Open Aerial Map, Drones and Archaeology

The implications of using drones to contribute and share aerial data on an open data repository

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The purpose of this research is to determine the potential benefits and challenges of volunteered aerial imagery by looking at OpenAerialMap (OAM) and by presenting how a repository like OAM may be applied in archaeological studies. The interviews and survey conducted in this research indicate that the main benefits of OAM are affordability, accessibility, rapid mapping and historic image preservation. Among the key challenges identified are concerns around data quality and privacy. Though most of the images on OAM are of high resolution, there is currently no way to guarantee the quality of images that people share on OAM. Similarly, there are no real safeguards against the misuse the openly available imagery. This is a prominent concern in archaeology, where open aerial images may increase the looting and destruction of heritage sites. Then again, OAM can aid in a number of ways in terms of archaeological research and it may even contribute to citizen engagement in archaeology. The research indicates that OAM is a positive endeavour that makes spatial data more accessible and provides drone users with the ability to engage in citizen science.

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DEDICATION

I wish to dedicate this research to the loving memory of my brother. I know you be proud of me for finishing my thesis.

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List of Abbreviations

API – Application programming interface

AUVSI – Association for Unmanned Vehicle Systems International

CAA - Civil Aviation Authority

CRM – Cultural Resource Management

DIY – Do-it-yourself

DOD - Department of Defense

ESA – European Space Agency

FAA – Federal Aviation Administration

GIS – Geographic information systems

GeoTIFF - Georeferenced tagged mage file format

GPS – Geographic positioning system

HIF – Humanitarian Innovation Fund

HOT – Humanitarian OpenStreetMap Team

ICAO – International Civil Aviation Organization

LIDAR - Light Detection and Ranging

NASA – National Aeronautics and Space Administration

OAM – Open Aerial Map

OIN- Open imagery network

OSM – Open Street Map

RPAS – Remotely Piloted Aircraft System

SAA - Society for American Archaeology

UAV – Unmanned aerial vehicle

UAS – Unmanned aerial system

UN – United Nations

UNESCO – United Nations Educational, Scientific and Cultural Organization

VGI – Volunteered geographic information

VHR – Very high resolution

VR – Virtual reality

CHAPTER 1: INTRODUCTION

1.1 Overview

Mapping used to be confined to the domain of geographers who were trained in cartography. Most mapping programs were launched by governments, who would send out experts able to translate ground observations of the actual world onto a generalized map. In the 20th century, remote sensing technologies, such as aerial photography and satellite imagery, introduced new ways of mapping. Instead of relying simply on ground observations, cartographers could now create maps based on aerial imagery. In the latter half of the 20th century, the growth of computer technology allowed for the emergence and development of geographic information systems (GIS), which shifted the focus from simple map-making to spatial data analysis. As technology continues to advance at a rapid pace, it diversifies the way in which geospatial data can be captured, stored and shared. Now, the collection of spatial data is no longer confined to the domain of experts. Modern technology has expanded citizens' ability to collect and contribute spatial data. Recent years have seen a transformation in terms of mapping with the development of Web 2.0 mapping services (Graham & Zook, 2011). These online tools continue giving rise to a huge amount of mapping projects. Since the Geoweb has a bidirectional aspect, it gives users the ability to contribute information or data (Johnson & Sieber, 2012). It not only allows citizens to access large quantities of geospatial information, facilitating new ways of using the available data, but it also enables them to participate in projects (Johnson, Belblidia, & Campbell, 2011; Mazumdar, Wrigley, & Ciravegna, 2017). Now anyone with Internet access is able to either create maps using online tools or to contribute to online mapping projects. An example is OpenStreetMap (OSM), a community project dedicated to creating a detailed, up-to-date street map of the entire world. Anyone with a computer and internet access can contribute or verify the information on OSM. In this way, OSM provides open access to geographic data to anyone, allowing the maps to be used by thousands of websites and apps.

More recently, unmanned aerial vehicles (UAV), or drones, are another technology that is becoming widespread. The growth of drone availability is related to the decreasing costs of this technology (Percivall et al, 2015). It is also tied to the fact that drones can be used for a broad range of applications, one of which is the ability to capture aerial data. As a result, drones certainly have the potential to make further impacts on mapping practices. In northern Ireland, some cemetery surveyors began using drones to keep cemetery maps up-to-date (Rosenblum, 2014). Drone images provide a great tool for cemetery managers to resolve the discrepancies between old records and existing maps by dramatically cutting down the surveying time. While a manual survey of a 12-acre cemetery typically requires around 100 work hours, a drone survey can be done in around 2 hours. In 2014, researchers from the University of Alaska Fairbanks used drones to photograph and map hotspots during the 200,000 acre fire on the Kenai Peninsula (Bourne, 2016). Local flight crews were grounded due to the smoke from the fire, so it was thanks to the drone maps that fire commanders were able to dispatch firefighters to the right areas (Bourne, 2016). Drones were used during the wildfire that hit Fort McMurray in 2016 to gather data that aided experts in determining the source of the fire (Mogg, 2016). Professionals are not the only ones who use drones for gathering aerial data. Due to their increasing accessibility, ordinary citizens are also able to use drones to collect aerial imagery. In the spring of 2016, DroneDeploy together with the Nature Conservancy launched a “Phones and Drones” project that sought to engage citizens to document the effects of the El Nino on the coasts of California (DroneDeploy, 2016; French, 2016).This shows how with drones, remote sensing is no longer just reserved for experts (Grainger, 2017).

As more people collect aerial imagery, there is more potential for this imagery to be shared online. OpenAerialMap (OAM) is a platform that seeks to fulfil this potential by creating a single website that would allow all this imagery to be easily accessible. It offers a set of tools for searching through aerial imagery both from drones as well as openly licensed satellite imagery. The idea is to create an aerial image repository covering the entire world, similar to Google Earth. Unlike Google Earth, the aerial imagery on OAM would be shared for free, under an open license so that it can be used and downloaded by anyone. Right now, OAM is still in the development process so it is worthwhile to explore whether it is a valuable endeavour not only in theory, but also in practice. It is worthwhile to look into some of the possible applications of a repository like OAM, such as in the field of archaeology. Looking at the imagery currently available on OAM as well as questioning some of the users of OAM could give a good indication in regards to the public interest in growing and using OAM for various applications. It could also aid in assessing some of the challenges that will inevitably occur. Based on existing research, one of the key difficulties with crowdsourced data in general is that it can be difficult to assess the quality and accuracy of the information that is gathered (Grainger, 2017). There are also the challenges surrounding privacy, policies, data protection, and standardization (Fritz, Fonte, & See, 2017).These challenges are particularly relevant to OAM, which will be bringing together data from an extremely diverse array of drones and cameras. Research into these challenges can be worthwhile towards developing solutions for these challenges.

1.1.1 Drones

The use of drones is becoming more common as they can be utilized for a broad range of applications, such as data collection, mapping, monitoring, disaster management, search and rescue missions, and even communication (Percivall, Reichardt, & Taylor, 2015; Ollero, 2017, p. 12; Yanmaz et al, 2018). The difficulties that were previously associated with obtaining drones are declining with the decreasing prices of drones (Johnson, Ricker, & Harrison, 2017). As a result, drones can be increasingly employed for purposes like humanitarian aid, where high costs can be a serious limitation.

The International Civil Aviation Organization (ICAO), an agency of the United Nations (UN) which brings together states and key organizations to develop civil aviation standards, sees a UAV as a pilotless aircraft that "is flown without a pilot-in-command on-board and is either remotely and fully controlled from another place" (ICAO, 2011). In other words, a UAV or drone can be defined as an unmanned, remote controlled aircraft. A drone can be any size and can be employed for a variety of purposes. Drones are part of a more complex Unmanned Aerial System (UAS). This is the official term used by the US Department of Defense (DOD) and the UK Civil Aviation Authority (CAA) (Colmina & Molina, 2014). In Canada, the Canadian Aviation Regulations use the term Remotely Piloted Aircraft System (RPAS), a term introduced by the ICAO (Government of Canada, 2019; ICAO, 2011). UAS includes not only drones, but also other components such as the associated hardware, sensors, software, control stations, navigation and communication systems, as well as the human operators themselves (Ermacora, Rosa, & Toma, 2016; Johnson et al, 2017).

According to the Small UAV Coalition, which is a partnership of consumer and technology companies who in some way support the research, development, and application of drones, UAVs "will transform our economy in a multitude of ways" (Small UAV Coalition, 2016). The popularity and use of drones is growing not only in the private citizen sector (Johnson et al, 2017). Based on Business Insider Intelligence estimates of investment in drone hardware over the last few years, businesses as well as governmental organizations are increasingly their use of drone technology (Joshi, 2017). As an example, in 2013, the government of Trinidad and Tobago decide to employ UAVs to collect the aerial data necessary to produce a precise map of the country and satisfy the growing needs for accurate and detailed spatial data (GORTT, 2013). Large international companies are also becoming invested in drones. Among the members of the Small UAV Coalition are large companies such as Amazon PrimeAir, Intel Corporation, Kespry, Precision Hawk, and Verizon (Small UAV Coalition, 2016). As part of the Coalition, they all work to resolve existing regulatory barriers and support policy changes that will encourage the growth of the UAV industry (Small UAV Coalition, 2016). A similar goal is sought by the Association for Unmanned Vehicle Systems International (AUVSI), which claims to be the largest non-profit organization dedicated to advancing UAV technologies (Association for Unmanned Vehicle Systems International). It brings together both companies and professionals, connecting them with each other and allowing them to stay informed through webinars, events, international symposiums, publications, and even an online database of relevant resources (Association for Unmanned Vehicle Systems International). The AUVSI also organizes outreach programs in order to collaborate with government agencies to help advance UAV technologies. UAViators is another organization which brings together members from around the world to collaborate on promoting the safe and effective use of UAVs in the humanitarian aid setting (UAViators). Governments themselves realize the potential of drones. The ICAO realized already in 2011 the broad potential of UAVs in various civil applications, especially those which may be dangerous or monotonous for pilots of manned aircrafts (Colmina & Molina, 2014; ICAO, 2011). For that reason, the ICAO put out a report addressing UAVs and providing an international regulatory framework that could guide UAV operation worldwide (ICAO, 2011).

1.1.2 Open Aerial Repositories

Despite drone costs going down, easy access and availability of aerial imagery will not occur without an open data platform to share this data on. Open data repositories are such platforms. They aim to facilitate data access by gathering it together. This concept of open data advocates for having easier access to information by allowing data to be acquired and used for free. The key aspects of open data, as illustrated in Figure 1.1, are: availability, reuse, universal participation, and interoperability. By making open data available, open data increases the accessibility to and distribution of information while reducing some of the expenses associated with collecting that data (Johnson, 2017). Not only is this information accessible, but it is available for reuse, which means it can be modified and redistributed for various purposes. Anyone interested is able to participate in sharing, using, and redistributing open data. This is significant in today's world which is increasingly data-driven. Data repositories are valuable platforms for collecting and storing multiple datasets, which can then be mined for information. Thus, interoperability refers to the ability of intermixing different datasets. Open data allows different datasets, from different sources, not only to be shared, but also to be combined and used to develop various products or services.

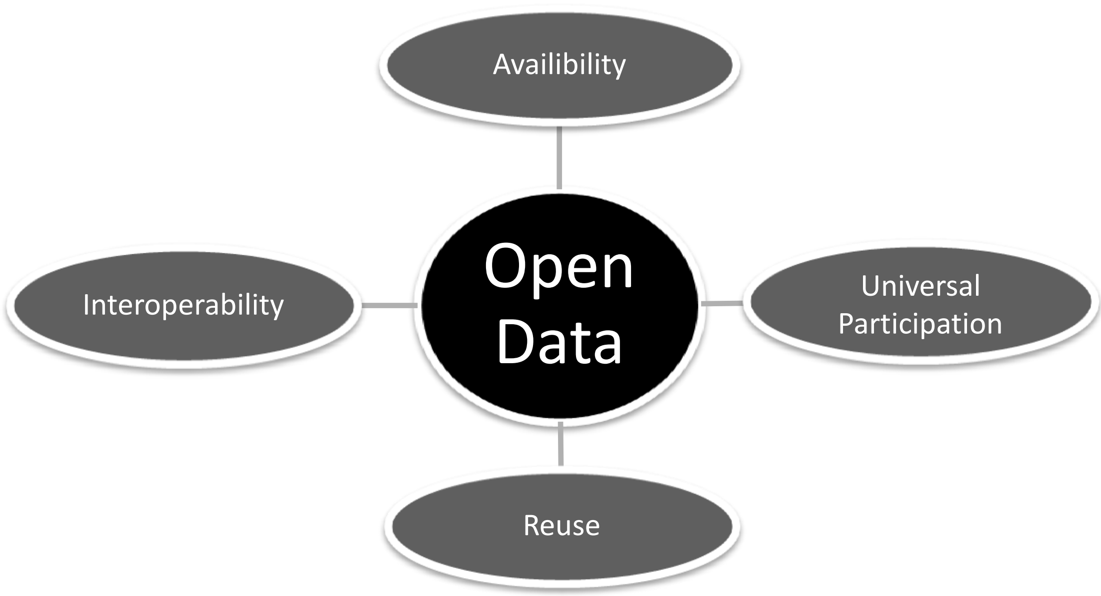


Figure 1.1: Key aspects of Open Data.

Currently, OAM is the only platform that allows people to share or access drone aerial imagery under an open data licence. In essence, it is an online catalogue of aerial images. This allows the data to be shared online without having to worry about the costs associated with creating and maintaining a server capable of hosting large amounts of high-resolution imagery. It allows the OAM project to be more sustainable for the future as it does not require large amounts of funding for maintaining large servers for hosting all the aerial imagery.

OAM is still a growing community of aerial imagery contributors. New images are continually being added and efforts are being made by the Humanitarian Open Street Map team

(HOSM) to improve the capabilities of OAM. Currently, OAM gathers both volunteered aerial imagery, consisting mostly of drone imagery, as well as openly licensed satellite images. As it grows, OAM has the potential to become an important resource for distributing open aerial imagery (Smith, 2017). The original aim of OAM was to aid in humanitarian response and disaster preparedness, since open imagery can be critical for disaster response in developing countries where respondents may not always have access to aerial data or accurate, up-to-date maps (Smith N. , Making open imagery accessible: OpenAerialMap comes out of beta, 2017). At the same time, OAM never meant to limit itself to humanitarian aid. The primary goal of OAM is to provide a simple and easy way for people to be able to access and share aerial imagery (Smith, 2016; Smith, 2017). Since the data on OAM is openly available, it has the potential to be used for any purpose.

