AARG) website (http://www.univie.ac.at/aarg/php/cms/index.php).

1.2. Internet

The World Wide Web has been immensely helpful when searching for information regarding new tools to perform aerial photography, UAVs, and the debate regarding ethics in remote sensing and archaeology. The UAV topic has only generated a few books regarding the subject, and in these rare cases the books have been written through a very technical and militaristic perspective. While being aware of the biased opinions that float around on forums I have been very critical to the information. The sources and opinions in the ethical discussion were very few, but come from respected sources such as Anthropology-news.com.

1.3. Arc-Team UAV

During the development of this thesis I had the opportunity to study a custom-built UAV, made by the owners of the company Arc-Team (http://www.arc-team.com/). Arc-Team is an Italian based company that is renowned for their work in many different areas in archaeology. They promote themselves as having a qualified team and strong connections with institutions all over the world (Lund University being one of them). The provide services in Archaeological Excavation, Digital documentation (2D and 3D), Survey and predictive modeling, GIS, WebGIS, DataBase Management System, 3D modeling and animation, Historical research and artifact study, Anthropology, Paleopathology, Geoarchaeology, Geophysical survey, Protection Project and Musealization. In several of their studies they have employed UAV systems to perform archaeological documentation. They have been featured in several news articles where their exploits with remote controlled drones for archaeological purposes are explained. The company is also known for having developed a free open source software known as ArcheOS and striving for a free open source platform in aerial archaeology and remote sensing. During the making of this Master's Thesis I had the opportunity to interview the staff from Arcteam about the attributes of their drone and the way of how these instruments are employed in the field. Drones. In the interview I also inquired about information on the budget that is required to build a drone and the limits and potentials of using such instruments in the field. Their responses were positive in all regards, which was due to the very few disadvantages of using a drone. When asked about the future of drone technology, they highlighted the attributes of altitude sensors and sonar instruments that allow a UAV to detect objects in close proximity. They were well knowledgeable in their field, and were able to answer all of the questions with an informative answer.

1.4. Case studies of survey

To further understand the impact that new aero photographic vehicles have had so far in archaeology, two different case studies will be presented. The first is from an acquisition campaign of insula V1 in the ancient roman town of Pompeii. The second is from an acquisition made in Monte S. Martino ai Campi di Riva del Garda in Italy. The data acquired during these two acquisition campaigns has been processed using a GIS platform and Photoscan to be subjected to several forms of study methods to visualize the capabilities and limits of the data procured by two different typologies of vehicles. The acquisition campaign of the Insula in Pompeii was procured via a balloon while Monte S. Martino was procured via a drone. The development of such case studies will showcase the attributes of using two different aerial vehicles in an archaeological survey.

1.5. Photo Scan

In the following case studies I will use a software called Agisoft Photoscan. This tool is capable of interpolating digital images creating high resolute scaled and georeferenced three dimensional models from them. Tests have revealed that Photoscan excels in processing aerial frame imagery which makes it very suitable for these studies. The first step in the program's procedure is called Structure from Motion (SFM). At this stage the software analyze the dataset, detecting geometrical patterns in order to reconstruct the virtual positions of the cameras that were used. The second step involves the creation of a complete geometry of the scene using a dense multi-view stereo reconstruction. At this stage the dataset of images are employed to produce a high-resolution geometry of the surface. This step successfully creates a 3D model or a Digital Surface Model (DSM) as they are also known. Photoscan allows the building of 3D models, Digital Surface Models (DSM) with different resolutions. Moreover the software has an automatic tool of texture projection. This feature makes it possible for an automatic projection from the color directly on the surfaces (Verhoeven, 2011, p. 68).

2. The field of Aerial Archaeology

2.1. Remote Sensing

Aerial Archaeology is a sub-field of Remote Sensing, a methodological approach which can be defined as “a means to observe the surrounding landscape”. Remote Sensing is a practice that has fundamentally existed since ancient times. Many ancient cultures used mountains to survey the landscape for resources and habitats. The “scientific” field of remote sensing was introduced about 100 years ago (Parcak, 2009, p. 13). Remote Sensing is all about observing the landscape; hence in archaeology it is used as a means to locate and verify ancient remains as well as study their relations with their surrounding territory.

This discipline and the recent technological development around it have strongly affected the studies in landscape archaeology. Remote Sensing techniques are in fact used today to determine the exact location of ancient structures or sites, as well as pathways and connections between these sites. It is also used to determine where resources have been, and why a community may have settled in a specific area. It is not limited to what one can see with the naked-eye as there are ways to survey what lays beneath the ground. To perform such a survey one can use for example a georadar, a piece of technology that will send radio waves through the ground and identify solid objects (Campana, 2009, p. 229).

Remote Sensing techniques such as Georadar and LIDAR photographs are employed to perform research in several fields, these tools allow the acquisition of information that are difficult or impossible to perceive. This is mainly due to its capability to see in the non-visible part of the human spectrum, and its ability to cover large geographical areas (Ihse, 1996, p. 59).

fig.1 a total station is a remote sensing tool that is frequently used in archaeology. Photo by Fredrik Nordin.

There are several ways and methods besides a georadar to procure information in the Remote Sensing discipline, such as through the use of a totalstation, GPS or camera among other means. These tools are used extensively by archaeologists as they are capable of providing very exact measurements and positions of any area or object. By the use of control points, the location of where an artifact was discovered or the boundaries of an excavation can be mapped by a totalstation and GPS. A camera can provide highly detailed pictures of a location, showcasing desired features which combined with the data from a totalstation can be used in further studies.

In the remote sensing field there are many ways to analyze and interpret the data that you have collected. There are digital applications such as Geographical information Systems (GIS) which are used to process data taken through remote sensing. A GIS is capable of analyzing and displaying spatially referenced features with connected geographic attributes and qualities (Ihse, 1996, p.59). This means that you can for example analyze the distribution of artifacts found during your surveys, and perhaps see if their distribution is clustered or uniform, from which you can create your theories.

Data taken through remote sensing is occasionally registered from an aerial view of the earth's surface. This allows the whole landscape to become equally accessible to the observer, and therefore allowed archaeologists to study the holistic view of the landscape. Which means that archaeologists are able to study how the landscape has been affected by human presence and how the landscape has affected them in return, both practically and cultural (Ihse, 1996, p.59).

2.2.1. Aerial Archaeology

Both aerial archaeology and aerial photography are practices that have been in use for almost a century, and they are still being used today. Aerial Photography is a practice performed while in flight over a designated study area, these photographs are then studied for signs of ancient remains. It is a cyclical process which involves taking aerial photographs, making them accessible in libraries and interpreting them for landscape and mapping projects (Luftbild, 1994, p. 83). “Air-photographs are enormously important, because they allow aerial observations to be communicated to others who were not originally there, while providing a record to future study and analysis, including measurement, transcription and accurate location” – David R. Wilson (Luftbild, 1994, p. 13). “It is easier to train air photo interpretations than it is to arrange a pilot, airplane and the weather…”- Robert H. Bewley, Swindon (Luftbild, 1994, p. 88).

The discipline of Aerial Archaeology is performed through the use of aircraft and is therefore considered a prime non-destructive research tool as it does not affect the landscape or the site in question (Norrman, 1984, p. 7). The main component of aerial archaeology is aerial photography which is the practice of taking pictures of various sites by the use of an aerial vehicle. It is the oldest remote sensing technique that is used in archaeology (Scollar, 1990, p 26). The photographs are taken while in flight over a designated study area. These photographs are then studied for signs of ancient remains. Historic aerial photographs are very valuable in landscape and geo-archaeological research, as it enables the reconstruction of changes in the landscape, changes in land usage as well as being a record for archaeological remains that have been concealed by vegetation or otherwise disappeared (Stoker, 2010, p. 33).

Fig.2 Small private aircrafts have frequently been used in aerial archaeology. Photo: Andreas Berggren

It is a cyclical process which involves taking aerial photographs, making them accessible in libraries and interpreting them for landscape and mapping projects (Luftbild, 1994, p. 83). Aerial archaeology is not restricted to airplanes, but can be performed through several flying vehicles. It is common to strap a camera to a balloon that you raise and direct over your designated area (Myers, 1992, p. 10).

Aerial Archaeology is a field that evolved from Aerial photography, a practice that started 1858 in France by a man named Gaspard-Félix Tournachon. Tournachon was a French photographer who was the first person to take an aerial photo, after having constructed his own balloon that he used to take an aerial photo of Paris. Aerial photography came to be mainly used for aerial reconnaissance in the military as it proved advantageous to have information of the landscape and the enemy army, such as during World War 1 when the French Intelligence Service flew over Germany in order to acquire material that would help in monitoring the military activities on the border (Ericsson, 1992. p.10). Although for militaristic purposes, the serendipity effect have been regular as ancient structures were often unintentionally photographed (Cowley, 2010, p. 1). The first photography that had intentionally been taken of an archaeological site was in 1906 when Lieutenant P.H. Sharpe took a photo of Stone Henge, from a balloon (Ericsson, 1992. p.10).

Aerial Reconnaissance increased during World War I, and several of the pilots that took aerial photographs came to become active in the field of Aerial Archaeology. O.G.S Crawford and G.W.G. Allens were two former pilots that came to symbolize the starting point of Aerial Archaeology in Great Britain. It would however take about half a century until Aerial Archaeology was officially designated a field in archaeology. The first international colloquium on air archaeology was held in 1963, and in its aftermath Aerial Archaeology was designated an official sub-field of archaeology (Parcak, 2009, p. 19).