1.1.3 Aerial Archaeology

Aerial imagery offers a variety of possibilities in archaeology. Archaeology seeks to preserve cultural heritage to ensure it is there for future generations. This cultural heritage is an important link between a society's past and present (Doneus, Forwagner, Liem, & Sevara, 2017). It consists of the physical remnants left behind by past peoples, which can enhance our knowledge of the past. The sites that contain these remnants of the past are unique, non-renewable stores of knowledge that once excavated or destroyed by erosion or land use, can no longer be recovered. That is why documentation is so important in archaeology. Photography in general has allowed archaeologists to record the spatial arrangement of artifacts and features, together with their context (Caraher, 2016). Aerial imagery goes beyond that as it serves as an important tool in providing comprehensive spatial data that can be used to discover archaeological sites, analyze a site's regional environment, evaluate a site's settlement pattern, as well as for planning site excavations and mapping sites (Harp, 1977).

Archaeological aerial photographs have been taken even before 1915 and the invention of airplanes; however, it was the skill acquired by military air reconnaissance units that truly revealed the value that aerial imagery can possess in terms of archaeological research (St.Joseph, 1945). In the course of the First World War, advancements in camera technology as well as military aerial reconnaissance resulted in many aerial photographs (Raczkowski W. , Aerial archaeology method in the face of theory, 2002). O.G.S. Crawford, a British geographer and archaeologist, was a pioneer in employing aerial survey in archaeology (Kirwan, 1958; Quigley, 1985; St.Joseph, 1945). He realized the value of air reconnaissance through his service in the British air force during the First World War (Quigley, 1985). He played a leading role in advancing aerial archaeology and in framing the principles of aerial photography (Kirwan, 1958; Raczkowski W. , 2002; Ramirez, 2009). In 1928, Crawford published a book demonstrating how aerial photography could be used to reveal past disturbances in the soil that could often be invisible from the ground (Quigley, 1985). In 1929, he published another work on the methods of aerial archaeology, in particular in regards to the importance of timing of aerial photography (Ramirez, 2009). Not surprisingly, therefore, the 1920's and 30's saw aerial photographs being employed in archaeology for site identification (Contreras & Brodie, 2010). Since then, aerial photography has continued to be the most commonly employed remote sensing technique in archaeology (Ciminale et al, 2009).

Traditionally, the aerial photographs employed in archaeological studies consisted of either airplane or of satellite imagery. Now, the appearance of drone technology is revolutionizing aerial archaeology (Wernke, et al., 2016). Studies employing drones for surveying archaeological sites have shown that drone aerial imagery can be extremely useful (Colmina & Molina, 2014). In archaeology, aerial image analysis consists of looking for any man-made or cultural features by detecting anything unnatural or unusual in the natural landscape (Harp, 1977). This often consists of variations in the vegetation that can signify the presence of ruins or remains of past structures (Harp, 1977). Since drones are less expensive and can be flown more often, they offer more potential for archaeologists in terms of image analysis. For example, images gathered at certain times or seasons might reveal buried features that otherwise remain invisible (Raczkowski W. , 2015). In this case, therefore, the fact that drone imagery offers the potential for gathering higher amounts of aerial imagery could really increase the chances of discovering new sites. This advantage holds true for volunteered aerial imagery as well. Having access to this imagery through an open aerial repository like OAM could thus be invaluable for archaeological efforts worldwide.

Though the academic literature has addressed various open crowdsourcing platforms, such as OSM, it does not address crowdsourced aerial imagery. There is a lack of literature in regards to the development of an open aerial data repository. Though there is a small body of literature that looks at the use of free aerial imagery in archaeology, it focuses on free satellite imagery available online on platforms like Google Earth, which cannot be considered open data. This research aims to address the gap that exists in the literature concerning open data by: 1) presenting OAM, a developing open aerial data platform, 2) identifying the benefits and challenges of sharing drone aerial data online, and 3) outlining how open aerial data may affect the field of archaeology.

1.2 Research Purpose and Objectives

Through an analysis of OpenAerialMap as well as its potential applicability in archaeology, this research will attempt to assess the potential benefits and challenges of developing an open aerial image repository that would consist of volunteered data. It will evaluate how volunteered drone imagery compares to imagery collected from satellites and in what ways is it can be leveraged by different user groups. Through this, it will aid in delineating its value both in research as well as in businesses and non-governmental organization applications.

1.2.1 Research Goal

The goal of this research is to determine the potential of sharing open aerial data, collected by drones, as open data. As drones become more widely adopted, they create the potential for everyday users to gather aerial imagery. This can contribute to the overall growth of VGI, especially if drone users share the aerial imagery. Despite more imagery being collected, there remain real challenges to effectively sharing this data through open image repositories, such as OpenAerialMap. This research aims to delineate both the general applicability of such an open aerial repository as well as its more specific applicability within the field of archaeology.

1.2.2 Objectives

Four objectives were identified to examine the potential advantages and challenges of a volunteered open aerial image repository:

1. Determine the advantages of an open aerial image repository featuring volunteered aerial imagery through an evaluation of OAM.
2. Consider how volunteered drone imagery compares in terms of resolution and recentness to existing sources of free satellite imagery from Google and Bing.
3. Identify the barriers and constraints that may hinder the continued development and use of an open aerial repository like OAM.

4. Assess how the imagery from OAM may be applied in archaeology by looking at both the benefits and risks it carries in terms of archaeological work and heritage sites.

1.3 Research Scope

This research focuses primarily on the implications of open aerial imagery that can be found on OAM. Archaeology is used as a case study to examine how open aerial imagery would work in an actual applied community of practice. In addition to the general benefits and challenges of open aerial data that can be applied across most fields, each field also has its own perspective on the use of aerial imagery. Examining the field of archaeology will provide knowledge in terms of the specific applications and challenges OAM brings to archaeology. The findings of this research could be used as a starting point towards further research into crowdsourcing drone imagery.

1.4 Thesis Outline

The following thesis attempts to evaluate the idea of having an open aerial image repository consisting primarily of volunteered data, with a particular focus on Open Aerial Map and its applicability to archaeology. As this thesis adheres to the manuscript style option, the literature review, methods, findings, and discussion are separated into two core chapters. Thus, the research findings are described in two separate manuscripts, which constitute the two core chapters of this thesis. These two manuscripts will be submitted to academic journals for publication.

An in-depth analysis of OAM is presented in Chapter 2. This chapter is focused on presenting the value of a repository like OAM. It does so by examining both what OAM is as well as by examining the benefits and challenges it brings along with it. The literature review provides background on Open Data, citizen science and volunteered geographic information (VGI), which are all key concepts that are necessary to the understanding of the whole idea behind the creation of OAM. The literature review also traces the history and development of OAM in order to provide a holistic understanding of OAM and indicate the goals it is meant to fulfill. An examination of the aerial imagery currently available on OAM assesses the current status of OAM and the quality of the volunteered drone imagery that is shared. The semi-structured interviews conducted with 5 different stakeholders involved in some way in the collection of drone aerial imagery provide valuable insights into the barriers and risks of openly sharing drone imagery. This information was supplemented by the results of an online survey that was shared in the online archaeological community to assess their views on having open aerial imagery.

Chapter 3 looks at one of the potential uses of OAM by examining its value to archaeology. A review of the literature illustrates the importance of aerial imagery in archaeology through a brief history of how aerial photography has been employed in archaeological work. It summarizes previous studies that looked at the usability of open satellite aerial imagery in archaeological research and exposes the gap that exists in the literature regarding open aerial imagery collected through other means, such as drones. The 45 online survey responses present a snapshot of how the archaeological community currently views the idea of open aerial imagery. It characterizes some of the benefits as well as limitations that are associated with open aerial data. It also highlights some of the primary concerns that the archaeological community has in regards to how open aerial imagery might affect the security of archaeological sites. Based on the constraints and barriers identified, some recommendations are provided that could mitigate these barriers and facilitate future research.

Finally, Chapter 4 presents a summary of the key findings from Chapter 2 and 3. It compares the use of drones in the general context to the context of archaeology, drawing universal conclusions about the strengths and weaknesses for each of those end user communities. Some future research recommendations are highlighted that would encourage a more in-depth exploration of open aerial image repositories and so contribute to the overall knowledge of open data.

Chapter 2: The Benefits and Challenges of Open Aerial Map

2.1 Introduction

The use and availability of drone technology has increased in recent years. Drones can be used for numerous purposes, depending on their size and build. One of the most advantageous capabilities they offer is the ability to collect geo-located aerial photographs. Drones can be used to complement the aerial images captured from satellites thanks to continuing advances in technological innovations (Percivall et al, 2015). They can be equipped not only with high resolution cameras but also with a variety of expensive sensors such as thermal cameras, LiDAR or multi-spectrometers (Percivall et al, 2015). High resolution aerial images from drones can be very beneficial in emergency response, planning, and monitoring activities (Joseph, 2017). They can be useful in real estate, where up-to-date aerial maps can allow clients to have more insight into a property (Dukowitz, 2017). In the forestry industry, detailed aerial images can be used to monitor health forest or detect illegal logging activities (Dukowitz, 2017).

Due to the increasing accessibility of drones, a wider range of individuals can collect aerial imagery. Ordinary citizens can now participate in the collection of aerial data, which has the potential to increase the overall availability and accessibility to aerial data. One challenge in leveraging this availability of imagery is developing repositories for sharing this data. Currently, Open Aerial Map (OAM) is an example of a worldwide project that aims to act as an accessible repository of user-contributed aerial imagery. OAM aims to provide a simple means for hosting and sharing aerial imagery that can be used for a variety of purposes, with a particular humanitarian response and disaster vigilance (Giovando, OpenAerialMap Catalog Tech Challenge, 2015).

This research aims to examine the benefits and challenges presented by the open aerial imagery gathered on OAM. In particular, this research seeks to present information that

1. Determines the usefulness of an open aerial repository featuring volunteered aerial imagery through an evaluation of OAM;
2. Identifies the barriers and constraints that need to be addressed as OAM continues to grow.

As the collection and dissemination of open aerial imagery is still in its early stages, there are still many questions regarding the benefits and challenges presented by open aerial imagery. There is also the matter of volunteered drone imagery and how that compares to free satellite imagery. Further research in this area could provide a valuable contribution in terms of developing applicable tools and strategies to promote the development of volunteered aerial image repositories. Examining the benefits and challenges presented by volunteered open aerial imagery will advance the knowledge of open data and aid in defining its value in terms of its applicability in solving various real world problems. It will also help identify further areas of research interest involving OAM.

2.2 Literature Review

2.2.1 Open Data

Open Data refers to any type of data that is collected and shared publicly online for everyone to use, with permissive licensing (Ayre & Craner, 2017). This data is provided for free and in a format that can be read by computers or machines (Johnson P. A., Sieber, Scassa, Stephens, & Robinson, 2017). It encompasses not only volunteered data (VGI), but any type of freely available data. The idea behind Open Data is that it enables easier access to information, which promotes entrepreneurship and innovation in the society (Ayre & Craner, 2017). The drive towards creating and maintaining open data repositories is motivated by the prospect of increasing the accessibility and distribution of information (Johnson, 2017). It is also motivated by the reduction of expenses that were once associated with obtaining that data. Open data can be particularly effective and useful in cases of disaster response as well as environmental monitoring, where remote sensing data that is collected via “traditional” methods is either too costly or no longer current (Fritz, Fonte, & See, 2017; Johnson P. A., 2017).

2.2.2 Citizen Science

Modern technology, such as drone technology, is an enabler of citizen science or crowdsourcing information. It allows citizens, not just experts, to work towards verifying and improving both the spatial and temporal aspects of various types of data (Fritz, Fonte, & See, 2017). The term “citizen science” refers to the collection and analysis of data by amateurs or members of the general public (Gharesifard, Wehn, & Zaag, 2017). It is based on the idea that every human being is able to act as “an intelligent sensor” for collecting data (Goodchild M. F., 2007). Crowdsourcing relies on large groups of individuals willing to contribute labour for free (Alvarez Leon & Quinn, 2019). It is a distributed and strategic problem-solving model where, instead of having one individual or team working towards a solution, a crowd or community of Web users is called to collaborate together on a certain project (Brabham, 2008; Brabham, 2010). James Surowiecki, a financial journalist for The New Yorker, writes that “under the right circumstances, groups are remarkably intelligent, and are often smarter than the smartest people in them” (Surowiecki, 2004, p. XIII). This is confirmed by other studies, where crowdsourcing was found to obtain better and quicker results than what could be obtained by any one individual. The study by Brabham (2008) that looks at crowdsourcing projects such as iStockphoto.com and InnoCentive, illustrates that crowdsourcing is capable of outperforming experts through faster and cheaper solutions. According to Surowiecki (2004, p XIX), the circumstances that allow this to happen, in general, involve maintaining group order and cohesion as well as allowing group members to communicate to a certain extent.

Though crowdsourcing brings with it much potential, it does not come without drawbacks. One issue is that it may, in certain cases, negatively affect the labour pool (Brabham D. C., Crowdsourcing as a Model for Problem Solving: An Introduction and Cases, 2008). Not all crowdsourcing projects are open data projects. This means that the businesses or researchers behind the project are the ones predominantly benefitting from the crowdsourced labour (Brabham D. C., Crowdsourcing as a Model for Problem Solving: An Introduction and Cases, 2008). Projects that employ crowdsourcing also reduce the need for experts, which can make certain careers either dispensable or less profitable. Another issue is that of data quality. Though citizen science projects are widely used and recognized in various business and research areas, there still continue to be questions around the reliability of this information. It is extremely difficult to ensure or guarantee the quality of crowdsourced data. The majority of crowdsourced data has proved to be useful and good or even high quality (Goodchild M. F., 2007; Mazumdar, Wrigley, & Ciravegna, 2017). One of the key benefits of citizen science is that – depending on the project – it allows data to be collected or interpreted at a low cost thanks to a large numbers of volunteers (Mazumdar, Wrigley, & Ciravegna, 2017). Citizen science also allows data to be collected over a widespread area or over extended periods of time, which would typically not be a feasible endeavour. Modern technology also makes it easier for more people to become engaged in citizen science projects by making it relatively easy to collect various types of data.

Particularly the prevalence of GPS technology in today's world, which is found not only on smartphones but also on a wide array of other electronics, allows almost anyone with this technology to collect spatial data.

2.2.3 Volunteered Geographic Information

Volunteered Geographic Information (VGI), a term coined by Goodchild in 2007, refers to geographical information or spatial data that is collected through the means of crowdsourcing (Deng & Newsam, 2017; Haklay, 2010; Mocnik, Mobasheri, & Zipf, 2018). It relies on the engagement of a large amount of people in the creation of geographic data (Goodchild M. , 2007). VGI would not exist without a community of volunteers due to the fact that it consists of spatial data that has been freely provided by citizens based on usually altruistic motives (Goodchild M. F., 2007; Mocnik, Mobasheri, & Zipf, 2018). This data can consist of both simple information that does not require any expertise or background in GIS, or it can consist of more complex data that requires either some expertise or equipment from the user (Goodchild M. F., 2007). The introduction of high-accuracy GPS and the continued improvement of related technologies has greatly simplified the process of collecting spatial data and allowed individuals with less training, or sometimes even no training, to replace highly trained surveyors (Haklay, 2010).