The country of Sweden has been a tricky place to perform remote sensing in due to the large forests that are spread out across the country, which limits the visibility and detection of ancient remains. Regions such as Skåne, Öland and Gotland have therefore garnered more attention as they are in abundance with flat agricultural land. Sweden has been a neutral country during the last big wars, but they have not been completely idle as a large number of aerial photographic materials have been acquired in order to constantly monitor the military activity on the borders. It was therefore that it was a soldier who took the first aerial photographs used in Archaeology in Sweden. The photo was taken in 1923 by lieutenant H. af Trolle who took pictures of Bulverket on the island of Gotland. The Swedish national heritage board (Riksantikvariatet) had been in contact with the Swedish military regarding aerial photography, in order to use this material for the archaeological investigation of the Bulverk. The resulting photographs were used in the investigation and were later published in an archaeological report in 1927(Norrman, 1994, p. 14). The first archaeologist who did a systematic use of aerial photographs to conduct an archaeological research was Mårten Stenberger, who in 1930 started a large study based on the island of Öland (Ericsson, 1992, p.12). Together with Lieutenant Gösta Hård, he acquired pictures of Öland's hill forts while flying in a two seated Heinkel He 5 T. Using the acquired material, Mårten was able to publish the first strictly aerial archaeological report in Fornvännen in 1931 where he discussed the benefits of aerial archaeology and how to achieve the best results. (Norrman, 1994, p.14)(Stenberger, 1931, p. 204,205). Another important contributor was Esse Ericsson, a former officer in the Swedish military who came to utilize aerial archaeology frequently in his work and is to this date the last prominent Aerial Archaeologist in Sweden. He is known for his continuous aerial-archaeological surveillance of the Skåne region which revealed many new and old features (Ericsson, 1992, p. 46).

The amounts of aerial photographs that have been taken since the end of the 19th century are millions and since the photos and films are fragile, especially due to age, they have been stored in archives. All the surviving aerial photographs acquired in the last 3 centuries have been stored in archives and are now available to the public. Each country has an institute that stores and preserves such information, but despite this there are international archives, examples would be the National Archives and Records Administration (NARA) and the National Collection of Aerial Photography (NCAP) (Formerly the Aerial Reconnaissance Archives, “TARA”). Secondary archives that are now defunct and/or merged with others are The Allied Central Interpretation Unit (ACIU), the Mediterranean Allied Photo Reconnaissance Wing (MAPRW), Luftwaffe's division GX and the Joint Air Reconnaissance Intelligence Centre (JARIC) (Cowley, 2010, p. 2). Collections of images can also be found in museum archives, such as The Imperial war museum in London (http://www.iwm.org.uk/) which hosts a collection of over 8000 pictures from WW1. Many of the archives have or are being in the process of becoming digitized to become more readily available, and because of the deterioration rate of the original prints and films. NCAP sees it as their role to collect and secure the future of the photographic records, both digital and physical. They aim to preserve the records so that they will be as accessible and available as possible for the generations to come. It has been stated that “modern digital imagery should not be considered as a replacement for the large volume of traditional and historical photographs that reside in various archives but rather as a valuable compliment to it”(Deegan, 2010, p. 63). The photographs are likely to reveal things that have been altered or removed since their conception and are not visible on recent photographs. Deegan makes it clear that there is no “one-stop” shop for aerial photographs, no more than there is a single approach to landscape history. Archaeologists, architects and other professions make use of the archives as they are a valuable source of information. For a city-planner it might explain why an area is suitable or unsuitable for habitation. Archaeologist and especially aerial archaeologists use them frequently to find traces of what once were. They are therefore used as foundations in several works that identify old buildings or places that do no longer exist.

2.2.2. Types of aerial archaeology vehicles in usage

Besides the airplane, aerial archaeology can be performed through practically almost any aerial vehicle. Aerostatic balloons with an attached camera are often used as they are easy to handle and procure. The larger a balloon is, the steadier it moves, hence when taking photographs, it is often preferred that a large blimp-shaped balloon is used. The balloon can be controlled via winces that are steered by the persons below, or through remote control. The camera is controlled through remote or set to take pictures on an auto function (Wilson, 1992, p.8-11). Kites are essentially used in the same way. Miniature models are becoming more and more popular as they allow for more freedom when taking pictures of desired sites.

2.2.3. Organizations

There are several organizations that keep the subject of Aerial archaeology alive and well, one of them is the Aerial Archaeology Research Group (AARG) (http://www.univie.ac.at/aarg/php/cms/index.php). AARG aims to spread information and exchange ideas in an international forum for the persons that are actively involved in the fields of aerial photography, photo interpretation, field archaeology and landscape archaeology. It tries to garner interest from the whole field of archaeology, and has members from over the whole. AARG has also been involved with aerial archaeology training courses across Europe (Brophy, 2005, p. 8).

2.2.4. Tactics of aerial photography

The weather plays a large role in the acquisition of aerial photography as weather conditions can affect the quality of the photographs. For example during a cloudy or rainy day, the low visibility will reduce the quality of the pictures. Due to the high costs of performing an aerial acquisition, Aerial Archaeologists have developed a number of guidelines in order to always achieve the most effective result. Relevant examples can be found in the work of Esse Ericsson, who in his book "Flygspaning efter Historia" describes how one can detect underground stone structures by looking at the vegetation growing on top. One can also detect raised features in the landscape by studying the shadows emitted by them, a common ancient remain that is detected like this are hill forts(Ericsson, 1992, p. 19). Another example is during spring, when cold frost nights are common. Stones, brick walls or other types of constructions that are buried underground will act as cooling aggregates, so when the frost melts away from the heat of the sun, the frost will form an outline of the stones or walls that lie beneath it (Ericsson, 1992, p. 21). In short, archaeologists are looking at images taken from the air of palimpsest landscapes, landscapes that have been altered but are still showing signs of what was before (Kijowska, 2010 p. 156).

A decline in Aerial Archaeology occurred during the "Space Race" in the 1950's when the development of space and satellite technology became more interesting to the leading governments of the world. It was important to face this new "frontier" as it would allow global mapping and surveillance of the planet. With the introduction of satellite imagery, the field of aerial archaeology changed drastically, redefining the role of aerial vehicles for archaeological studies. The satellites act as a platform in low earth orbit, to capture images of the earth's surface on a large scale. The first satellite capable of high resolution photo capture was the Earth Resource Technology satellite (ERTS), which was launched on the 23rd of July, 1972(Fowler, 2010, p. 99). The satellite imagery was as with the Aerial photographs initially, strictly for military purposes, but as time progressed, satellite imagery became available to the public. The internet age has seen the introduction of software such as GoogleEarth™, a computer program in which the user can look at the whole world through satellite imagery, which has made the working process much easier for archaeologists (Parcak, 2009, p. 43).

2.2.5 Spectrum

Even though we are able to acquire images of landscapes with good resolution and detail, we are still only able to see a part of what our technology is capable of showing us. If we go deeper we enter the field of spectrum science. The spectra are the range of colors that the human eye can and cannot see and are measured in nanometers. Human eyes are only able to see red, green and blue followed by the many colors that can be made from mixing those three. The Spectrum is divided in four main categories called wavebands, which are classified in several types such as near, mid- and short-waves. The Spectrum consists of the near-Ultraviolet (near-UV) between 300-400nm, the Visible between 400-750 nm, the near-Infrared (near-IR) between 750-1100 nm and the shortwave-Infrared (SWIR) waveband between 1100-3000(Richards, 2001, p. 1).

The non-visible spectrum consists of the spectra, near-IR, near-UV and SWIR. The chemicals in our eyes constrict our color vision allowing us only to see the visible Spectrum. The photons in near-IR are for example not able to stimulate our eyes due to a lack of energy. The lenses in our eyes block near-UV light; hence we are unable to see those colors as well. The glass and photographic film specifically made for cameras that are in the near-IR and near-UV wavebands have optical properties that are similar enough to the visible waveband. So by using special filters and film, scientist have a way of seeing them.

X rays and Gamma rays lie on the opposite side of the Spectrum and have such short wavelengths that they interact with matter in very different ways compared to the longer waves. With their ability to pass through solid matter they are frequently used in studies in several sciences like in archaeology and remote sensing. They are considered dangerous because of their ability to initiate permanent chemical changes in human bodies, but the probability is low that it will happen.

Human visions cuts of at about 400 nm on the spectrum scale, so to visualize what we cannot see we have cameras. All cameras have the ability to take photos in near-UV while infrared has to be taken with special filters (Richards, 2001, p. 5).

2.2.6 Cameras

One of the main foundations in aerial photography is cameras, a fundamental tool that is used avidly in archaeological sciences. The visual and multispectral component in this discipline is dependent on the technological development of cameras. The development has come a long way from the camera invented by Joseph Nicéphore Niépce in the 1820s that was able to acquire and produce the first permanent photograph (Gustavson, 2009, p. 5). The development has gone from analog cameras where images are developed through a complex process involving different chemicals into being developed by heat and now currently digitally. Breakthroughs came with the introduction of flashbulbs in 1925 and the camera film in 1936(Gustavson, 2009, p. 232,243). A camera specifically produced for aerial reconnaissance known as the Williamson Airplane Camera was invented in 1915, and is to date the only one. It was designed to be powered through a propeller that used the force of the wind currents that forms around an aircraft (Gustavson, 2009, p. 259).

fig.3 Williamson Aeroplane Camera, invented in 1915, the first camera to be specifically made for aerial photography.

The biggest change came in 1975 when the first digital camera was invented, which would spur the development into the digital era (Gustavson, 2009, p. 336). The advancement in technology allowed both normal cameras and the cameras in satellites to receive the ability to take photographs that extends beyond the electromagnetic spectrum of the human eye. The ability allows the camera to take pictures through and beneath the environment, enabling us to see hidden objects (Parcak, 2009,

p. 3). As the science of the spectrum progressed, development of cameras ventured in the same direction. The simplest multispectral camera system is made by placing a color filter in the camera, and is usually referred to as the sensor-side filter system. The multispectral cameras have the ability to separate light, based on their color. The resulting images are presented in such a way that every feature is defined by a separate hue of color (Hardeberg, 2001, p. 4).

2.3. Geographical Information Systems in archaeology

Aerial photographs have been analyzed through the study of their contents and comparisons with regional maps. These analyses required huge photos and maps that had to be carefully stored to avoid damage. With the introduction of Geographical Information Systems (GIS), the whole practice changed. A GIS system is several computer programs capable of analyzing and displaying spatially referenced features with connected geographic attributes and qualities (Ihse, 1996, p.59). It is also defined as being a collection of computer hardware, software, personnel and geographic data, which is designed for the acquisition, manipulation and management of spatially referenced data. It can also be defined simply as a data management and mapping tool.

GIS is a valuable tool for every archaeologist as there are countless of analyzes that can be performed. Each GIS program contains several tools that will allow the post-processing of archaeological data. The systems allow the inputting of a coordinate system into data, which makes it possible to georeference data to exact coordinates. Georeferencing is one of the main tools, which means aligning two sets of data with each other, often matching the exact coordinates. Another set of tools are used to make distribution and cluster analyzes of findings. By creating or using a preexisting map of an archaeological site, one can input the exact coordinates of the findings and the coordinate system will mark these locations as features on the map. The ability to create features is another main tool, features that can be manipulated and created in different shapes such as line, point or polygons. These features can be connected with attribute data to distinguish them between each other. Features will be displayed and organized in layers. The features will not interact with each other unless manipulated to perform an interaction. Several GIS systems are capable of creating digital elevation models (DEM), 3D representations of a landscape. By inputting height data, the programs are able to construct a virtual model of a landscape (Chapman, 2006, p. 16). Through the construction of this typology of simulations it is possible to perform what is known as a least-cost path analysis, an instrument capable of calculating the most energy efficient path through a landscape between two points. The last main tool is the ability to create images out of these features. By illuminating the features in various colors you are able to create overviews of sites, as well as maps.

It is fundamental that a meaning is obtained from the data in order to perform an archaeological study. A level of interpretation is therefore required in order to understand the archaeological landscapes (Chapman, 2006, p. 18). It is often desired to understand the behavior or visual patterns of a culture, as well as their development. With a GIS you can solve questions relating to artifact distribution, energetically efficient routes, if artifacts are clustered or uniform, deducing where potential sites of archaeological importance are situated (Conolly, 2006, p. 2, 11, 13). Distribution and cluster analyzes are frequently used as tools in determining the spread of objects or monuments. One could for example analyze and interpret the spread and placement of rune stones in Sweden. Communities are dependent on resources, and people are most likely to take the least energy demanding path to the resources. By performing a least-cost path analysis, the GIS program will deduce what would be the fastest way through a landscape to a resource or location, though one have to be aware of other factors that may have influenced the path. Digital photographs are often employed and implemented as reference to archaeological maps or to mark points of interests, such as the exact locations of important finds. In a GIS you can also analyze your satellite imagery and by comparing it with an aerial photography, you as an archaeologist will have access to a high resolution image as wells as the non-visible part of the spectrum (Parcak, 2009, 34) The most common way to use a GIS is to construct maps over excavations, or structural layouts. By the use of layers, one can for example make features that visualize the different levels of a posthole, or the generations of different structures that have been built on top of each other. Another employment in a GIS is to be able to rectify old maps with new maps in order to find old locations that might be long gone or over built by new constructions (Conolly, 2006, p. 86).

2.4. Satellites

Today's archaeologists have access to images that can be acquired from different kinds of satellites such as, Ikonos, Quickbird and SPOT. Every satellite present different characteristics in resolution and typologies of their sensors used to acquire the pictures. It varies between each system if it is capable of capturing images in the different spectrums of the electromagnetic (EM) spectrum. It ranges from the visible spectrum through the near, far, middle infrared and thermal portions, spectrums that allow archaeologists to detect ancient remains that are not visible to the naked eye. Several of the systems record images in a technique called “Hyperspectral” which captures multiple parts of the EM Spectrum in one image (Parcak, 2009, p. 43). Infrared (IR) is for example able to capture images showcasing the heat signatures in the landscape, revealing for example buried rocks that shows of a cold temperature. With pictures taken through multispectral photography you can perform a wide range of analyzes such as on geomorphology and land usage. It should be noted that the landscape does not have the same values across the world, and it is therefore important that archaeologists use more than one type of remote sensing tool (Parcak, 2009, p 21). Satellite imagery is frequently used as a method by archaeologists as some are free to acquire through the internet. The images are able to cover large surfaces providing valuable material for landscape studies.

2.5. Visualization Tools

GoogleEarth is a semi-free software that is available through the internet and is provided by the Google corporation (www.googleearth.com). Users are able to look at and download satellite images from all over the world. Archaeologists frequently use images from softwares such as GoogleEarth. Many of the pictures have such a high resolution that it allows the viewer to zoom in until they see buildings and people up close. This feature is mostly just available in largely populated areas, whereas in rural areas the resolution is not so high. The user can also access a "street view" at certain points of each road, where the viewer can look at a panoramic view of that exact spot. The images have been acquired by a "Google" car that has taken pictures of its surroundings progressively as they traverse the roads of the world (Parcak, 2009, p. 43).

3. Aerial Drones

A drone is an Unmanned Aerial Vehicle (UAV) that can be autonomous, semi-autonomous or radio controlled. This technology has previously been used mainly by the military for reconnaissance and monitoring in areas that are not accessible to humans. A standard non-remote controlled UAV relies on a navigation system that is dependent on GPS and inertial sensors (Conte, 2009, p.61-62). Drones that are very small and compact in scale are called Micro Aerial Vehicle, MAV (Conte, 2009, p.1-2).

fig.4 The Boeing Phantom, a global corporate founded UAV.

The concept of unmanned aviation had its beginnings in the first half of the 19th century during World War I. Aerial torpedoes were modified to become remote controlled so that they could be used in anti-zeppelin trials. Until the year 2000, UAVs have mainly been used for surveillance duties (Brookes, 2000, p.5).

In 2004 there was an estimation of 2400 UAV's in use around the world, of these were 65% produced in Japan and used for agricultural purposes such as spraying insecticide and fertilizer. Western Europe had the second largest fleet with the majority of them in military service. Europe is followed by USA, Australia, Eurasia and Israel, with Israel having the smallest fleet (Newcome, 2004, p. 127).

The drones can be grouped in five categories of what sector they are utilized in, military, academic, commercial, civilian and nonprofit or nongovernmental organizations. The first category is characterized by a higher technological development due to its larger budget. Despite the mass produced version in all sectors there are also countless of prototypes made by both private and government enterprises that covers a large numbers of operations and show several possibilities in using aerial drones (Newcome, 2004, p. 130).

3.1. Development and use of UAV in military environments

The UAV's or drones as they are known have mainly been used by the military until recently, and there are therefore many different types of UAV's. Many of the drones that are currently used by the military are autonomous and capable of controlling and performing actions by themselves, in contrast to a radio controlled drone which is dependent on a human. The military types have been developed based on their intended deployment and use. The RQ-5A/MQ-B5 Hunter by the US army is for example capable of transporting munitions from point A to B. Aside from transportation of general goods, there are drones meant for warfare or scouting. The X-45 UCAV designed by Boeing Corp was designed for strike missions in combat zones (Valavanis, 2007, p. 26).

3.2. Development and use of UAV in society

The civilian types are more "inventive" in terms as they have to be affordable and at the same time be able to perform adequately during flight and surveys. Archeological drones stem from radio controlled hobbyist models, in example radio controlled miniature helicopters. They are often built from components that are marketed primarily to radio control model enthusiasts (Hill 2013). Many users customize their drones by themselves with their own expertise, adding additional features such as sonar, larger batteries or a sturdier frame. The UAV platform is available for purchase in different types based on rotor configuration, such as four rotors set on an "X" shaped frame, or nine rotors set on a larger frame. During the last years a large community of amateurs has presented different typologies of UAVs, which has led to today were several companies have started a commercial distributions of very powerful instruments that can be successfully employed in different areas of the private sector.

3.3. Commercial distribution and diffusion

Private enterprises like the Boeing Corp are known for building UAVs meant as test-beds for new technology such as the X-50 which was built to demonstrate the "Canard Rotor Wing" configuration (Valavanis, 2007, p. 31). United Drones () is a USA based company that offers services in creating customized drones, manufacture drones of the highest quality available on the market, training programs for software and hardware. There is however legal restrictions on the commercial drones industry, due to the ethics on privacy and misuse which I will discuss in a later chapter (Hill 2013).