VGI has the potential to be more relevant than government data or data that is collected by experts in the field (Johnson et al, 2011). VGI can be more detailed and more applicable to local needs and issues (Johnson et al, 2011). Goodchild wrote in 2007 that he sees VGI as the only feasible solution to sustain a high rate of map production and updating. Governments and authoritative agencies are not always able to obtain geographic data at an appropriate scale or timeframe (Olteanu-Raimond, et al., 2017). According to the 2010 study by Haklay, the most impressive aspect of VGI is the speed at which data can be collected. Another benefit is that if data is missing or erroneous, there is no lengthy process required to report and then correct the data; instead, users can fix the dataset themselves and allowing errors to be corrected within a short period of time (Haklay, 2010). The people collecting this data are typically volunteers who, unlike experts in the field, do not receive much or any compensation for their work regarding data collection (Johnson, 2017). On the other hand though, unlike experts, volunteers usually do not provide a significant investment of their time or resources (Haklay, 2010). In order to utilize its full potential, however, VGI requires some type of mechanisms that would ensure data quality, detect and eliminate errors, and thus provide the same type of reliability in regards to data quality as was traditionally provided by mapping institutions (Goodchild M. F., 2007). Though over a decade has passed, data quality continues to be a central issue for VGI as, due to its nature, it is not controlled by a single authority but by a community-driven process (Ballatore & Zipf, 2015; Mocnik, Mobasheri, & Zipf, 2018). VGI typically relies on qualitative spatial knowledge versus data collected using scientific and authoritative methods (Sieber & Haklay, The epistemology(s) of volunteered geographic information: a critique, 2015).

Successful VGI Projects

OpenStreetMap (OSM) is an example of a one of the most successful VGI projects, which provides a wide variety of data that can be used for a variety of purposes (Deng & Newsam, 2017; Mocnik, Mobasheri, & Zipf, 2018). OSM has managed to gather such a large community that other projects relying on VGI, such as Mapillary, actually rely on attracting users from the OSM community to contribute data (Alvarez Leon & Quinn, 2019). They do so by developing a relationship with the OSM community, which is based on allowing the user contributions in these platforms to then improve OSM in return (Alvarez Leon & Quinn, 2019). Mapillary is an open image repository that provides access to crowdsourced street-level imagery (Mapillary). It is a versatile platform that allows users can upload images using a mobile app, a web uploader, a desktop application or using command line tools. In addition to providing open access to imagery, it provides some tools for data analysis, such as the capability to extract map or geospatial data, such as traffic signs, from the imagery shared on Mapillary. All Mapillary images can also be downloaded or edited on OSM and on ArcGIS Online. OSM users can also employ Mapillary images to easily and effectively verify and add points on OSM without needing to physically go to the location they might wish to map.

Unlike OSM, Mapillary images are licenced under the CC BY-SA 4.0. This allows the imagery to be shared and adapted for any purpose under the same share alike license as the original imagery. If the CC BY-SA license does not suit the needs of a user, organization or company, Mapillary offers the option to purchase a subscription for a commercial license (Mapillary). Another intriguing feature that Mapillary offers is the Mapillary Tasker, a tool for connecting the Mapillary community to work together on a specific task in a specified location. These tasks can be submitted by any member of the Mapillary community by filling out the online form and having their task approved by a Mapillary admin. Using the Mapillary app, other users can then contribute images and so complete specific tasks. This gives contributors a specific purpose for which to collect imagery, versus just casually collecting and contributing images. Another interesting user-engaging aspect that Mapillary offers is the leaderboard feature showing top 50 Mapillary contributors, which can be sorted by location as well as time period. There are also occasional competitions, such as the competition launched in March 2019 to celebrate Mapillary reaching a 500 million image milestone (Neerhut, 2019). These measures contribute to giving users a sense of community and accomplishment, which increases Mapillary's potential to remain a sustainable platform by continuing to attract contributors and encourage existing Mapillary users to keep contributing new images. Mapillary's success is illustrated by the fact that in just over five years, Mapillary collected 500 million images covering more than 6.2 million km across the globe (Solem, 2018). According to the CEO of Mapillary, Erik Solem, however, the key factor that plays a role in Mapillary's continued growth is the fact that the imagery is accessible to everyone, from individuals to humanitarian organizations and even all the way to governments (Billing, 2019). Solem also adds that people are self-motivated to contribute images because Mapillary helps them solve some kind of problem, either with the collected images or with the data that can be extracted from them (Billing, 2019). Instead of hoarding the data like Google or Apple, Mapillary licenses it to those who need it or are willing to pay for it (Billing, 2019).

2.2.4 Development of OpenAerialMap

A similar approach of depending on the OSM community is taken by OAM, which actually has its roots in OSM. The idea of creating an open repository for sharing free aerial imagery arose around the year 2006 and 2007 (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015; Giovando & Radford, 2016). It was proposed by a group of students from San Diego University as well as members of the OSM community who noticed that though aerial imagery was becoming available online, it was spread out on different systems that used varying standards (Giovando & Radford, 2016). As a result, OAM was started up in 2007; however, this first attempt at creating an open collection of aerial images failed due to a lack of popular interest as well as a lack of resources (Giovando, 2016). The largest problem was the fact that the limited budget made it impossible to host a centralized server for all the aerial imagery (Giovando, et al., 2015). There were also too many difficulties in processing and storing data at the time (Giovando, 2016).

In 2010, after the massive earthquake in Haiti, large amounts of high resolution aerial imagery of the affected areas were released online by the World Bank as well as other companies or organizations (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015). Similar situations arose following other large-scale disasters, resulting in high-quality aerial imagery being available online under more and more open licenses (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015). In 2015, the Humanitarian OSM Team (HOT), an international team dedicated to humanitarian action through open mapping, which included Cristiano Giovando and Blake Girardot, began working together in an attempt to relaunch OAM (OpenAerialMap, 2018). Kate Chapman, the executive director of the Humanitarian OSM team at the time was involved in obtaining a grant from the Humanitarian Innovation Fund in order to launch OAM (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015). Together, the HOT discussed the direction and development process of OAM.

Based on the team's discussion from the one of the initial meetings that was held on January 22, 2015, the participants determined that OAM should aim to for the following 5 goals:

1. Create a Web map of the up-to-date high resolution open imagery for the entire world;
2. Provide a searchable catalog of all the open aerial imagery that is available;
3. Deliver a platform dedicated to the upload and sharing of open aerial imagery;
4. Make standard Web services accessible to users interested in mapping;
5. Exist as a self-contained and easily distributable software that can be installed on multiple operating systems.

During this meeting, Blake Girardot, currently working as the HOT community support manager, made note that "OAM would definitely have to be concerned with helping end users process UAV imagery" (Giovando, et al., 2015; Voting Members). Thus, ideally OAM is not only meant to simply provide an aerial view of the world like Google Earth, but it is also meant to enable the analysis and manipulation of the aerial data. Figure 2.1 presents a graph illustrating some of the key uses that OAM is envisioned to fulfill.

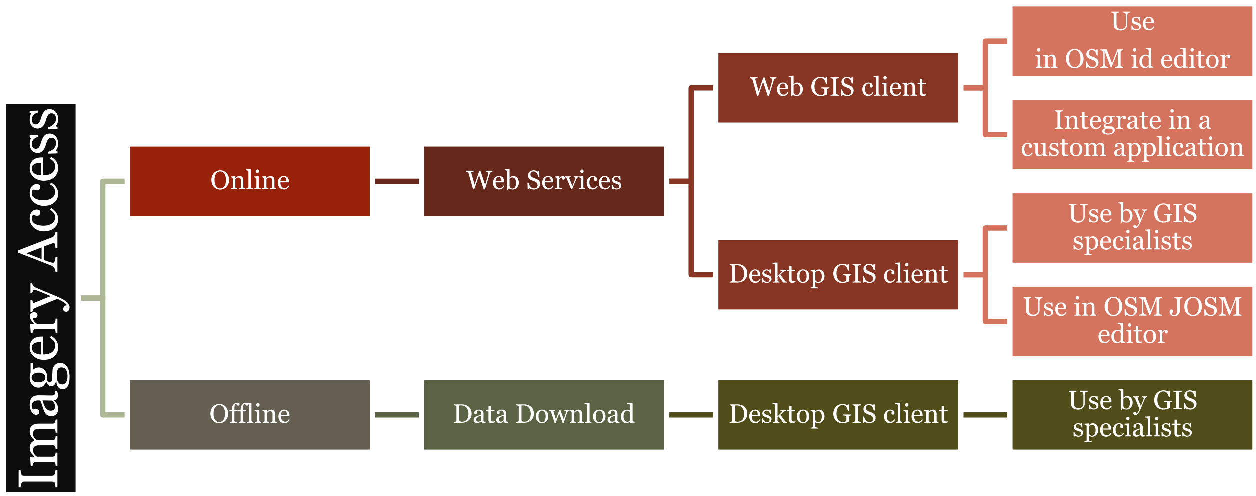


Figure 2.1: A broad framework of how OAM is envisioned to work as well as the main uses that OAM is foreseen to fill (Chapman, 2015).

The HOT launched a call for developers in February. From the applicants, they chose the Development Seed team that was led by Nate Smith (Humanitarian OpenStreetMap, 2015). Figure 2.2 illustrates the technical overview of the way this developer team of the components and tools the developer team used to create OAM. The team created OAM as a catalogue of aerial images that are stored on the Open Imagery Network, which is a network of openly licensed imagery available online (Ecosystem). The employment of the Open Imagery Network (OIN) is of particular importance as it provides a solution to avoid the high data storage costs that storing large amounts of data on a single server would entail. These costs are avoided as the OIN allows the data to be stored on various cloud servers that OIN members use. This spreads the cost of hosting the data. OAM then just provides the necessary API to access the collection of images. It is basically an index of open imagery, allowing imagery to be shared online without needing a single site or server to host all the imagery (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015; Open Imagery Network).

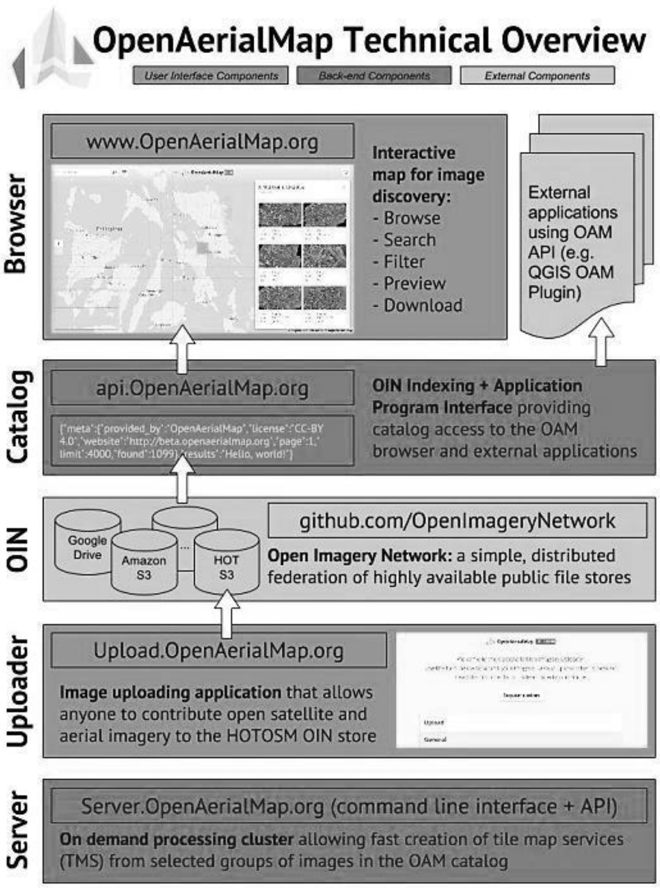


Figure 2.2: OpenAerialMap Technical Overview. Adapted from "Access to Open Imagery: Innovation" by Humanitarian Open Street Map from https://www.elrha.org/project-blog/openaerialmap-final-blog/

OAM also aims to be structured in a way that allows the aerial imagery to be accessible to users who may have a limited bandwidth or lower computer processing power (Humanitarian OpenStreetMap, 2015). It has also been designed to be easily scalable so that the project can continue to grow and be sustainable, without requiring a large source of funding (Humanitarian OpenStreetMap, 2015). The Humanitarian Innovation Fund (HIF) reports from August 2015 as well as from May 2018 both indicate that the project has been significantly successful in the goals it set out to achieve (Humanitarian OpenStreetMap Team, 2015; Humanitarian OpenStreetMap Team, 2018). Since it launched in 2015, OAM has managed to collect drone imagery from around the world and the amount of images available on OAM continues to rise.

2.2.5 Drones

A drone, or UAV, is an unmanned, remote controlled aircraft of any size. The features on drones vary depending on their intended application. Most drones allow for manual, semi-autonomous and autonomous flight using pre-programmed waypoints (Eisenbeiss, 2011; Hayat, Yanmaz, & Muzaffar, 2016). They can be equipped with a variety of sensors such as a GPS, camera, barometer, magnetometer, and even ultrasonic, infrared or laser sensors (Hayat et al, 2016). There are two types of drones: multicopter and fixed-wing (Turner, Harley, & Drummond, 2016). The advantages of small multicopter drones are ease of use as well as lower acquisition and maintenance costs (Yanmaz et al, 2018). As of 2018, the cost of most multicopter drone models available online or in popular North American store chains such as Walmart, Staples, and Best Buy ranges between $47 and $1,200 (Appendix A: Table 2). Multicopter drones can also fly closer to objects and allow for more flight maneuverability, though they are limited in terms of maximum weight (Eisenbeiss, 2011; Ermacora, Rosa, & Toma, 2016). Fixed wing drones allow for longer flight time, making them more suited for covering larger areas (Hayat et al, 2016). They are also able to fly higher than most multicopter drones (Eisenbeiss, 2011). This makes them particularly well-suited for topographic surveys (Turner et al, 2016). The increasing availability of various drone models is opening up new avenues for crowdsourcing. It allows volunteers to contribute to specific citizen projects or just sharing whatever drone aerial imagery they collect on open data portals such as OAM.

Apart from allowing citizens to take part in remote sensing, drone imagery can offer certain advantages over satellite imagery. Unlike satellite imagery, cloud cover is rarely an issue for drone imagery either due to a lower flight altitude or the ability to adjust flight time to local weather conditions (Ruwaimana, et al., 2018). Thanks to pre-programmed flight paths, drones allow users to conduct repeated flights over an area with minimal variation (Barnas et al, 2019). Drones are also able to capture images with a spatial resolution of a few centimeters as can be seen in Figures 2.8 to 2.10. While this can be an advantage in applications requiring a detailed view of the landscape, such high resolution means that the processing time of a drone image is typically much longer than that of a satellite image (Fornace et al, 2014; Ruwaimana, et al., 2018). Another limitation is that drones are dependant on weather conditions. They cannot collect data in rainy, stormy, or extremely windy conditions (Fornace et al, 2014; Ruwaimana, et al., 2018). They can also overheat when performing multiple continuous flights in high temperatures (Fornace et al, 2014) Thus, while both drones and satellites are valuable technologies for gathering aerial imagery, despite their advantages, drones are generally more appropriate for gathering data for smaller geographical areas.