A UAV is in a sense not just a remote controlled aircraft, but also a robot. This is because as a robot it is equipped with sensors that gather data about the surroundings. A computer system then processes the sensor data and through it, performs actions based on the data by using physical actuators such as flight actuating rotors. Being a robot and not just a remote controlled aircraft means it has a lot of potential to be developed further, and helping archaeologists in many areas such as being able to maintain stability in flight allowing photography (Asplund, 2011, p. 2).

fig.5 A UAV or aerial drone, equipped with a camera.

Several drones are equipped with a system called Path Control Following Mode (PFCM). This system allows the UAV to follow a 3D geometric path, by receiving the spatial information from the path planner inside the CPU of the drone. A completely functioning Artificial Intelligence (AI) system is not easy to implement as it is not yet able to substitute a human pilot (Conte, 2009, p. 2). Drones or UAVs are highly dependent on GPS and the loss of a satellite connection could negatively affect the flight. A modern UAV can automatically handle all the operations of take-off and landing. The standard payload on a UAV is a video camera which also acts a sensor for the drone (Conte, 2009, p.62). The technology used in UAV's are constantly progressing in their development, modern UAV's employ the use of gyroscopes for stabilization or with sonar devices which enables the UAV to detect objects bellow itself and perform evasive maneuvers corresponding to it. With over 250 models to choose from, a technology under continuous development to develop additional abilities and the high demand on UAV's across the world, the future of UAV's look promising.(Newcome, 2004, p. 128-138).

3.4. The use of UAVs for the development of archaeological investigation

Archaeologists are currently using drones or UAVs as a compliment to the regular fieldwork of digging and measuring control-points. More than often are they used to take photographs of the excavation area to be able to provide a more exact overlay of the site. The data from the site is often post-processed in a Geographical Information System (GIS), and together with an image of the site you are able to analyze your data further. Surveying is currently the main usage of drones in archaeology as they can traverse high heights with little effort. The newest way to use UAVs in archaeology is for mapping and 3D photogrammetry. Using images of maps and sites of interest it is possible through computer technology to produce a very accurate 3D model. Instead of personally visiting a site you are able to view it on your computer (Hill, 2013).

4. Theoretical Discussion

4.1. Digital Archaeology

Aerial photography is in all its rights connected to digital archaeology as both cameras and the post-processing of the images are performed through digital means. Digital archaeology is not strictly methodological, as it can enable and impact particular theoretical positions (Evans, 2005, p. 27). There are often two views of digital archaeology, the first is that it is purely methodological, a set of tools to solve a problem. For example by inputting data into a software, which in turn processes the data into a desired result.

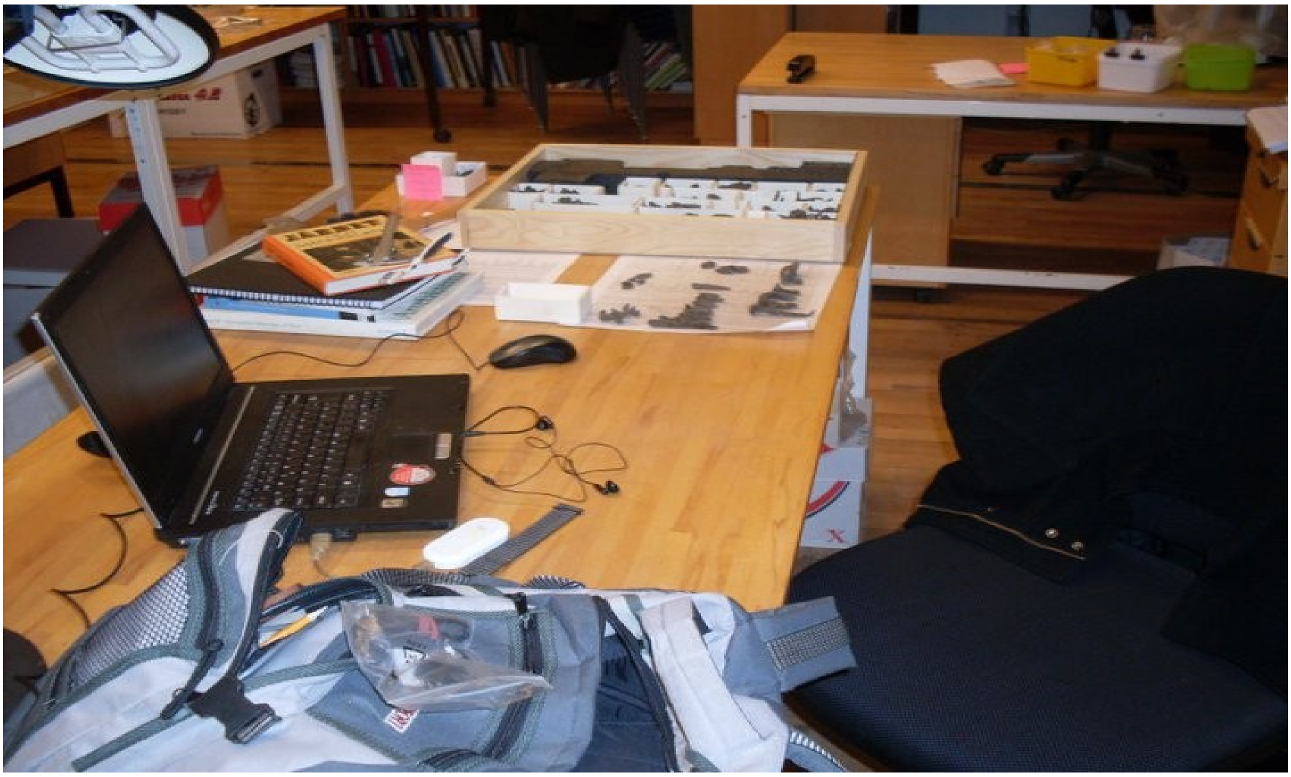

fig.5 Using digital means in archaeological analyzes.

The second view is that it creates or at least influence the creation of theory, such as showcasing resources in an inhabited area. It then acts a proxy for theory as it shows a reason for the inhabitants to have settled in that area (Zubrow, 2006, p. 11). It is more of an approach than a theoretical school or specialism, an approach to better utilize computers and understanding their limits. Digital archaeology shows how the daily connection between archaeologists and Information and Communication Technology (ICT) functions and how it affects how archaeology is performed. Digital archaeology is continuing to develop as we see new methods for analyzing information every year. As such it also affects aerial archaeology, whose cameras and image processing software are digital instruments.

4.2. The use of UAVs for the transfer of archaeological knowledge

There is a certain responsibility for us as archaeologists to communicate the results of our research to the public. There will always be a need to garner interest and providing understanding of archaeological research to the public, as that is how archaeology will remain an interesting topic. The abilities of a drone could easily be what we will use more frequently in the future as UAVs are a combination of three “worlds” archaeology, avionics and robotics. Three “worlds” that are interesting to many people as they are connected to time, the past and the future. I feel it represents the future of archaeology due to being a combination of technology that is easy and affordable to handle (Hill, 2013). But not only for its convenience but the sheer amount of possibilities that it will bring to the field are endless, especially when thinking about how the technology can evolve in so many ways. It is therefore necessary to show the capabilities of aerial drones to the archaeological community and the world in such a way that will encourage the continued development and integration of UAVs in the field of archaeology. The results in my study will showcase several of the capabilities that the drones are capable of, and I hope I will therefore lay a foundation for the expanded usage of aerial drones here in Sweden. Although the visual presentation of the results of an aerial archaeological study is a minor part of the whole, it is still very important. The visual presentation will showcase the information in such a way that I will spark interest and perhaps a continued interest in the field. Just like with all of archaeology we are telling a story of how people once were.

The visual information of a landscape or site will reveal the ways and patterns of the endless amount of inhabitants that have lived and walked over those lands. Vision is in most cases the sense that is responsible for the structuring space. A visual structure connected to a cultural landscape is often undeniable and may or may not have had a specific purpose (Evans, 2005, p. 149). With the glimpse we get of their habits and travels we can formulate a story of how they once behaved, traded, built and lived in their structures of habitat.

Visualscapes is an operational concept that within remote sensing attempts to organize, unify and extend both the scope and methodology of work that focuses on the study of visual space. It follows the idea that every cultural landscape generates, or can be associated with a visual structure. The emphasis is therefore put on the whole visual structure at large than focusing on a single site (Evans, 2005, p. 149). We often hear that we must look at the larger context, and in the case of aerial photography we are literally able to look at the large context.

4.3. Image interpretation

The landscape is what is all around us, trees, buildings and rivers. We continuously keep walking forward and backwards on a ground level. We are never able to look down on a landscape on a daily basis, seeing the trees and rivers, like a bird in flight. We therefore have different associations and knowledge of how trees and objects look from above, we see what we want to see (Brophy, 2005, p. 22). What I am trying to say is that aerial archaeologists must form a perception of how trees, buildings, rivers and objects look from above as. Not though objects that have been drawn by hand, but a real life landscape as it is seen from above. Without the associations and perception of how a real landscape looks, we would not be able to give a thorough analysis of a landscape (Brophy, 2005, p. 40). An office employee working on the top floor of a high-rise building does for example see the city landscape. It is somewhat from above, but not something that constitutes the creation of an association on how all buildings look from above. A pilot does however view the landscape from above on a daily basis and might form a perception of how the landscape looks from above. Just like an archaeological perception is a cumulative learned skill, which can be argued is achieved through successive excavations, which impacts on what they see from there on. One does however not go through these successive repetitions, and it is therefore of great importance that one study and identify how trees and objects look from above. Creating an association with how they look and therefor understanding the visible landscape in front of him (Brophy, 2005, p. 39).

fig. 6 Aerial photography is used to detect features that are not visible from the ground.

This is especially important to aerial archaeologists who will study aerial photos of landscapes and creating conclusions based on them. It is imperative that you have knowledge of how plants and stones act in cohesion with nature, as the aerial archaeologist will look at them to find the ancient remains that he is looking for. The aerial archaeologist need to be aware that in our field, memory and perception are inextricably intertwined, and the more we are aware, the more we will be rewarded (Brophy, 2005, p. 31).

There are arguments that from the time of observation, the process of interpretation has already started in the archaeologist's mind. In that process there will always be decisions of whether to include or exclude a structure based on if they are archaeological recognizable. The decisions will be based on reasons such as gut feeling, indecision, tiredness, boredom, alertness and time pressure (Brophy, 2005, p. 37-38).

There are always the questions of 'should I record that today?” or 'do I need to record that?' as there are never any lines to highlight features of interest. In the end it all comes down your personal choice.

4.4. The advantages & disadvantages of using a drone in archaeological research

This comparative and qualitative study is meant to illuminate the possibilities of aerial drones in the field of archaeology and will be showcased through digital means. As it is a relative new field, there are several parts that are still under development such as the ethics of remote sensing and aerial photography. There is also the question of why archaeologists should even use an aerial drone in their field work when there are satellites capable of similar feats? The main reasons archaeologists choose to work with drones are because of as previously stated the limitations to satellites and the photometric technology they use. A drone is portable and can be used whenever the user wants to in contrast to procuring data via a satellite which depends on the satellite's orbit as it has to be in range of the desired location to be able to photograph. The drone is able to take aerial photographs of the site by using or choosing the typology of camera that is better suited for the investigation. The desired quality is always a matter of cost when it comes to technology; the desired outcome is as such dependent on your available resources. All types of aerial photography are prime non-destructive research tools, meaning they will not alter anything of archaeological importance when performed. Their actions are therefore highly appreciated in archaeological research and field-work that does not have the means to fully document a site. (Stoker, 2010, p. 33) The current UAVs that are used in Archaeology are light-weighted and can be damaged by wind currents. The flying actuators and batteries are likewise susceptible to weather as cold temperatures can reduce the operability of the batteries.

4.5. Why the continuing development of drones

Drones or UAVs have proved highly efficient in their areas as they perform their respective task with ease. The drones are either self-maneuverable or can be controlled by radio and are therefore highly enjoyable to work with. Many people, especially hobbyists find building and maneuvering UAVs to be highly enjoying (Hill, 2013). Hobby building of small radio controlled vehicles has existed for a long time, and the feeling that the hobbyists have when putting together their vehicles will most likely remain for the future. As mentioned before, self-maneuverable drones will keep being developed as their self-sustenance has proven to be very desirable in military and agricultural associations. The desire to have fully autonomous and self-sustainable machinery is a dream that has existed for a long time and should come as no surprise (Newcome, 2004, p. 133-138).

4.6. Hermeneutic circle of taking photography

In aerial archaeology you often study your materials more than once, and you find yourself having to go back and take photos of your study several times. The hermeneutic circle is evident both through this practice as well as the studying process that occurs afterward. A hermeneutic circle is a process where reaching interpretations and understanding occurs more than once, causing the creation of new inspiration (Alvesson, 2010, p. 91). The serendipity effect is often the cause for this circle as the pictures might reveal things of interest that was not apparent to the human eye on the day the picture was taken. The knowledge inhibited by the person that studies the material is naturally of great weight. The circle might become shorter depending on the amount of prior knowledge that he has, as the knowledge acquired from the pictures are completely new. One might argue against this, saying that the knowledge collected can also be new to oneself solely, but I disagree as the knowledge has been known before in current times and is therefore not new. Nevertheless, the length of the circle depends on your prior knowledge. Going step by step, you first choose your site of interest and evaluate what parts of the site that is valuable to your research. As stated before, the weather and season of the year affects the visibility of ancient remnants greatly, and is one of the biggest reasons for missing objects and locations of archaeological importance. You then proceed with the photographing and conclude in step two with the post study of the images. Having acquired the knowledge you proceed to formulate it into coherent information, and depending on your prior knowledge you either finish or start again in either step one or two.

4.8. The effects it will have on archaeology

The affects aerial drones have and will have on archaeology are very positive. With the passing of time, technology becomes smaller and their prices lowered. It will become easier for archaeologists to acquire the technology needed to construct and use their own aerial drone. By using a drone, archaeologists will be able to acquire pictures and data of their excavation or survey, with the possibility of post-processing of the data immediately after. With various customizations to your drone and camera you will be able to procure picture data taken in the different spectral fields, which will reveal more interesting data. Procuring the desired data will become faster and ensures a quick process that would be appreciated during field-work with tight schedules (Hill, 2013). There will of course always be a reluctance to accept new technology, and it will therefore hinder the technological process (Parcak, 2009, p. 28). In the last years, we have seen the introduction of computer software that are capable of generating 3D models such as Photoscan. A drone is of great value when it comes to constructing digital models of a large structure as it is capable of reaching places a cameraman cannot.

4.9. The debate regarding ethical issues in remote sensing and aerial archaeology.

In this paragraph I would like to discuss the ethical perspectives of using an aerial drone or UAV in an archaeological context. Since the introduction of GoogleEarth™, archaeologists have been concerned that many undiscovered sites of archaeological importance will be subjected to thieves and looters (Parcak, 2009, p. 224). It has therefore been debated although not a lot; on how to protect these sites. The ability to falsify data is also an issue, as incorrect data can be unfruitful in the long run. This goes into the issue of promoting a good knowledge of how to manage data and information in the remote sensing professions. A few guidelines of ethics in remote sensing have been defined from it. Due to the overlap between the ethical usage statements of remote sensing and archaeological practices, an ethical issues' code has never been easily established. There is currently no international organization that promotes the usage of ethics in Remote Sensing and archaeology (Parcak, 2009, p. 232). The "American Society for Photogrammetry and Remote Sensing" (ASPRS) has a set of firm rules regarding the ethics; the Society for American Archaeology (SAA) has a separate set of rules of ethics. Despite similarities, the two set of rules presents differences and it is therefore vital that a set of rules for the ethics of remote sensing in archaeology is established. The Code of Ethics of the ASPRS was approved in 1975 and can be read at http://www.asprs.org/About-Us/Code-of-Ethics-of-the-American-Society-for-Photogrammetry-and-Remote-Sensing.html and the SAA's set of rules for ethics can be read at
http://www.saa.org/publicftp/PUBLIC/Resources/ethics.html

The first rule of the SAA conflicts with the ASPRS rules as the SAA deems that all archaeologists should work for the preservation and long-term conservation of the archaeological record. Free imagery poses the problem that it might be used by looters and robbers who might seek to rob and damage the archaeological sites. As said before, the issue here is that sites with an archaeological importance might be of interest to the wrong people. Thus without the initial intervention of the archaeologists, many things of archaeological value will be disturbed or removed from the site. Some might consider it a minor issue since the sites have previously not been either documented or lacks historical importance. It is precisely that which makes it an issue, since the sites could hold untold potential and give archaeologists crucial information. The remaining rules are similar between the two lists in that both disciplines want to promote a good usage of how to practice and teach the disciplines. It is fundamental for a community that a good behavior is upheld in order to keep the discipline's reputation in balance. If someone uses the knowledge of the disciplines in a bad way it will affect the reputation and the public image of the discipline. Ensuring that all parts of performing and promoting the two disciplines are upheld will result in a continued quality in the disciplines. There is also the dilemma of what should be reported, as a whole illegal settlement might lie upon historic remains, and if you report the findings the citizens might be evicted by force, effectively ruining people's lives. Claims such as discovering Noah's ark on top of Mt Ararat are usually done without the involvement of a proper remote sensing analysis or specialist (Parcak, 2009, p. 227).

fig.7 Aerial drones respecting the privacy of others is a debated issue.

One attempt at forming these rules was made by Sarah H. Parcak in 2009 in her book "Satellite remote Sensing for Archaeology". She suggested that Archaeological remote sensers should not publish data that can harm archaeological sites, promote good remote sensing, not create false data, geocode data points for internet publications, discuss functional techniques, promote the usage of remote sensing and keep safe while performing remote sensing activities (Parcak, 2009, p. 220-231). All points are good and valid but they have not been implemented as of yet. Currently there are laws being discussed in several states in the USA that would make the ownership of an archaeological drone illegal. The reason the laws have been proposed is due because of the potential harm that they may cause, such as invasion of privacy (Hill, 2013).

5. Case studies

These two case studies are meant as a way to illustrate the possibilities and ways of aerial photographs to be manipulated and used in different case studies to gain different typologies of archaeological information. The following work has been developed employing a combination of photogrammetry (Photoscan), Mesh processing (MeshLab) and Geographic Information system (ArcGIS).