2.3 Methodology

Primary research involved a search for open data repositories hosting aerial imagery, conducting semi-structured interviews with experts, distributing an online survey to a group interested in aerial imagery, and looking into what might be motivating current imagery contributors. The search for relevant websites or repositories was performed through the use of the Google search engine, though an additional search was also done using Bing. The search was primarily limited to websites, portals and data repositories that aim to provide aerial data for the entire world and do not limit their dataset to small geographic regions such as a single urban area, region or country. Searches were conducted using a Boolean search containing the following terms or keywords: GIS AND Open Data; free GIS data; free spatial data; open spatial data; open aerial data; free aerial data. A manual search was also done to supplement the automated search using Google and Bing. This search involved looking over the websites identified by the automated search to see if it might contain any useful links to other sites offering open spatial data. Relevant links were then explored to see if they might contain open aerial data and whether they collected crowdsourced aerial imagery or not.

Following the online search, the aerial imagery available on OAM was examined. The goal was to assess the current status of OAM, by looking at the amount of drone imagery as well as the quality of drone imagery currently available on OAM. It was not feasible to do a thorough search of all the drone imagery, however. This was partly due to the fact that new images continue to be added every few days, partly due to the time constraints of this research and in part due to the overall amount of imagery on OAM. Any image search on OAM needs to done manually as OAM currently does not provide an option to search data by platform type or apply a filter on the OAM explorer that would provide a list of drone imagery shared on OAM. The OAM explorer, shown in Figure 3, only offers the option to search images by location or to filter data by resolution and the time they were added.

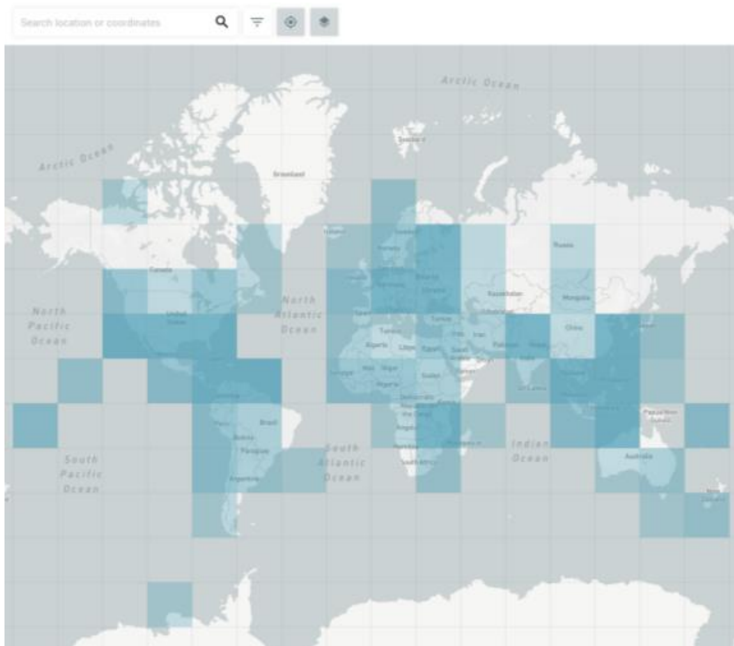


Figure 2.3: OAM explorer map providing a visualization of high-resolution aerial image availability by area (by filtering the results to show only high-resolution imagery). The darker grid squares indicate a higher amount of imagery while clear grid squares indicate a lack of data for that specific region.

Following the online research on open data repositories and OAM, semi-structured interviews were conducted to gain insights into some of the stakeholder views regarding the value of having an open aerial imagery. In total, five online interviews were conducted with experts working in companies or organizations that are in some way involved with using drones to collect aerial imagery. The interview script was designed to examine both what benefits as well as what barriers and risks do they foresee in terms of sharing volunteered aerial drone imagery online, based on their experiences with aerial data. It was directed primarily at providers of aerial data, seeking their perspective on the feasibility and challenges associated with sharing aerial data online. Invitations to participate in the interview were sent out to 50 researchers, companies and organizations that are in some way concerned with either drone aerial imagery or collecting open aerial data. Contact information was obtained from each company's or organization's public website. These prospective participants were then contacted by e-mail with an attached information letter describing the purpose of the study. The interviews varied in length from 15 to 60 minutes and were all recorded with the participants' consent.

In addition to the online interview, research was done into the factors that motivate users to contribute data. It would have been ideal to get in touch with OAM contributors; however, that turned out to be impossible. Currently OAM does not feature any option that would allow users to easily get in touch with one another. Also, OAM users, for the most part, did not really provide much information regarding themselves in their bios. Many contributions are effectively anonymous as the username does not necessarily reflect the user's identity. For this reason, it was decided to look into what might motivate data contributors of Mapillary, a similar platform to OAM which is also a volunteered image repository. The idea, behind looking at what factors may be motivating image contributors, was to provide some insights into how might OAM develop to become a successful crowdsourcing platform.

An online survey was created to supplement the information gathered from the interviewees. Its aim was to assess the benefits and risks of open aerial data as seen by users of specific groups. Unlike the interview questions, the survey questions were geared towards individuals working in archaeology in order to assess how open aerial data might benefit that specific subgroup of users. As there were no responses from the archaeologists that were contacted for the interview, the interview was modified into a survey. The survey consisted of both multiple choice and open-ended questions that would allow respondents to share their insights on open aerial imagery. The survey was then shared on public Facebook groups concerned with archaeology: Archaeological Aerial Photography (over 1,000 members), Canadian Archaeological Exchange (over 2,800 members), and Archaeology (over 7,500 members). After filtering the survey responses to eliminate spam responses, the resulting data pool consisted of 46 responses that could be used to supplement the information obtained from the online interviews with experts.

2.4 Results

2.4.1 Open Aerial Data Repositories

Based on the online search of websites offering open aerial data, a list was made of all the open data platforms that offer access to aerial data. This list can be found in Table 1 of Appendix A, alongside a short description of each site. From the list, Open Topography is one repository that accepts some volunteered aerial imagery, but overall, only Mapillary and OAM were found focused on sharing of volunteered aerial imagery. Even so, these sites still continue to offer data collected by governments and organizations as long as the data allows for sharing.

This leaves OAM as the only project dedicated to sharing open aerial imagery. As it is a new project compared to Mapillary, OAM has both less imagery as well as a smaller pool of contributors. Despite this, OAM, like Mapillary, has potential to grow with continued effort and time. As can be seen on Figures 2.4 and 2.5, the number of providers and images on OAM continues to rise. Based on the 2018 final report by HOT, between January 2017 and February 2018 the number of providers on OAM rose 507% from 28 to 170, while the number of images rose 80% from 3,029 to 5,438 (Humanitarian OpenStreetMap Team, 2018). Since 2018, the number of providers and images has almost doubled. As of April 2019, OAM features 339 providers and 9,522 images (HOT partners and Community). It can be assumed that this increase in imagery on OAM is due in most part to drone users since most satellite images on OAM date back to 2016 and earlier. In addition to providing access to aerial data, OAM also strives to promote data sharing and analysis. All the imagery on OAM is available for editing on OSM. OAM also provides the OpenAerialMap QGIS plugin, which is a free tool that can aid in analyzing the aerial imagery. The plugin was developed in 2015 by one of the OSM Outreachy interns, Tassia. Using this plugin, users can easily upload, browse, search, and download aerial imagery from the OAM catalogue straight in the QGIS desktop application (Humanitarian OSM Team, 2018; Tassia, 2015). The plugin also supports simple raster image processing to aid QGIS users in analysing the aerial images.

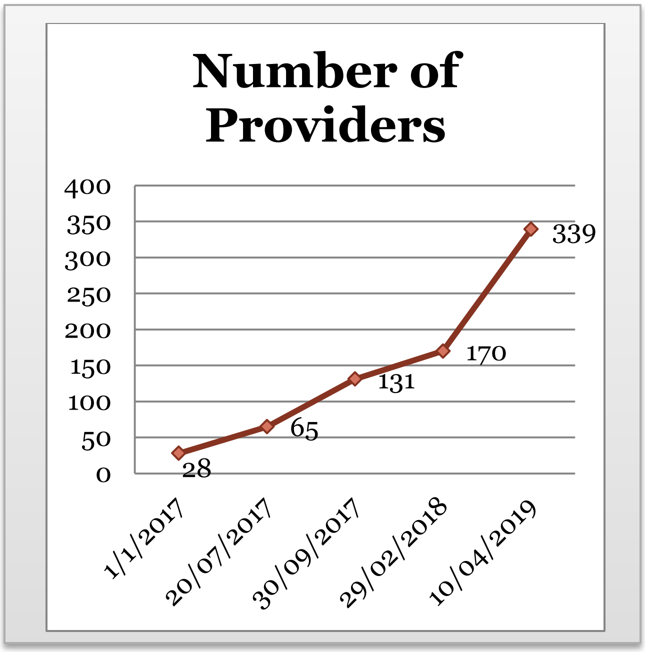


Figure 2.4: Number of OAM providers based on the Humanitarian Innovation Fund Final Report from 2018 and OAM status as of April 10, 2019.

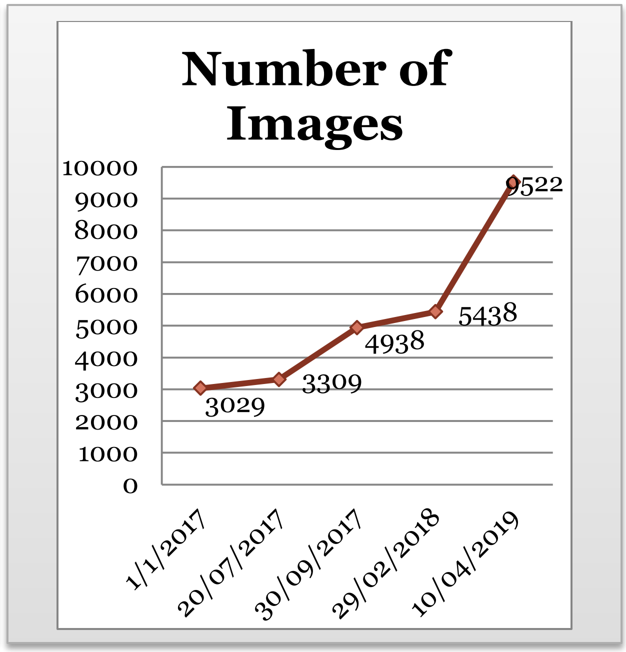


Figure 2.5: Number of images on OAM based on the Humanitarian Innovation Fund Final Report from 2018 and OAM status as of April 10, 2019.

2.4.2 Interview and Survey Findings

From the 50 interview requests that were sent out, there were 5 positive responses from the companies that are listed in Table 2.1. All the participants, at the time they were interviewed, had over 7 years of experience in their respective occupations. Four of the participants had varying levels of engagement with conservation efforts as well as various experience with data collection in the field as well as data processing software. In addition to having hands-on experience collecting aerial imagery with drones, the interviewee from AeraCoop also had experience using OAM, which he found useful for sharing the aerial data he collected. The remaining participant was primarily involved in the data and software side of the process, though he was aware of OAM. The interviewees revealed a wide array of applications which could benefit from open aerial imagery, such as surveying, construction, mining, archaeology, environmental project management, and conservation efforts.

Table 2.1: List of companies/organizations which participated in the interview.

AeraCoop **(aeracoop.net/en)**	An organization that collaborates on projects involving drones in order to aid both individuals and groups in various projects, such as territory mapping, environmental research or even search and rescue operations.

Azavea **(www.azavea.com)**	A B Corporation whose goal is to advance geospatial technology so that it can be applied for various civic, social and environmental applications. It supports the idea of Open Data and was involved in a number of open source projects such as GeoTrellis, OpenTreeMap, DistrictBuilder, and OpenDataPhilly.
Conservation Drones **(conservationdrones.org)**	An organization that aims to share the knowledge regarding the use of low cost drones for various conservation efforts worldwide. Its aims are to help build a capacity for employing drones in conservation efforts, raise public awareness in regards to the challenges faced by conservation projects, and encourage the use of new technologies in conservation efforts.
DroneMapper **(dronemapper.com)**	A company specializing in photogrammetry and aerial image processing. Among the various services offered is the collection of imagery using drones as well as the data collection training a client would need for his/her specific application.
Open Forests **(openforests.com/drone-mapper)**	A consulting company that is focused on supporting conservation projects. It specializes in providing drone-based mapping and training. Its goal is to provide open source mapping solutions in order to democratize public access to drone-related technologies.

In addition to the interviews, there were also 45 responses to an online survey. The respondents were all from online groups interested in either aerial archaeology or North American archaeology in general. This pool of respondents was, therefore, certainly biased in terms of assessing aerial imagery based on its usability in archaeology. Responses may have differed if other user communities have been chosen; each field may influence a community to view aerial data differently, depending on how it is used in that field. Nevertheless, the responses gathered from the archaeological community gives a valuable glimpse into how this particular community views open aerial imagery. The respondents stated having varying degrees of experience with open data. None of them mentioned having experienced any negative effects related to open data. There was one respondent in particular who specifically brought up having used Open Aerial Map imagery, which indicates that despite the fact that OAM is relatively new, there already is some interest in OAM in the archaeological community.

Table 2.2: **List of relevant questions that were asked in the online survey as well as the answers received in response to those questions.**

What is your experience in regards to open data, and specifically, open aerial imagery?	Positive experience (40)	Some experience (6)	Negative experience (0)	
In your opinion, what is the future of user-contributed open aerial imagery in terms of real-world applications?	Virtual reality (3)	Archaeology (13)		
In your experience, how does the quality and quantity of volunteered imagery compare to data collected through traditional means (satellites, etc.)?	Better (30)	Equal (4)	Worse (4)	Uncertain (6) Valuable regardless of the quality (1)
Might the risks or negative effects of image repositories have the potential to outweigh the benefits?	Yes (17)	Maybe (11)	No (16)	

2.4.3 Quality of Volunteered Aerial Imagery

In regards to how the quality and quantity of volunteered drone imagery compares to data collected through traditional means, the majority of the survey respondents found volunteered imagery to be better. 30 respondents found volunteered drone data to be better, 4 thought it was just as good and 1 person was of an opinion that aerial imagery is always valuable regardless of the quality. Only 4 respondents saw volunteered data as being worse quality than authoritative data. The remaining 6 respondents were uncertain.

Three of the interviewees had experience with OAM. Unlike the survey respondents, only one of the interview respondents found the quality of volunteered imagery on OAM to be of adequate quality. The two other interviewees were disappointed with the imagery. One interviewee plainly stated that the last time he visited OAM he found at least half of the images on OAM to be of bad quality.

2.4.4 Potential Risks Associated with OpenAerialMap

All the interview respondents thought that the risks of an open aerial repository are unlikely to outweigh by the benefits. The main risk that the interviewees saw was that the aerial imagery might be used for non-desirable purposes. One of the interviewees mentioned that "people might do things with the data that we might not like." Another interviewee mentioned that a repository of imagery could mean that despite any precautions or preventative measures, there will be individuals who will be able to "extract sensitive data using multiple sources of data. They could fuse the data to pull out certain phenomenology." A similar concern was expressed by another interviewee who said that "there are a lot of smart people in the world and if they [...] had multiple sources of data and they fused that data to pull out certain phenomenology, there's a risk that when the data's combined with certain algorithms, you could pull out data that could be considered a national security risk or a threat."

Unlike the interviewees, not all the survey respondents thought that the benefits of an open aerial repository could outweigh the risks. Out of 45, 17 were concerned that the risks may be greater than the benefits, 11 expressed uncertainty and 16 were certain that the risks will not outweigh the benefits. 2 of these survey respondents thought that advancing technology will aid in outweighing the risks and negative effects. 2 others thought that the financial benefits will outweigh the risks, while 2 more did not foresee any negative effects in regards to open aerial imagery. One of the individuals stated that despite the risks, "if used correctly, [open aerial repositories] could be extremely useful." From the individuals who answered "maybe" to the survey question, 1 was concerned about the cost of data storage, 2 saw issues in terms of ease of access, while 3 others were concerned about the risks that open aerial data might bring to certain research fields – in their case, archaeology.

2.5 Discussion

2.5.1 Quality of Volunteered Aerial Imagery

Image quality is important in terms of both image resolution as well as in terms of the area it covers. The image resolution needs to be high enough to allow identification of the ground features that are of interest. This varies depending on what the images are used for – some uses might need lower resolution than others. Most of the drone imagery that was found on OAM ranges from extremely high resolution images of less than 1cm (as seen in Figure 2.6) to imagery featuring a resolution of around 6 or 7cm (Figure 2.8). This is both due to the high resolution cameras featured by most drones as well as the relatively low height at which drones are flown. One of the survey respondents remarked that since most drone imagery is collected at a max of 400 feet (according to US drone flight regulations) the resulting imagery is able to be more detailed than much of the available satellite imagery. Not all applications require high resolution imagery; some might rely more on regular revisit times provided by satellites. Nonetheless, having high resolution imagery had generally more applicability as it allows for application in large-scale mapping. If high resolution is unnecessary, the image resolution can easily be converted to a lower resolution.

Regardless of the resolution, the UAV pilot's skill in surveying also plays a role in image quality, such as in regards to the image's levels of distortion or area coverage (Johnson, Ricker, & Harrison, 2017). A survey respondent mentioned that having multiple images from multiple contributors will allow users to rule out any errors in the imagery. This is a common strategy that VGI communities tend to employ to ensure data quality is having a number of people working on the same area (Ballatore & Zipf, 2015). Having more people assess the same data tends to result in higher quality data (Ballatore & Zipf, 2015). In OAM, this would ideally translate to having multiple images available for the same area. This way, as brought up in one of the survey responses, image comparison and analysis could be used to aid in verifying the quality and reliability of the data one needs. Another quality control strategy employed by VGI communities relies on community surveillance and control (Ballatore & Zipf, 2015). This was also mentioned by one of the survey respondents who wrote that in his experience the quality of volunteered imagery can be dependent on the amount of quality control put in place. Right now, OAM does not feature any such measures, which can be seen as a limitation of OAM in regards to assessing data quality.

Date: *2016-05-01*

Resolution: *0 cm*

Provider: *Douglas J Ellison*

Sensor: *Phantom 3 Pro*

Size: *53.55 MB*

http://tiles.openaerialmap.org/58e870a5cfbcc90010aca443/0/09c6d420-ae7a-4316-a4ad-8aaf81977e21/{z}/{x}/{y}.png

Figure 2.6: An aerial image on OAM of Pisgah Crater Cinder Cone, California, US.

One survey respondent answered that in their experience, the quality of volunteered imagery was never the issue for him – the lack of data was. He saw any available data as valuable regardless of the quality. A similar view was expressed by an interviewee who added that drones typically produce high quality images with very high resolution. The stabilization technology featured on many of the drone models contributes to ensuring good quality aerial images. In addition to that, the flight pattern apps and programs for drone piloting can go a far way in ensuring that the drone images are of good quality. The weather remains the last factor that may influence the quality of aerial imagery. It may prevent drone flight altogether or it may result in blurry images, especially in strong winds or rain. On the other hand, climatic events may play a role in the amount of data available for a region. For example, the Haiti earthquake resulted in a large volume of drone imagery collecting by people in order to aid in search and rescue.

Regarding image resolution, some interviewees pointed out that high resolution images might not always be necessary, especially when considering a larger area. The interviewee engaged in conservation efforts also noted that high accuracy is not always necessary when it comes to how aerial images are used in conservation efforts. There can be a larger margin of error in regards to coordinates, for example. A conservation specialist will be more interested in obtaining a sense of how many trees there are in the area of interest versus pinpointing the exact location of these trees. Data can have some degree of error yet still be a valuable data source. This indicates that despite any potential inaccuracies in the data, there are user communities that may find the imagery on OAM beneficial nonetheless.

2.5.2 Benefits of Open Aerial Imagery

In general, the social outlook on OAM is one of interest; all the interviewees appear to be in favour of having open data repositories and are interested in seeing what OAM can grow into. The interviewee from Aeracoop – having used and contributed to OAM – described OAM as an "amazing tool" which provides exactly what he needs in order to share aerial maps with others. Another one of the interviewees, who also had some experience using OAM, was in agreement that OAM is a valuable tool, particularly in regards to the easy sharing of georeferenced images. An interviewees engaged in conservation work, also said that OAM is a great idea. He said that he likes the idea of creating a high resolution map of the world and openly sharing the data. He also mentioned that open data platforms such as OAM are "potentially very useful options for conservations efforts." Patrick Ribeiro from OpenForests was a bit more skeptical towards the OAM due to the poor quality imagery he encountered the last time he checked out OAM; however, despite that he said that he would be curious to see how OAM works out. He also mentioned that he would be open to sharing some of the imagery collected through different OpenForest projects.

Affordability

One of the factors that speaks in favour both of drone imagery and open data repositories is cost. As drone technology continues to advance, drones are becoming less expensive and more widely available on the market (Ollero, 2017, p. 1; Percivall, Reichardt, & Taylor, 2015). The small multicopter drone models in particular have both low acquisition and upkeep costs as can be observed in Table 2 of Appendix A (Yanmaz et al, 2018). In addition to buying drones online or in stores, there are also many options available for building a custom drone. There are also various DIY drone websites, like Drone Nodes, Drone Lab, Instructables, Tech Republic, and DIY Drones, that offer guides and instructions for those who might wish to build their own drones. Conservation Drones, which started up in 2011, is an example of an organization that began using drones in conservation efforts by employing DIY drone websites and open source solutions to build their own drones. Conservation Drones continues to build affordable drones for environmental and conservation groups concerned with surveying and mapping forests and monitoring forest biodiversity. This was task was particularly significant back in 2011, when the cost of most commercial drones was too high for conservation groups in developing countries. Now, as pointed out by one of the interviewees, the prices have evened out and on the low end, commercial drones might be similar in cost, but have better performance than DIY drones. Nevertheless, organizations like Conservation Drones, DIY websites and the growing variety of drone manufacturers are all factors that contribute to a growing and diverse UAV market, which allows a wider sector of the population to become involved in drones and perhaps interested in the collection of aerial data. This also results in drone imagery becoming a more cost effective alternative form of aerial imagery when compared to satellite imagery.

Though OAM is still in the development stage, if it continues to attract users and contributors it has the potential to grow into a valuable repository of aerial imagery. Based on the interviews and research that was done, people see OAM in a favourable light. The individuals that were interviewed generally thought that this could be a useful undertaking. An interviewee from Conservation Drones stated that developing such a platform could be "very useful for conservation efforts." Another interviewee referred to it as a "pretty great attempt at trying to make it easy to upload imagery." The HOT team come across a similar positive approach regarding OAM when presenting the project to the wider public. The Humanitarian Innovation Fund Final Report from 2018 makes note that OAM was "very well received and people have been highly engaged in OAM and its potential use" in all the conference and workshops where HOT presented OAM (Humanitarian OpenStreetMap Team, 2018). OAM was presented at over 10 conferences and workshops. It also has a page on Twitter (https://twitter.com/openaerialmap?lang=en) and a blog (https://blog.openaerialmap.org/) in order to increase OAM's presence on social media (Humanitarian OpenStreetMap Team, 2018).

Supporting Humanitarian Efforts

Supporting humanitarian efforts is intended to be one of the key benefits of OAM. This can be gathered from the background of OAM presented earlier; however, people realize this potential themselves as well. One of the survey respondents considered rescue support as being an important real-world application of open aerial data. The key factor that plays into OAM being a great tool for humanitarian aid efforts is the fact that it is accessible and free. No complex software or expert knowledge is required to upload imagery onto OAM. All one needs is a drone (or another means to take aerial images), a computer and an internet connection. As mentioned by Lot Amoros, who frequently used OAM, uploading imagery onto OAM itself is easy. Figure 5 illustrates a screenshot of the upload form used by OAM. As can be seen, it is not a complex or long form. It also allows multiple datasets to be uploaded simultaneously using the “New Dataset” option. Once the files are submitted, the images become publicly available on OAM. This process is relatively simple and quick. This is can be an important factor in humanitarian efforts following natural disasters, for example, when images need to be quickly uploaded and shared on a frequent basis to aid first responders and other relief groups in staying updated on the situation.

Christiano Giovando and Tyler Radform (2016) from HOT mention in an interview an

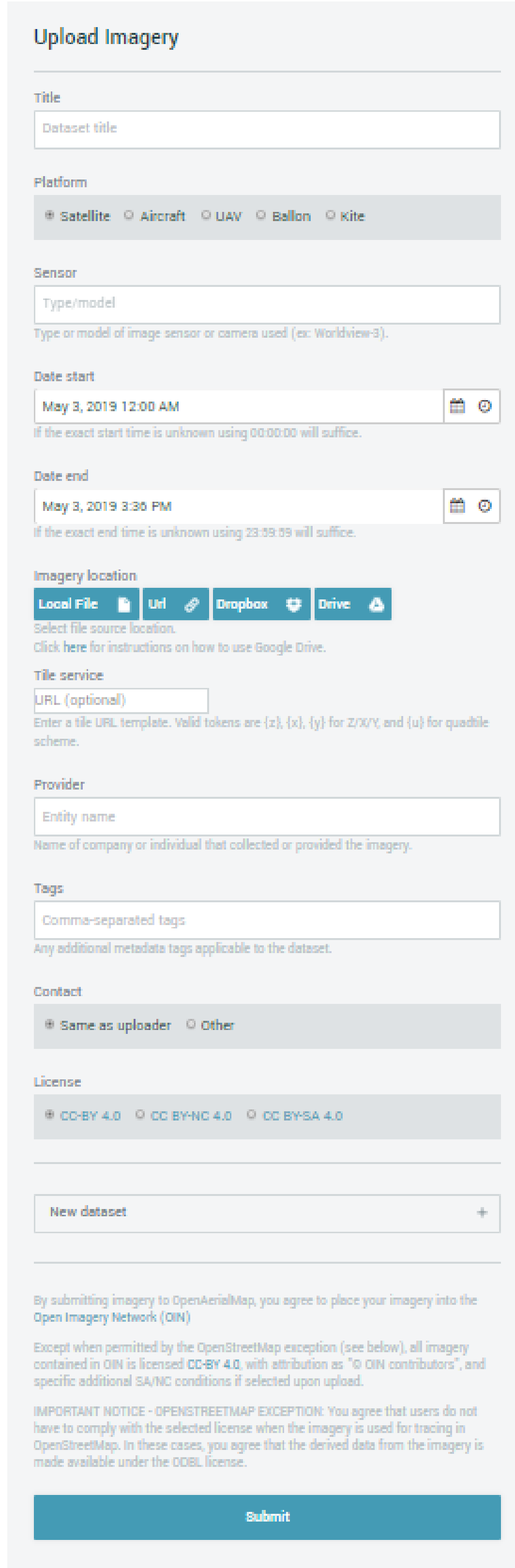


Figure 2.7: Screenshot of the OAM image uploader

example of local groups in Dar es Salaam in Tanzania, who share the imagery they collect on OAM in order to aid humanitarian teams in making a comprehensive map of the region. Examples of the images collected by these groups, which are part of Tanzania's Open Data Initiative, are illustrated on Figures 2.8 and 2.9. As of April 2019, there are around 16 high resolution drone images available for Dar es Salaam – most of which are from that mapping initiative in April 2015 – that can be downloaded and used to for various mapping applications. Since Dar es Salim is prone to flooding, these images provide great aid to local disaster management groups in forming resilience strategies that will alleviate the risks and damages brought by floods (Giovando & Radform, 2016).

Date: *2015-04-14*

Resolution: *4 cm*

Provider: *Tanzania Open Data Initiative*

Size: *297.39 MB*

http://tiles.openaerialmap.org/7/0/556f7a49ac00a903002fb042/{z}/{x}/{y}.png

Figure 2.8: Example of an aerial image on OAM showing Dar es Salaam, Tanzania.

Date: *2015-04-17*

Resolution: *6 cm*

Provider: *Tanzania Open Data Initiative*

Size: *426.08 MB*

http://tiles.openaerialmap.org/7/0/556f7a49ac00a903002fb01d/{z}/{x}/{y}.png

Figure 2.9: Example of an aerial image on OAM showing Dar es Salaam, Tanzania.

Mapping and Accessible, Up-to-Date Imagery

Another advantage of OAM is that it facilitates rapid mapping as images can be uploaded and shared on frequent basis if that is the need. The images are publicly licensed and available for download by anyone who might need them. In order to facilitate easier access and sharing of imagery, OAM is connected to private cloud storage servers, such as Google Drive and Dropbox, as well as linked to OSM and social media, such as Facebook. Two of the interviewees mentioned that they found this very useful. One of the interviewees mentioned that what drove him to use OAM a few times was that he was in need of a cloud optimized GeoTIFF. Geo-tiffs are geographically referenced tag-based files for storing raster images (Mahammad & Ramakrishnan, 2009). They have become a standard format used for aerial imagery (Mahammad & Ramakrishnan, 2009). GeoTIFFs can include an array of spatial information such as the latitude/longitude, the coordinate system, the map projection and other spatial data which would make it easier to analyze the image using various GIS software. As a result, TIFF images are significantly larger in size. The system used by OAM, which makes use of cloud-based storage, allows these images to be shared online without needing to worry about a single server to store all these large files. It then makes it easy to find the appropriate GeoTIFF by either searching for the desired location or b visually finding it using the OAM map explorer.