5.1. Pompeii

Archaeologists have been excavating and working in the archaeological site of Pompeii since its first discovery in the 19th century. The Swedish Pompeii Project (www.pompejiprojektet.se) is a field-work project initiated in 2000 by the Swedish Institute in Rome, and is currently directed from the Apartment of Archaeology and Ancient History in Lund. The project was created to encompass all major disciplines that are promoted by the institute. Their aim was to document and analyze insula V1, an entire Pompeian city-block. This segment of structures, often referred to as an *Insula*, consists mainly of standing walls and floors. The debris that was covering the insula was hastily removed in the 19th century, and was not documented. Hence the aim of the project was to remedy the lack of documentation and use the results as a platform for a wider contextualization. Field-work is still proceeding on the insula, as of recently when a laser scan was performed over the insula with the intent of creating a 3D model. The buildings in insula V1 consists of both large and small structures, all situated wall to wall. There are approximately 16 small shops as well as a larger bakery that are situated next to the SW and SE roads. In conjunction with these shops are larger structures referred to as Domus such as *Casa di C. Iucundus* (Leander, 2010, p. 1).

5.1.1. Acquisition of photographs

The acquisition campaign was performed in 2009 by employing an aerostatic balloon equipped with a camera. A route that encompassed the whole of the insula was prepared for the balloon, in order to capture images of the whole site. The camera was set to take photographs on a regular basis with a resolution of 10 megapixels. The photographs were not taken with the intent of being post-processed into a 3D model; hence they have been acquired without a specific strategy for the generation of a 3D model of the site. Despite the impossibility of acquiring information about the camera characteristics employed during the acquisition campaign, it was possible to generate a resolute 3D model of the entire site with an acceptable level of accuracy.

5.2. Monte S. Martino ai Campi di Riva del Garda (Italy)

The archaeological site of Monte S. Martino is a location that has a history that stretches beyond the Roman civilization which is evident due to the findings of stone axes and arrow heads. The roman ruins that sit prominently on the hill remained undiscovered until 1969 due to dense vegetation and the fact that the ruins were buried. A group of enthusiasts happened upon several roman tiles in the soil and decided to perform an excavation of the area. After six years, the site fell under the protection of Provincia Autonoma di Trento, and has been the subject of a series of systematic investigations since then. The site has been the locale for rituals prior to and during the roman age, where in the end of the first century B.C. a shrine was built on the site. The structure was built in several phases with the east section being built in several additions. It consists of several rooms that are adapted into the terrain of the hillside. A numerous set of dwellings on artificial platforms were added later. The site was seemingly abandoned in the sixth or seventh century due to fire, but several of the buildings continued to be used. One of them was converted into a church that was evidently abandoned in the 17th century due to being in poor condition (Bezzi, 2012, p. 4-5).

5.2.1. Acquisition campaign

The images were acquired by the ARC-Team who was hired by the *Soprintendenza per I Beni Architettonici e Archeaologici della Provincial Autonoma di Trento*, Italy in the winter of 2012 to take aerial images of Monte S. Martino. During the first flight, the drone was equipped with two different digital cameras: a Nikon CoolPix S210 and a GoPro HD Hero. The photo shooting would be performed via a remote. The whole area was able to be successfully captured due to the use of a wide angle lens. The lens distortion did not represent a problem as it could be easily removed in post-processing. The Nikon camera was hard to manage in the windy weather and the manual shooting with the slow shutter speed was a cause of problems in piloting the drone. Many of the produced images were out of focus, hence it was decided that the other flights where supported by the GoPro camera. Despite that a post processing have already been performed using open source tools I had the possibility to use the material acquired during the acquisition campaign to perform a different workflow of data post processing. In specific I applied the same pipeline used to develop the data from Pompeii.

5.3. Post-processing & results

In both cases the images were imported into the Photoscan software and post processed using identical work-flows of data post processing. Once I had imported the data set of images I performed the “align photos” tool, in order to estimate the camera position for every set of images. The software allows settings in three different steps: Low, Medium or High, these options define the accuracy in detecting the geometrical pattern used by the algorithm to define the camera position. This parameter has been calculated for both data sets in high accuracy.

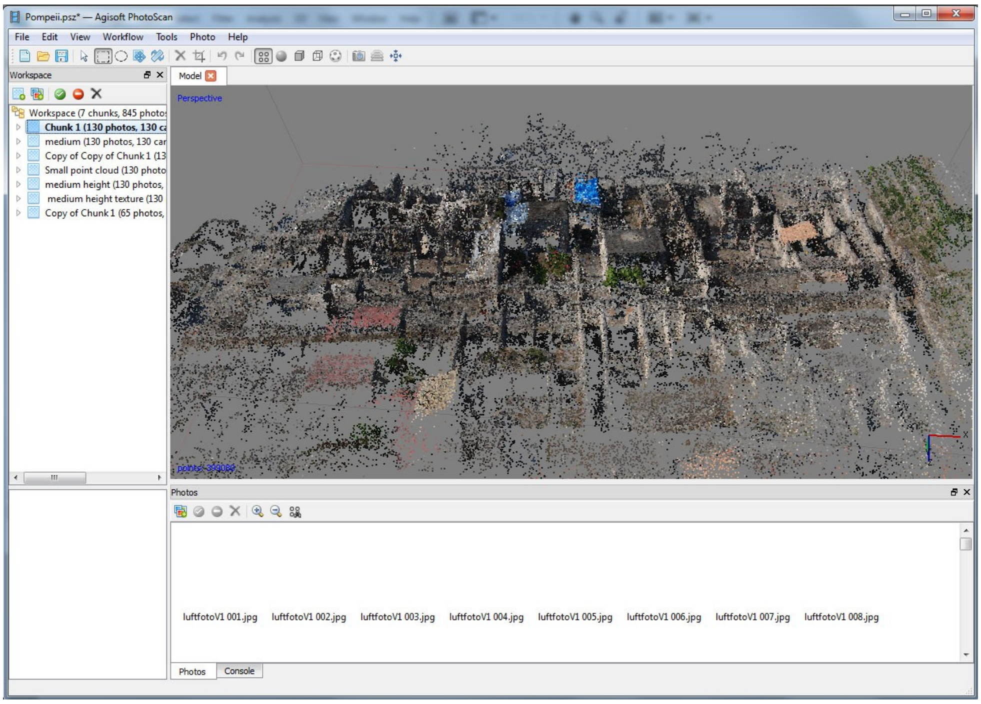

Fig.8 An elaborate point cloud model of the insula in Pompeii, made in Photoscan

The result was an elaborate point-cloud that allowed the creation of more elaborate models. The second step was based on building the geometry. In order to perform this operation I chose the following settings: Object type “Arbitrary”, Target quality: Medium, Geometry type: Smooth, with a facecount value of 0. Because of the large numbers of images of Pompeii I decided to use the medium setting in target quality (a high setting would have taken too much hardware resources). To develop the pictures of Monte S. Martino (only 16 images) I used the high setting.

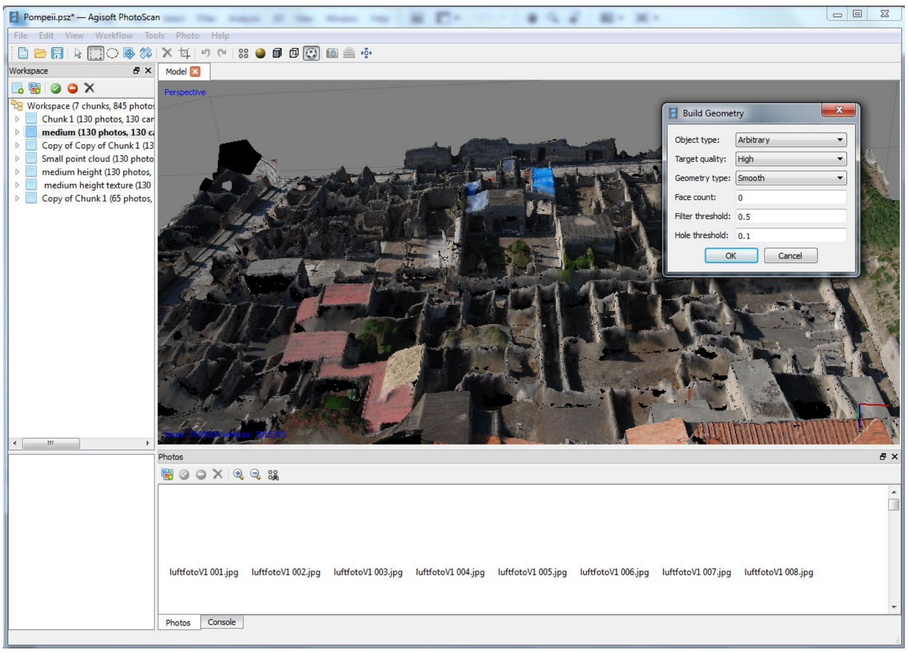

fig.9 Image of how the applicable geometry settings are seen

Once the two models were complete I used the parameterization tool to add the color information to the models. In order to perform this operation I used the settings of Mapping Mode: Generic and Blender Mode: Average, as any other setting would distort the texture. In order to not waste texture memory, I cleaned the model before the projection, removing parts that had been processed but were not relevant for the model.

Once created, the models have been exported and post processed in MeshLab. This is an open-source software for the processing and editing of unstructured 3D triangular meshes. It contains a set of tools for cleaning, editing, healing, rendering and inspecting meshes. Through this software it has been possible to change the light settings of the models and exporting ortho-images of the sites.

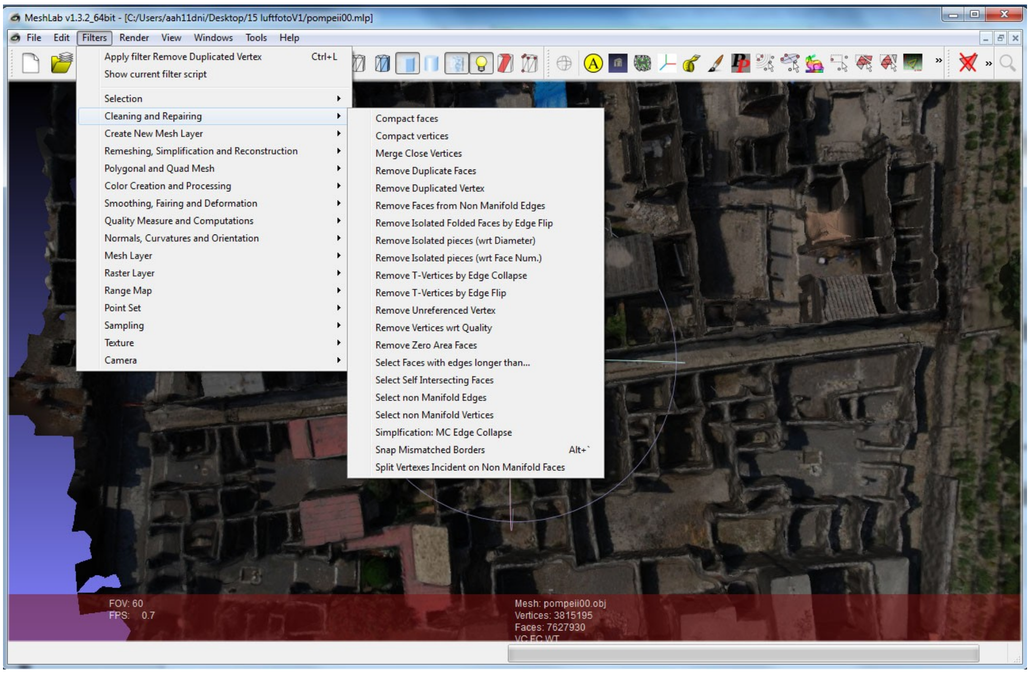

fig.10 Various applicable filters that are available in Meshlab

As a final step I imported the images into ArcGIS. Through this software I performed an analysis of the sites, creating several layers in order to represent the different features in the two archaeological sites. In order to perform such an operation I employed the use of ArcCatalog to generate shape files in order to edit the detected features.

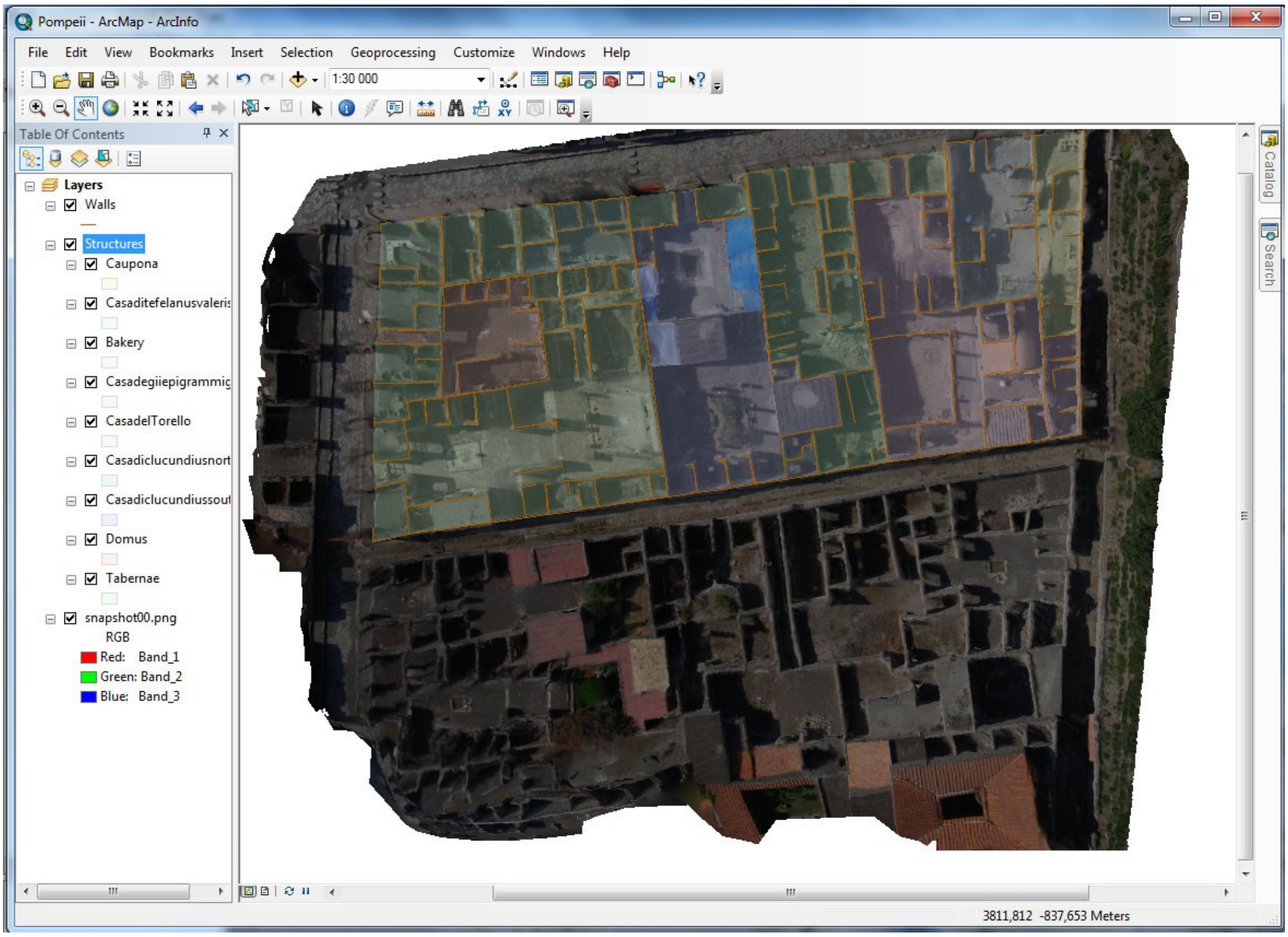

fig.11 The construction of polygonal and linear features in Arcmap GIS

6. Pros & cons after usage of UAV.

Through the analysis of this process it is possible to clearly and efficiently visualize a complete picture of large-scale archaeological sites. The development of this photographic material has proven the efficiency of UAVs and aerostatic balloons, and their ability in documenting extensive archaeological sites. Through the development of a low cost work-flow they are able to provide a new typology of documentation in a short time. In specific, the Pompeii data set demonstrates how using and elaborating pictures can create 3d reconstructions, even without the intent of doing so, and as such they have proved to be a valuable source of research material.

fig.12 Finished model of the insula V 1

The 3D model of the insula (fig.12) is of medium quality, but the result, is as can be observed very good. The quality makes the model unsuitable for deeper interpretations, but is sufficient to provide a good overview of the structures. There are some locations in the model that were not fully recreated as the photoscan software depends on the visibility of the site from the aerial photographs. It means that the order to recreate a complete model, the software requires that every crevice and small areas are photographed from every angle.

The finished model of Monte S. Martino is more detailed than the Insula model. As can be observed, the details of the features are better. This is due to the images it was based on were taken from more angles than the insula in Pompeii.

Fig. 13 Finished model of Monte S. Martino. This model has been realized using a photographic acquisition campaign realized by the Soprintendenza per I Beni Architettonici e Archeaologici della Provincial Autonoma di Trento under the direction of Dr. Pisu.

The following illustration (fig.14) shows the comparison between a sketch of the Insula and its buildings with a drawing made in a GIS from the 3D model based on the aerial photographs.

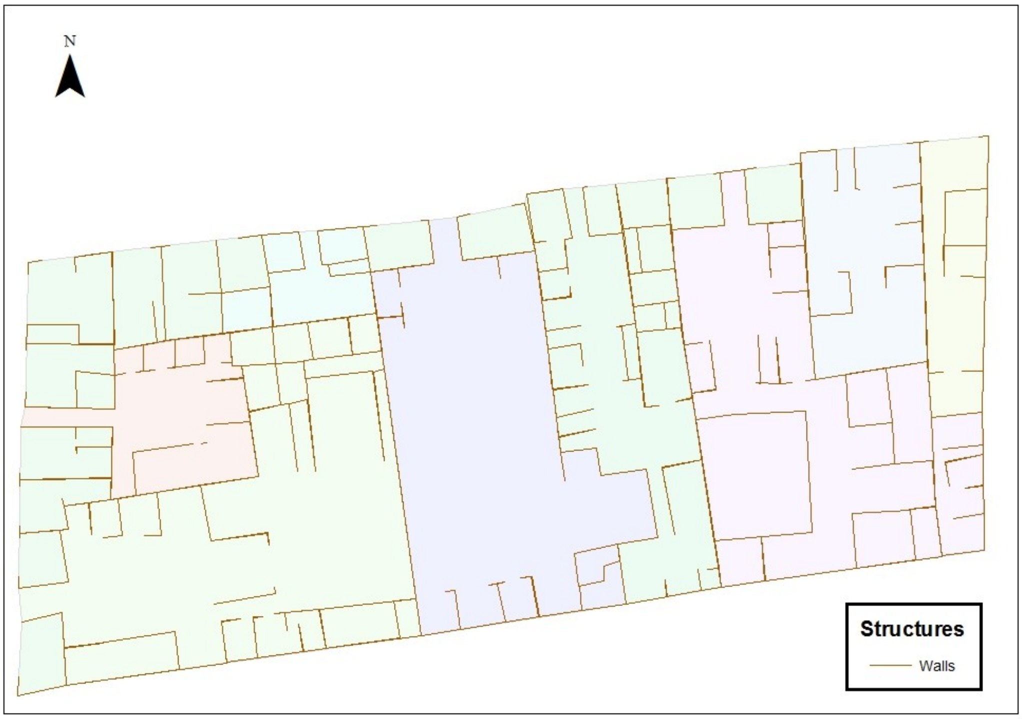

fig.14 Digital drawing of the structural walls from the insula V 1, made from a 3D projected ortophoto.