Giovando and Radford (2016) give the example of the 2015 Nepal earthquake when humanitarian responders were able to daily update their maps using OAM to reach the people affected by the earthquake. Those post-earthquake images are unfortunately no longer available on OAM; however, figures 2.10 and 2.11 show two other images from Nepal that illustrate the difference between the drone and satellite imagery for that area. Not only is the satellite image of lower resolution, it is also older and possibly no longer relevant in terms of accurately presenting what the area currently looks like. This issue seems to be the case for much of the satellite imagery that is available online for free, starting from the popular platforms like Google Earth or Bing Maps to those run by international space agencies like the Sentinels Scientific Data Hub and NASA Earthdata Search. Figure 2.12 depicts an example of this, showing one of the drone images on OAM alongside the same area as seen on Google Earth and Bing. Though there is no date for when the satellite images on Google or Bing were taken, they are clearly much older as can be seen by coming them to the fairly recent drone image from 2018. Though not specified on Google Earth, a study by Corradina (2015, pp. 11-12) makes note that the average resolution on Google Earth satellite imagery is 2.5 meters for the DigitalGlobe imagery and 15 meters for the Landsat imagery. The area presented on the images, specifically the drone image from OAM, depicts the Kalobeyei Integrated Settlement. It is a refugee camp that is located around 40km northwest of the city of Kakuma in Kenya that covers around 15 km^2. It is an expansion of the Kakuma Refugee Camp, which was established in 1992 to aid Ethiopian and Somalian refugees. It hosts refugees from South Sudan, who fled the armed conflict that began around 2013. Despite the settlement's large size and the fact that it has been around for the last few years, neither Google maps nor Bing maps feature the refugee settlement on their maps or aerial imagery.

Date: *2016-09-09*

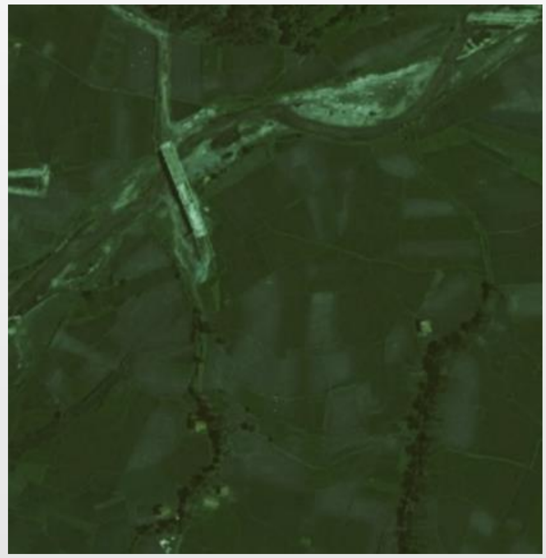
Resolution: *4 cm*

Provider: *WeRobotics*

Sensor: *UAV Phantom*

https://tiles.openaerialmap.org/5a00bbb731eff4000c380576/0/108ed7ec-700e-41d1-a39d-5e09320e4569/{z}/{x}/{y}.png

Figure 2.10: Drone image of the Kathmandu Ricefields in Bhaktapur District, Nepal.



Date: *2015-04-27*

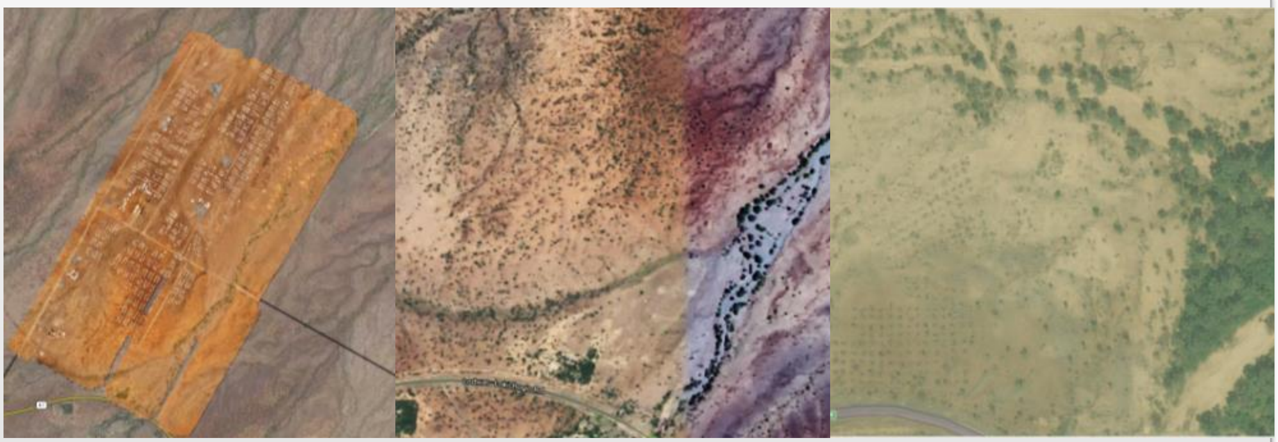
Resolution: *40 cm*

Provider: *DigitalGlobe*

Sensor: *Satellite WV3*

http://tiles.openaerialmap.org/14/0/55bf966a2b67227a79b4f400/{z}/{x}/{y}.png

Figure 2.11: Satellite image of the Kathmandu Ricefields in Bhaktapur District, Nepal.



Date: *2018-11-02*	Date: *unknown*	Date: *unknown*
Resolution: *6 cm*	Resolution: *unknown*	Resolution: *unknown*
Provider: *Tayyar Cansizoglu*	Provider: *Google Earth*	Provider: *Bing*
Sensor: *DJI*	Sensor: *Digital Globe, HERE*	Sensor: *Digital Globe*

Figure 2.12: Comparison of 3 images (from OpenAerialMap, Google Earth and Bing) showing the location of the Kalobeyei Integrated Settlement in Turkana County, Kenya.

A case study performed by Kanthi and Purwanto from 2006 presents how aerial imagery from OSM was used to map a village in Indonesia. The imagery from OSM proved to be a good source of data allowing for aiding the Indonesian government in integrating geospatial information and making it more organized through the Village Mapping initiative (Kanthi & Purwanto, 2016). The aerial imagery on OSM at the time was primarily Bing Data, but even with this free satellite data (especially in terms of mapping small buildings, for example) the resulting maps were only around 1 meter off (Kanthi & Purwanto, 2016).

Preserving Historic Imagery

Another valuable advantage of OAM, which was already mentioned previously, is that it offers the capability of retaining historic data. This greatly expands the versatility of OAM. Being able to observe landscape changes over time by comparing current aerial images with those from the past holds a broad range of potential, from environmental monitoring, to urban planning, to tracing social changes in regards to settlement patterns and land use. The possibilities are extremely diverse.

The ability to retain historic data, and not just offer current data, seems to be a significant feature offered by OAM that speaks in favour of crowdsourced imagery. Pierre Stoermer from Drone Mapper brought up that historical time series can provide abundant information for many applications. Another interviewee mentioned that having openly available historic aerial data would be very useful for conservation efforts. He said that the even having geotagged aerial imagery would be relevant and beneficial for any new conservation projects that are undertaken as they would allow conservationists to compare the current state of the environment to what is was before. A respondent of the online survey explicitly stated that according to him, “the most important real-world application [of aerial imagery] in the future is to see change over time.” He explained that the reason for this is that seeing change over time is extremely useful both in human and environmental contexts. In the human or cultural context, historic aerial imagery allows for pattern analyses of human population, migration, urban growth, and evolution of architecture. In an environmental context, historic aerial imagery allows people to view land change over time, to document and analyze climate changes or to track ecological changes over time. Making historic data available is also seen by some people as an incentive to collect and contribute data. An active image contributor on Mapillary, Simon Mikkelsen, revealed that he was motivated to contribute imagery primarily by a desire to record the local region for the future generations (Billing, 2019).

2.5.3 Limitations of Open Aerial Repositories

Quality Issues

Though open aerial data has the potential to offer many benefits and open up a wide range of opportunities, there are barriers that need to be overcome. One of these is the uncertainty in regards to the quality and accuracy of data that has been crowdsourced or created by volunteers instead of experts (Grainger, 2017). Unlike satellite imagery or government data, it is not possible to guarantee the quality of crowdsourced aerial imagery. One of the interviewees mentioned that the fact that there is “no guarantee on geographic coverage or quality of the data” is an issue when using the images for business purposes. He added that “there’s definitely a lot of concerns about basing any sort of decisions on it.” This can be a major issue in regards to using volunteered data for any type of analysis or research. The premise underlying this concern is that citizen science and crowdsourced data is seen as the domain of amateurs, enthusiasts and hobbyists (Brabham D. C., 2012; Gharesifard, Wehn, & Zaag, 2017). Yet as aptly pointed out in a study by Brabham (2012), the crowds contributing towards crowdsourcing projects are not really composed of just amateurs, but actually of “self-selected experts and what we might otherwise call professionals." Other scholars have also identified VGI contributors as ranging from novices in the field to professionals (Coleman, Georgiadou, & Labonte, 2009). This holds true in terms of OAM. There are certainly amateur drone users who want to share the imagery they collected, but there are also contributors like the interviewee from Aeracoop, who run projects involving the collection of aerial imagery and wish to share the data they collect.

Regarding the quality of aerial imagery, there is also the technical aspect of drone data collection. As mentioned by one the interviewees, people may use various drones and cameras to collect aerial imagery. This will result in differing image quality and varying levels of image distortion. Even if the camera or drone model is specified in the metadata, the distortion level of various cameras is not well known and therefore can be hard to account for. Pierre Stoermer pointed out that latency can potentially be another issue. The length of time taken to photograph an area can be significant for some projects. For other projects, the time the images were taken in might play a role. In these cases, relying on open aerial imagery might not be appropriate. Even if an aerial image features detailed metadata, this information is typically provided by the contributor who may or may not accurately specify all the pertinent information. Even simple information may be not be classified correctly by a contributor uploading or sharing an image. The metadata can provide an important tool in this regard, as long as it provides the necessary information that can be used to assess the quality of the data. The problem is that just like the data might be faulty, so might the metadata that accompanies it. This can make verifying the image quality potentially most challenging aspect regarding volunteered aerial imagery. An example is the image shown in Figure 10, which is identified in the metadata as a satellite image. Despite that classification, the image does not seem to be a satellite image as the metadata indicates. It does not even look like the image accurately overlays the satellite imagery that forms the background layer of the map.

As one of the interviewees mentioned, there needs to be some knowledge or training involved in order to collect good quality data in the field. There also needs to be an understanding in regards to inputting and uploading the metadata onto OAM, as indicated by Figure 11 and 13. The coordinates attached to Figure 13 place it in the middle of the South Pacific Ocean, west of Peter I Island (an uninhabited volcanic island) and north of Thurston Island (an ice-covered island just off the coast of Antarctica). Based on the vegetation and landscape presented in the image, the image is incorrectly geotagged as it was definitely not taken off the coast of Antarctica. This type of spatial inaccuracy can be an issue, especially when taking into account that the primary way to search for imagery on OAM is by location.

Though so far there are only a few faulty images like the one in Figure 2.13 found on OAM, it is still an issue that needs to be taken into account as OAM grows. Since OAM allows anyone to share data, it must be acknowledged that some users might not pay too much attention to ensuring the data they share is correctly described. Perhaps it might be impossible to completely eliminate the uncertainty around data accuracy; however, the issue could be minimized in a few ways. One way would be selecting a few experts to monitor data quality and decide whether or not the data is acceptable. Another way could be through a community-based approach where OAM users can either rate images or report certain images or information as being poor quality or possessing inaccurate information.

The examples in Figures 2.13, 2.14 and 2.15 indicate that some quality control would benefit the imagery on OAM. Nevertheless, it would be unreasonable to set the standards too high or be too strict in regards to what data is accepted. It might not be realistic to have someone manually check every single image uploaded onto OAM, while having an automated process for quality control will understandably not be able to detect with 100% accuracy which images are useless. One solution might be the development of an app that drone users could download to help them collect aerial imagery in a uniform format. This type of solution was actually tested in the fall of 2017 by Drone Scholars, who launched a global initiative, Fly4Fall, that encouraged drone enthusiasts to contribute aerial photographs of fall landscapes (Lyons, 2017; Press, 2017). The goal was to use the imagery to carry out a global survey of plants (Press, 2017). The free app, Hangar 360, that was released as a part of this campaign made it easy for anyone with a drone to capture aerial photography as it was capable both of flying the drone as well as stitching all the photographs together (Lyons, 2017).

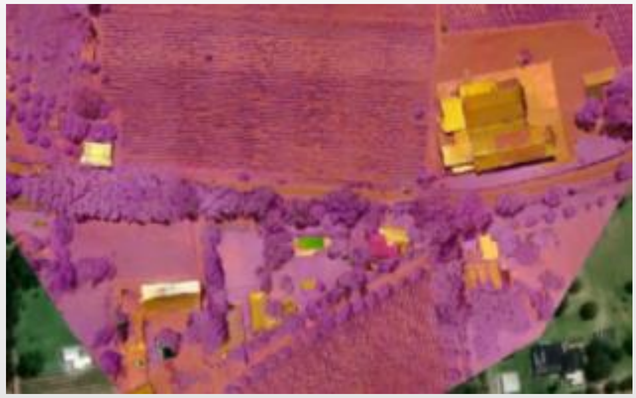
Date: *2019-03-27*

Resolution: *5 cm*

Provider: *Jeremy Hetzel*

Sensor: *Satellite*

Figure 2.13: High-resolution image of small area north of Inuvik, NW, Canada.



Date: *2019-02-15*

Resolution: *5 cm*

Provider: *AgroCam (Miguel Carminati)*

Sensor: *AgroDat DAPI*

Figure 2.14: Drone image of farm in Bajo Lunlunta, Mendoza, Angentina.

Date: *2019-01-29*

Resolution: *6 cm*

Provider: *WebODM (Carlos Canto)*

Sensor: *DJI FC330*

Figure 2.15: Drone image titled Casa Club ORVE located in the South Pacific Ocean west of Peter I Island and north of Thurston Island, Antarctica.

Sufficient Quantity of Imagery

One of the interviewees was disappointed by the amount of aerial images currently available on OAM. He was also dissatisfied with the fact that many of the images were of bad quality. This was due to the fact that as of right now, for many regions, the only aerial images available on OAM are Landsat 8 satellite images from Astro Digital, which have an average resolution of around 40m (depending on the area it ranges between 35m to 50m). Most of these satellite images were taken between 2013 and 2016. There are also some odd drone images, such as the one in Figure 2.13, whose quality is questionable. The metadata does make note that this is a "test" image, but the fact remains that it is by no means a good image and its usefulness seems limited. Figures 2.14 and 2.15 are two other examples of lower quality images. Figure 2.14 is an aerial image taken with an agricultural drone, capturing NDVI imagery; however, there are gaps in the image. A similar issue appears in Figure 2.15. The areas of missing data are not large, but they are there nevertheless.