As can be noted, the digitally created feature is missing several of the minor walls of the structures. This is due to a difficulty in distinguishing the features that could be observed in the image once imported into GIS.

The data can be manipulated further, like in this case (fig.15) were I have marked each of the different house and workshop structures of the insula. By adding attributes to these it creates a simple map that would be hard to create without a UAV.

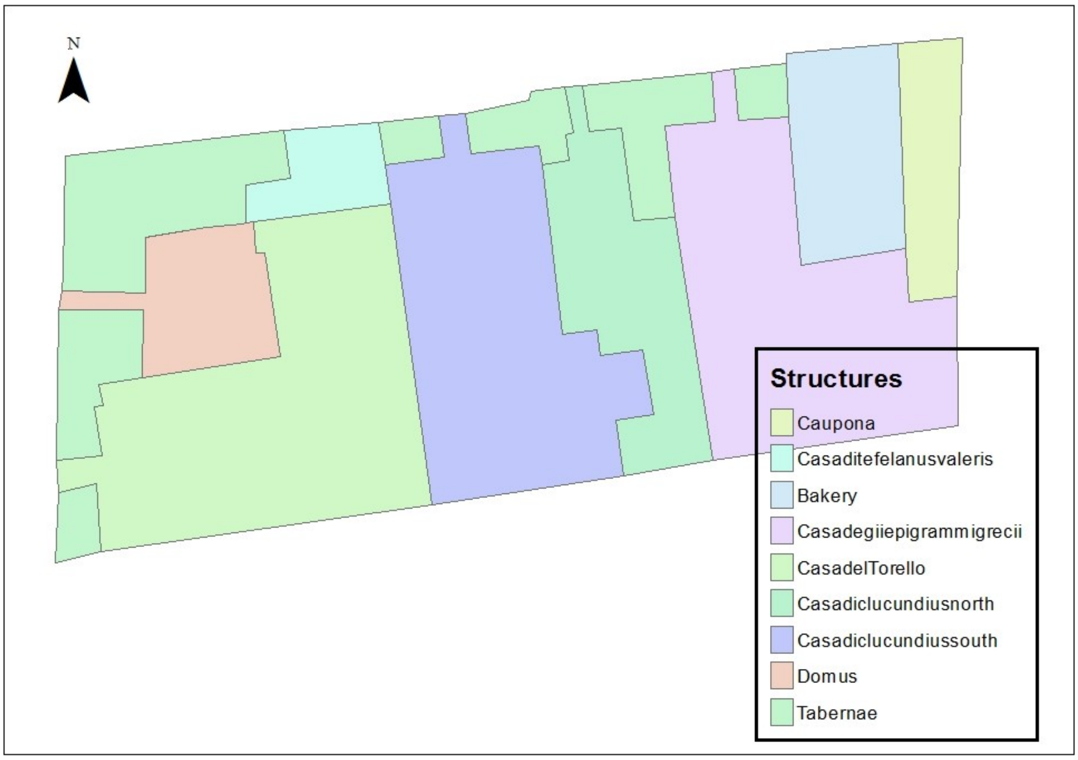

fig.15 Structural segregation of insula V 1, *made from a 3D projected ortophoto in Arcmap GIS.*

Even though the data-set of images have been realized without the intent of being post-processed to generate a 3D model, the images have proven to be a rich source of information. With more time I would have been able to produce better results and showcasing a lot more of information. The downside was the lack of images that was required in order to create a complete 3D model.

When viewing the results of the case study from Monte S. Martino it is evident that the quality and detail of the 3D model is greater than the Pompeii insula. This is attributed to the use of a wide angle lens and that the ancient remains were photographed with the intention of constructing a 3D model.

7. Results

My research has shown very positive results to employing UAV systems and Aerostatic balloons in archaeology. The initial theoretical research revealed that these instruments are very practical for archaeological surveys as they are easy to handle and in budgetary boundaries for common archaeological surveys. Rescue archaeology is very beneficial of this method due to the easy and quick handling of the UAVs, hence they are a great asset when there are time constraints. These new acquisition instruments allow the acquisition of imagery data of any sort depending on the type of camera that is used.

The positive attributes were several, such as the ability to perform aerial photography and to venture into areas that are unreachable by humans. They are also capable of capturing the data of large areas, be it from a high or low point. One attribute is the ability to post- process the UAV acquired data, through several ways such as using computer softwares to create comparative and discourse analyzes among others. The main negative attribute was that these typologies of vehicles are not able to operate in all types of weather, since wind for example might destabilize the flight.

The case-studies revealed that thanks to these new tools, the discipline of Aero photography has great possibilities in archaeology. The ability to create virtual models of ancient sites will minimize the time needed to spend on excursions as a great part of the research material will be in a computer. It is also important to point out that to acquire a detailed and qualitative research material it is necessary to gain experience in the field. It is possible that one might create new “false” data during the post processing, due to over excessive cleaning of the data or wrong interpretations. It is therefore important to have a camera capable of taking high resolution pictures, but at the same time be suitable for equipping it to a UAV. The UAV needs to be capable of a stable flight and built from quality materials in order to perform an archaeological survey. The post-processing stage demands an amount of material that showcases all corners and edges of an archaeological site to be conclusive. Without such material, the result will lack in quality and detail.

In conclusion, the positive affects the usage of aerial drones and balloons will have on archaeology outweighs any disadvantages that UAVs are susceptible to. Being practical, easily maneuverable and ability to capture imagery data makes it one of the greatest additions to an archaeologist’s equipment. The abilities of drones and UAVs are still being developed, and the future shows great promise for a continuing evolution of this technology.

8. Summary

Unmanned Aerial Vehicles (UAVs) are a relative new tool in the field of archaeology, yet their capabilities remain untapped. The purpose of this study was to illuminate the potentials of using UAV's in archaeology as well as the downsides. By performing two case studies it would show how conclusive the data from UAVs is and how it can be used in further studies. UAVs main purpose in archaeology lies in Remote Sensing, a means to observe the surrounding landscape. Remote sensing is prominently used for landscape studies in archaeology, aided by tools such as total stations and aerial photography. Aerial photography is the main utility in the usage of drones. The ability to take photographs from the air by the means of aerial vehicles has aided archaeology in countless of ways. An archaeological field known as aerial archaeology was developed for the sole purpose of interpreting aerial images to find remains of ancient structures and objects. Aerial vehicles such as aerial drones, kites, aerostatic balloons are all counted as UAVs.

Despite the military use of aerial photography, the practice has spurred the development of aerial reconnaissance into the creation of satellites. Combined with high resolution cameras, satellites are another way of performing aerial archaeology. Despite their advantages, satellites are limited in their actions. UAVs are however developed to traverse where humankind do and cannot travel. The technology has just as aerial reconnaissance been developed for military purposes, but have in recent years become available for the public. Although this is not completely true as aerostatic balloons, kites and remote controlled miniature aircrafts have been available to the public for a long while. The main difference between military and civilian UAV's is the technology. Technology has become successfully more available to the public, hence the development of civilian UAVs are progressing quickly. Aerial drones are built to be compact, light and able to carry equipment such as cameras and sensors. These small aerial vehicles are usually remote controlled and are able to reach places a human cannot. In archaeology they are frequently used to photograph archaeological sites. In recent years they have been used to acquire photographs with the purpose of constructing 3D models from them. This is something neither photos from satellites or airplanes can accomplish as the photos need to be from many angles. Aerial drones can travel far and wide, but are nevertheless dependable on its human operator. All UAV's are susceptible to the weather, as wind might blow them of course or mist and snow might cloud the vision of the operator.

To further illustrate the capabilities of UAV's, two case studies were performed. The first comprised photos of a Pompeian city-block called insula V1 in Pompeii, taken by an aerostatic balloon. The second was composed of images from Monte S. Martino ai Campi di Riva del Garda, an old roman ruin in Italy was taken by an aerial drone. The material was post-processed in Photoscan were the sites were reconstructed into 3D models through the photos. They were also further processed in GIS and Meshlab to showcase analytical ways that the information could be used in such as structural drawings. The comparison between the studies showed that the aerial drone was able to capture more information than the aerostatic balloon. Despite this, the aerostatic balloon was able to take photos that could be used to properly construct a 3D model. The results were very positive as they showed that there were many useful ways that aerial drones or any kind of UAV can be used in archaeology. In conclusion the research showed that aerial drones are a very useful tool in archaeology. The end result is dependent on the quality of your acquisition campaigns. To achieve the best result one will need a camera capable of taking quality pictures, and a UAV that is capable of moving freely and stable. The conclusiveness of the data depends on this, as bad quality might lead to incorrect results. There are still many ways that UAVs can be used on, and hopefully we might see them in the future.

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