Technical Challenges

Another limitation of OAM is the limited interface and the occasional bugs encountered while sharing data using OAM. One interviewee found the OAM interface "a little bit awkward," which discouraged him from using it or looking into it further. This may be in part a personal preference of someone who might prefer a more sophisticated interface that allows users more options in terms of searching for and viewing imagery. As of right now, finding imagers can be done by either selecting tiles on the OAM explorer or by using the search toolbar. The search toolbar limits users to either to searching by location or by selecting one of the filters from the dropdown menu which allows them to filter images uploaded within the last week, the last month or the last year. The dropdown also allows users to filter images by high, medium or low resolution. Apart from these simple filters, there is no advanced search option which would allow users to use more specific search criteria. This limits users' ability to find specific datasets they might be looking for. Lot Amorós from Azavea mentioned in the interview that it was not always easy for people to find the data that he shared on OAM. Though OAM does offer the option to easily share a link to a given image, Lot Amoros found that in day-to-day use the links did not always work.

It is important to note that apart from any limitations of OAM itself, there are also outside limitations such as internet cost and availability. Limited internet access or high internet costs may prohibit individuals from sharing their aerial data, particularly when taking into account the fact that the size of high-resolution aerial imagery can be quite large. The difficulties associated with flying drones, which can easily crash, might be another barrier deterring new contributors from becoming engaged in aerial data collection. Finally, legislation surrounding drone operation can be an impediment preventing people from collecting aerial data. This was mentioned by one of the survey respondents who noted that the current legislation surrounding UAV operation "presents an impediment to the expedient collection of aerial data in many areas." Another respondent also mentioned UAV legislation as a constraint, recounting the troubles he underwent when he wished to incorporate the use of drones in his academic work. The university he is affiliated with "has an entire campus wide drone ban" based on the premise "that drones was a banned, dangerous tool that puts human lives in danger." Despite the fact state laws did not prohibit drone use or the fact that this survey respondent acquired the U.S. FAA UAS 107 drone license, the department refused to condone the use of drones for the research he was conducting. The respondent concluded that this type of "miseducation of many professors can hurt aerial data research."

2.5.4 Privacy and Security

In addition to considering the limitations, it is important to bear in mind that providing open access to aerial data can bring with it some risks. One of the first facts that need to be acknowledged is that data impacts people in one way or another. Even data that seems to have nothing do with people might impact end up affecting individuals in ways that might be hard to foresee. An example might be of aerial imagery being used to influence property values. Aerial imagery might be also be used by various states and businesses in order to gain an unfair advantage. The issue lies in the fact that the reuse of the data shared on OAM might be in opposition to the original intents of those individuals who created or shared the data.

The matter of privacy and security is a difficult issue. There is the issue of personal or individual privacy, on one end, all the way to community or national security on the other end. Privacy is not just a public/private binary, but it is also contextual and situational (Zook, et al., 2017). Privacy encompasses the nature of the data, the context in which that data was created, as well as the expectations or customs of those that the data affects (Zook, et al., 2017). The Humanitarian UAV Network Guidelines on Data Protection state in one of the points that reasonable measures should be taken to obtain informed consent before collecting aerial imagery (Humanitarian UAV Network, 2016). If it is not feasible to obtain consent, extra care should be taken in regards to data privacy, such as by using solutions such as blurring in order to prevent people’s right to privacy from being violated (Humanitarian UAV Network, 2016). Other times, it might be necessary to use judgment in regards to what images perhaps shouldn’t be shared. For example, three of the interviewees mentioned that open aerial imagery might potentially facilitate poaching. The interviewee from Conservation Drones said that “in terms of national parks, for example, poachers might use aerial imagery to find high value trees or certain types of vegetation where high-target animals may live.” Similarly, a number of the survey respondents (12) were concerned that looters may use open aerial imagery to find and plunder archaeological sites. Other individuals may use this information to visit and vandalize sites. One respondent from the US recounted how in his experience with photographing various heritage sites, he found “places that are freely shared online as mystical places are peppered with graffiti and vandalism.” He also “followed police reports of the many arrests of people and their friends who often went on a 'fun adventure' but crossed the line with vandalism and exploitation of the area.” These are just some of the concerns that arise regarding the potential misuse of aerial images, should they be freely available online in high resolution.

Ownership and Consent

Based on the interviewees and surveys, people did not seem to see any issues in regards to data ownership. One of the interviewees stated that he doesn’t “think it is a problem for the submitter.” He added that what would be more concerning “was if they had imagery that someone else wouldn’t want uploaded.” A similar concern was expressed by another interviewee, who thinks it’s illegal to upload aerial imagery featuring private residence without owners’ permission. On the other hand, he mentioned that it might sometimes be hard or impossible to get this permission, especially if one is mapping a large residential area. He also brought up that, in his experience, even when permission is obtained, some people do not fully comprehend that aerial imagery of the area where they live – their house – will be publicly available online for anyone to see. There’s also the issue regarding who is collecting and sharing the imagery. Patrick Ribeiro from Open Forests mentioned the fact that one of the privacy issues on the social side concerns remote or indigenous communities that may not wish to have their location revealed to the entire world. Outsiders sharing aerial images of the areas inhabited by these communities and thus revealing the location where they live and have their resources in some ways may be infringing on these communities’ right to privacy. They may also be unintentionally putting these communities at risk depending on where these communities are and what the local social and political outlooks are regarding these communities. Even if permission from these communities has been obtained, there might be no guarantee that these communities understand all the implications that may come from having the aerial data shared online. They might not be aware of the ways it can impact their privacy.

Security of Drone Users

In addition to risks related to openly sharing imagery, there is also a growing realization that the collection of the aerial imagery itself may bring with it some risks to the individuals collecting this data. This may be either due to difficulties in the field (such being in as remote, inaccessible terrain or in a dangerous area) or in terms of the repercussions that drone users may face if flying drones in a thoughtless manner. The Humanitarian UAV Network (UAViators), founded by Patrick Meier, is one international group that strives to promote the safe and effective use of UAVs in humanitarian settings by establishing clear standards for the use of UAVs, documenting best practices, providing UAV training, and organizing research and information sharing (UAViators). UAViators has over 3,200 members in over 120 countries worldwide (UAViators). It worked with over 60 organizations worldwide in order to come up with a UAV Code of Conduct that was launched in 2014 in order to guide UAV users as to how to collect data in an ethical and sensitive manner that will minimize any risks associated with collecting that data and ensure the data is collected in an ethical manner (Humanitarian UAV Network, 2016). Though these guidelines, presented in Appendix D, are meant for drone users engaged in humanitarian aid, they can be applied to drone users in general as these guidelines aim to ensure that data is collected in a safe, legal and impartial manner that does not negatively affect people's privacy and security. By following standard guidelines, any undesirable impacts will be kept to a minimum. Drone users will be less likely to be faced with resentment or to fall prey to hazards.

So, on the one hand, open aerial imagery bring with it the potential to be misused and some people might feel that high resolution imagery of their private properties in some way invade their privacy or make them feel more vulnerable; on the other hand though, the notion of open data is based on the idea that data should not be censored to fit with what a certain entity thinks the rest of the population should or should not have access to. Yes, giving people access to data will present them with an opportunity to use it for illicit purposes; but, it also presents people with the opportunity to use it for a wide variety of constructive purposes, which may otherwise be limited by lack of funds or time to collect the necessary aerial imagery. Nevertheless, there are certainly some areas or circumstances which would not be suitable to share on OAM for security reasons. This issue has been considered by the HOT team who are developing OAM. The Final Report for Diffusion Funding mentions that HOT will look into the option of allowing OAM providers to restrict access to the data they contribute to users with a specific license (Humanitarian OpenStreetMap Team, 2018). For example, someone contributing post-disaster aerial images may wish to restrict access to that data to humanitarian NGO's responding to the disaster (Humanitarian OpenStreetMap Team, 2018). The same idea could apply to those in conservation management sharing imagery of sensitive ecosystems that are inhabited by endangered animals, for example. Having such an option available could be one strategy for minimizing the potential misuse of sensitive geographic information, while still allowing the imagery to be accessible to those who will use it for the intended purposes. In terms of the remaining aerial imagery, overall there seems to be more benefits than risks from making it openly accessible. Besides, both Google Earth and Bing already provide an aerial view of the entire world. The main drawback of that imagery is that, though free, the imagery is copyrighted and so illegal for people to reuse without permission. OAM would be remedying this state of affairs by providing similar data, but allowing people to share and reuse it.

2.5.5 Attracting and Maintaining Users

Though the current research was unable to gain insights into what drew OAM contributors to start contributing data to OAM, the literature indicates that volunteer motivations may be altruistic, professional, intellectual, or emotional (Coleman, Georgiadou, & Labonte, 2009; Olteanu-Raimond, et al., 2017). Volunteers may contribute to gain some type of personal investment, social reward, personal reputation, creative outlet and pride of place (Coleman, Georgiadou, & Labonte, 2009). The case study by Brabham (2010) of the crowdsourcing company Threadless indicates the primary factors that motivated people to contribute to this project were the opportunity of financial gain, opportunity to improve creativity, prospect of freelance design work and the love of community. A survey of OSM users from Finland pointed to personal interest and pride of place as being essential motives for that particular section of OSM contributors (Seitsonen, 2017; Välimäki, 2011). Based on the information provided in the short bios that some of the top Mapillary contributors share, a few of the key reasons that seemed to inspire Mapillary users to become involved in collecting and sharing imagery are: the idea of supporting Open Data, a passion for mapping, and hobbies that support or enable imagery collection. PeeWee32 was attracted to contribute to Mapillary because unlike Google, the data is not copyrighted and it can be used for mapping and editing OSM (PeeWee32, 2015). Another contributor, canadarunner, who contributed over 750,000 images, states in their bio that their reason for contributing imagery is that they wish to map the entire world. Yet another contributor, Javier Sanchez (username javiersanp), is influenced to contribute imagery and geographic data by his passion for hiking and cultural heritage, which leads him to map mountain routes and heritage features (Sanchez, 2018).

Research on OSM, which has more than 5 million registered users, has indicated that the drive to contribute can go beyond such altruistic drives all the way to ones dictated by vandalism (Anderson, Sarkar, & Palen, 2019). A study by Budathoki and Haythornthwaite (2012) discerns committed mappers as motivated by a sense of community and learning. Economic drives are certainly a powerful motivator as well, despite the fact that open data is shared for free. Corporate and government institutions have been significant contributors, increasing the amount of map data and the usability of the OSM map (Anderson, Sarkar, & Palen, 2019). Career consideration was also shown to be a motivator for individual OSM contributors, though it is not one the primary motivators (Budhathok & Haythornthwaite, 2012). Nevertheless, some active OSM contributors use the skills they learned through OSM towards furthering their career while others employ OSM data within their own businesses.

Using previous studies and some of the declarations coming from Mapillary users, it can be assumed that a least some of these motivations are shared by OAM contributors. It all depends on the type of user one has in mind. Based on community discussions, HOT (2018) was able to form seven broad categories of OAM users:

1) **anonymous users**, who want to use imagery but are not technologically savvy;
2) **low-bandwidth users**, who work in remote areas, have poor internet connection and want to provide imagery access for a specific area
3) **DIY imagery collectors**, who have the equipment to capture aerial imagery, want to share the imagery, but do not know much about image processing;
4) **power users**, who want to share imagery with other and know how to process imagery;
5) **generic image providers**, who have imagery freely available online, have a good network connection and want to be active members of the OAM network;

6) **corporate imager providers**, who have both raw and processed imagery but want to restrict image access or usage for specific purposes and do not want to host the imagery;
7) **wandering researchers**, who are in need of raw or unprocessed imagery with high quality metadata.

Keeping this in mind can be advantageous in the future development of OAM. Each category of users will have different motivations for contributing and using OAM. For example, the corporate image providers and wandering researchers will have professional and intellectual motivations, while the generic image providers might have more emotional motivations, wanting to be a part of an online community. Ideally, steps should be taken to ensure that OAM features aspects that users with these various motivations will find attractive. The more users are involved in OAM, the more likely it is to be a sustainable project. A start could be creating more of a sense of community. This could be done by providing a means for users to communicate with one another either through direct messages or through a forum. There are multiple working ideas in this regard that could be adopted from OSM, which has been successful in creating a strong online community of mappers. Promoting OAM in communities that are engaged in Open Data or mapping could also serve to draw new contributors and users to OAM. It would aid in growing OAM. Not only does such a VGI project require a large numbers of contributors, but it also needs repeat contributors who are willing to contribute for the long term (Budhathok & Haythornthwaite, 2012).

Using social media to promote OAM can be the quickest and cheapest way to attract contributors. The developers of OAM realized this potential as the report published in May 2018 makes note that social media presence was one of the activities that were undertaken to promote OAM (Humanitarian OpenStreetMap Team, 2018). A Twitter page was created in May 2015 as well as a blog on the OAM website. The drawback is that since then, both the OAM Twitter page and blog seem to have suffered from a longer periods of inactivity. As of April 2019, the Twitter page features only 120 tweets, while the blog features only around 15 posts. There have also been no new posts on Twitter since July 2018 and no new posts on the OAM blog since May 2018. Hopefully this state of event is just temporary and social media activity will pick up again sometime soon. Not only will it assist in attracting new contributors, but it will also allow current contributors and interested users to stay informed regarding the progress of OAM.

2.6 Conclusions

This research indicates that OAM has potential to make spatial data more accessible. OAM provides drone users with a platform where they can participate in citizen science by sharing the aerial data they collected. This will make it possible to accumulate a high amount of high-resolution aerial data from large geographic areas. Available aerial imagery will no longer be limited only to aircraft or satellite imagery that are not only costly to acquire, but are also taken only during scheduled flights. Through OAM, citizens have access to a catalogue of open aerial imagery that can be visually searched through a web map. They also are provided with an easy interface for users to share their aerial imagery. One of the respondents to the online survey wrote that it is “the ability to quickly and easily obtain high resolution imagery” that forms a starting point to the use of aerial data. This is the goal of OAM. As such, OAM can be valuable towards a wide array of uses, beginning with humanitarian aid efforts for which OAM was tailored towards.

The effectiveness of OAM is apparent in the continued increase of both the number of images and the number or people sharing images on OAM. Furthermore, the drone images on OAM are higher resolution than most of the free satellite imagery available online. They also tend to be more recent, highlighting the advantage of collecting volunteered drone imagery, which offers the potential for frequent updating of imagery. At the same time, OAM retains historic imagery as well. Having free access to both recent and historic imagery will be a significant aid in spatiotemporal analysis. The interviews and surveys reveal that people have had positive experiences with open data. They view the idea of an open aerial repository as an advantageous undertaking. There is interest in OAM and people seem interested in seeing how it continues to develop.

Data quality is a key consideration, especially in regards to the future use of the imagery shared on OAM. Both the interviewees and some of the survey respondents point out that accuracy and availability seem to them to be the most significant issues regarding user-contributed open aerial imagery. As of right now, OAM cannot guarantee image quality may prevent it from being used in business or research as reliable data. Data quality is not an insurmountable challenge, however. Overall, drone imagery tends to be of high resolution and sufficient accuracy thanks to the camera, GPS and stabilization technologies with which drones tend to be equipped with. In addition to that, some uses do not require very high accuracy; they rely more on what the aerial images present versus on pinpointing the exact location of the features presented in those images. Higher numbers of imagery will also aid in ensuring quality, as they will allow users to compare imagery. There are also tactics that can be implemented to confirm data quality and accuracy. Community surveillance and control can be one way to ensure the quality control of the images on OAM. Future research in this area would be constructive in determining not only what could be the most effective measures to safeguard data quality, but also in looking at how volunteered image quality compares to authoritative aerial imagery. That would allow users to have a better awareness of the strengths and weaknesses of the data, allowing them to use the data with more confidence.

Finally there is the issue of privacy and security. Privacy is one of the most important aspects relating to having open aerial imagery that needs to be addressed. This research has not uncovered any current issues in this regard. Since OAM is still in an early stage of development and it does not yet feature a high number of images, it is hard to predict the effect such an aerial repository will have on privacy. Nevertheless, as pointed out by the interviewees and survey respondents, privacy is an issue that is likely to arise with a high amount of extremely high resolution imagery. As OAM continues to amass more and more imagery, the issue of privacy will certainly need to be addressed. It would be beneficial to look at how aerial imagery affects various levels of privacy and whom it would affect most severely. Based on that knowledge, recommendations could then be made as to how the negative effects can be effectively mitigated.

While OAM remains limited for now due to the relatively low number of images, nevertheless, people have found it a useful platform for sharing georeferenced images. This lack of data is actually what seems to be the largest constraints on OAM right now. If OAM is to continue to successfully grow and remain a sustainable project for years to come, social media can be an influential platform to spread this awareness of the benefits and advantages presented by OAM. It can also help attract more contributors as most people now have some type of contact with social media, be that Twitter, Facebook, Instagram or another platform for connecting people online. Right now, the current status of OAM as well as its future is unclear due to the lack of any new information on what is happening or being planned in regards to the continued development of OAM. The first key step would be to remedy that situation by releasing updates on the OAM blog or Twitter page regarding future plans for OAM. The next step could be to continue making OAM more accessible and attractive both to drone enthusiasts as well as those to whom aerial data is of interest in terms of their work. The larger a repository like OAM will grow, the more people it will have the potential to attract, allowing it to further evolve and remain sustainable for future years.

TRANSITION

Chapter 2 presents a background and overview of OAM. This chapter discusses all 5 interviews as well as answers to select survey questions (questions 1, 2, 6, 9 and 10). It also looks at a select number of drone images from OAM. The purpose of Chapter 2 is to tackle the first 3 objectives of this research project:

1. Determine the advantages of an open aerial image repository featuring volunteered aerial imagery through an evaluation of OAM.
2. Consider how volunteered drone imagery compares in terms of resolution and recentness to free satellite imagery from Google and Bing.
3. Identify the barriers and constraints that may hinder the continued development and use of an open aerial repository like OAM.

The aim of Chapter 3 is to examine the above objectives through the lens of archaeology as well as address the remaining objective:

4. Assess how the imagery from OAM may be applied in archaeology by looking at both the benefits and risks it carries in terms of archaeological work and heritage sites.

Chapter 3 focuses specifically on the potential OAM presents in terms of archaeological work. It presents one of the possible uses of open drone data by looking at its applicability in archaeology. To do so, it uses the all the answers gathered through the online survey responses. It also looks at drone imagery from OAM that presents an archaeologically significant feature. Combined, Chapters 2 and 3 fulfill the research goals of assessing the benefits and challenges of volunteered drone imagery through an examination of OAM.

CHAPTER 3: VOLUNTEERED AERIAL IMAGERY IN ARCHAEOLOGY

3.1 Introduction

Location plays a key role in archaeology. The spatial organization of artifacts and archaeological features can reveal a great deal of information regarding a past society. On a small scale, location can be important in understanding the use of space, the social organization, and the social structure of a society. On a larger scale, it is an important aspect in considering, for example, ancient land-use or migration patterns. Spatial analysis is significant in discovering how people organized space (Clark, 2017). In this regard, aerial imagery is extremely beneficial in archaeological work and research in terms of the spatial analysis of archaeological sites. It has been used in archaeology for site discovery, site monitoring, documentation, conservation and site monitoring (Ciminale, Gallo, Lasaponara, & Masini, 2009; Elfadaly, et al., 2017). Aerial photographs are able to record the landscape in greater detail than any ground survey is able to do (St.Joseph, 1945). They offer the ability to capture the whole site. They can also be used to capture the whole region where a site may be located, allowing archaeologists to perform broad-scale analyses of ancient road networks, for example. They can be a source of quantitative information, offering archaeologists a means to identify and assess either the archaeological sites themselves or the damages to those sites (Contreras & Brodie, 2010). They can support archaeological investigations of fragile landscapes, such as those affected by degradation or pollution (Lasaponara, Yang, Chen, Li, & Masini, 2008). They can also support cultural heritage management, which goes beyond academic research and focuses on protecting monuments and archaeological heritage for future generations (Wernke, et al., 2016). Human activities, particularly in the modern era of mechanization and urbanization, have severely impacted many archaeological sites (Lasaponara, Yang, Chen, Li, & Masini, 2008). The possession of historical aerial imagery could thus provide valuable information that can no longer be obtained from sites that have been affected by these processes.

The importance of possessing an aerial image library or repository was realized quite early on. Already in 1945, Sir George Clerk, the president of the Royal Geographical Society at the time, said that he hopes one day Britain will possess “the fullest and most complete” library of aerial photographs that it is possible to achieve (Clerk & Richmond, 1945, p. 60). He added that it is also important that this collection of aerial photographs be easily accessible (Clerk & Richmond, 1945). Historically, archaeology has often depended on historical data that was acquired by others for various other purposes (Snow, et al., 2006). Now crowdsourcing offers a way to assist archaeology in obtaining geospatial data such as aerial imagery, while open data repositories allow this data to be shared (McCoy, 2017). Together with the advantages offered by Web 2.0 and drone technologies, they offer the potential to create the "most complete" library of aerial imagery which Sir George Clerk hoped for back in 1945.

The following research paper aims to delineate how the development of an open aerial repository, like OpenAerialMap (OAM), may be advantageous in archaeological work by:

1. examining the benefits crowdsourced aerial imagery to the field of archaeology
2. identifying the challenges and risks that open aerial imagery pose to archaeology.

Though there has been some research done on the use of open satellite imagery in archaeology, there seems to be no existing literature regarding the utility of open image repositories. Thus, this research attempts to investigate this topic by looking into the existing literature on the use of aerial imagery in archaeology; examining currently available open image repositories; as well as collecting user opinions in order to assess the views of the archaeological community regarding the use of open image repositories in archaeology.

3.2 Literature Review

3.2.1 Aerial Archaeology

Aerial photography was the first remote sensing technique to be applied in archaeology (Lasaponara, Yang, Chen, Li, & Masini, 2008). It has been used for visualization purposes, to help understand the landscape by viewing its entirety from above. It aided archaeological discoveries by revealing features that were too large or indistinguishable from ground level. It allowed archaeologists to use crop, soil, frost or shadow marks to find buried sites. It has been used to survey, record and map archaeological sites. More recently, archaeologists have also been able to employ aerial photographs in monitoring sites and tracking looting. Early aerial photographs made it clear to archaeologists that the new vantage point they offer can lead to new discoveries even in well-known sites (St.Joseph, 1945). Aerial images draw attention to the details of form and site structure; they emphasize any outstanding features in terms of its form and shape (St.Joseph, 1945). Though most of these early aerial images were taken for purposes other than archaeology, they could still be useful in terms of archaeological discoveries as well as in term of the comparative value they offer (St.Joseph, 1945).

Through the 1970s and into the 1980s, aerial photographs were employed in archaeology primarily in order to solve problems or answer research questions (Raczkowski W. , 1999). In Italy, Prof. Giulio Schmiedt relied on aerial photography in his archaeological research on ancient city-ports in Italy (Liritzis, Miserlis, & Rigopoulos, 1983). In the United States, aerial photographs of the archaeological mounds at Cahokia were used to reconstruct the archaeological site and locate underground features (Fowler, 1977). Harp (1977) used aerial photography to discover archaeological sites in the Arctic. A study in Greece employed aerial photography in an attempt to determine the reasons that may have led to various ancient Greek towns being established in particular locations (Liritzis et al, 1983).

In the past, resolution was one of the main issues faced by archaeologist using aerial photography. For example, for the Arctic region, Canada only possessed imagery at a scale of 1:30,000 and 1:60,000, which was too small scale for discovering archaeological sites left behind by hunter-gatherer sites in the Arctic regions (Harp, 1977). In the 1980s, satellite data from the Landsat Thematic Mapper (TM) began to be employed in archaeological research, though 30m resolution was the highest resolution available (Lasaponara, Yang, Chen, Li, & Masini, 2008). Despite the fact that a 30m resolution is much lower than what can be obtained nowadays, it was still useful in landscape archaeology (Lasaponara, Yang, Chen, Li, & Masini, 2008). It was used at a regional scale to detect archaeological sites, to trace ancient road networks as well as to observe changes in ancient river courses over time (Clemens, 2008; Lambers & Remondino, 2008). Satellite images at this resolution were also useful in aiding archaeologists in documenting and measuring the scale of looting that befalls archaeological sites (Contreras & Brodie, 2010).

In the 1990s, after the satellite imagery from the American Corona satellite program was declassified, the images proved to be quite useful to archaeologists studying the Middle East regions in terms of identifying the changes occurring in areas rich in cultural resources as well as discovering unknown sites (Lasaponara, Yang, Chen, Li, & Masini, 2008). The early images from the early 1960s had a maximum resolution of 7 to 10m, which limits their usability, but the later images featured a higher resolution of around 2m (Hammer et al, 2018; Lasaponara et al, 2008). The use of Corona satellite imagery in archaeological research grew particularly between 2000 and 2010, when numerous archaeological studies were conducted using this imagery (Lasaponara, Yang, Chen, Li, & Masini, 2008). Archaeologists made an extensive use of the Corona imagery, which was collected primarily in the 1960s and 1970s, in order to acquire or recover information regarding areas of archaeological interest that are now degraded or built over (Lasaponara, Yang, Chen, Li, & Masini, 2008). Despite its age, Corona imagery continues to be used in archaeology even in recent years as it can be easily obtained for free on the USGS Earth Explorer website [https://earthexplorer.usgs.gov] as well as on the Corona Atlas & Referencing System website hosted by the University of Arkansas [https://corona.cast.uark.edu] (Lasaponara, Yang, Chen, Li, & Masini, 2008). It is used for various spatial analyses that are done for archaeological research or for looking at regions which present archaeologists with too many difficulties to collect aerial data themselves (Lasaponara, Yang, Chen, Li, & Masini, 2008).

In the 2000s, Elizabeth Stone demonstrated the utility of satellite imagery by using them in her research evaluating the extent to which looting is affecting archaeological sites in Iraq (Contreras & Brodie, 2010; Stone E. , 2008). Based on the study of DigitalGlobe satellite imagery, she was able to determine that the area of looting holes in Iraq total to around 6 square miles, which is an area around a hundred times larger than that which has been excavated by archaeologists (Stone E. , 2008). Snow was thus able to use aerial imagery to highlight the magnitude of site looting, to track looting patterns over time and space, and to reveal the severity of this issue in conflict-stricken countries like Iraq (Stone E. , 2008). Similar studies using aerial imagery were performed by Carrie Hritz, Contreras and Brodie (2010), as well as Hammer et al (2018), who used satellite imagery to try to analyze the problem of looting that plagues archaeological sites in various Near Eastern regions.

3.2.2 Archaeology and Open Aerial Imagery

Free access to satellite imagery began expanding with the launch of Google Earth in 2005, though it took years before there were high-resolution images available for the entire world (Hammer, Seifried, Franklin, & Lauricella, 2018). Now, among other free sources of aerial imagery there is the European Space Agency (ESA) Sentinel data, Landsat TM, NASA Earthdata Search. The recent years have seen a growth in open image repositories that allow volunteers to contribute aerial imagery. Drones are giving ordinary citizens the ability to collect aerial imagery, which they can then share online on open data repositories like OpenAerialMap.

Despite the challenges that are facing the continued growth and evolution of volunteered open aerial imagery, it offers a large potential in terms of the benefits it could bring to various sectors, such as disaster and environmental management, business and academia. One of the areas which could particularly benefit from open drone image repositories could be archaeology. Aerial photography has long been used in archaeology to document cultural heritage and excavation sites. The traditional methods of gathering using aircraft or satellite sensors are expensive and often require expert knowledge in order to be collected; therefore, the high resolution images that can be collected by drones provide a much less expensive alternative of collecting aerial imagery (Themistocleous, 2017). Having available drone imagery will be useful for sites that may be inaccessible or remote sites as well as for documenting sites that may be at risk of being destroyed as a result of conflicts or natural disasters. Using aerial photographs collected by volunteers would even further reduce the costs associated with archaeological work and preservation of culturally significant sites. Employing ordinary citizens to aid in archaeological work is not a new idea for the field of archaeology, as citizen science projects have already made significant contributions to archaeology in the past (Mazumdar et al, 2017; UNESCO World Heritage Centre, 2019). Repositories of open aerial data collected by citizens would allow archaeologist and enthusiasts from all around the world to find, view and study various archaeological or culturally significant sites. Crowdsourced aerial imagery can not only serve in documenting a given site, but can also be used by archaeologists over time to monitor cultural heritage sites (Themistocleous, 2017; Sylaiou et al, 2013). A study done by Themistocleous (2017) looks at how crowdsourced or openly available images can be useful in archaeology to digitally reconstruct and create 3D models of archaeological features and sites. It did so by employing open data and a range of imaging techniques to create 3D models of landscape features that could be viewed using Google Earth (Themistocleous, 2017). As this study focused primarily on the technological aspects of using open aerial images for archaeological reconstruction and its feasibility, it would be constructive to delve further into the issue and research other benefits and challenges that open aerial imagery presents, such as in terms of data quality and accuracy as well as in terms of data protection and security.

Free aerial imagery, such as that provided by Google Earth, has already proved useful in a number of archaeological studies. The main advantages of Google Earth is that is it free, easy to use, and accessible, as it offers the ability to be launched as a web, mobile and desktop application (Myers, 2010). A study by Thomas et al (2008) used the imagery available on Google Earth to document and create updated maps of archaeological sites in Afghanistan. Since 1979, large areas of Afghanistan have become unsafe for archaeologists to conduct fieldwork (Thomas et al, 2008). Thomas et al (2008), therefore, employed aerial imagery to conduct a form of "remote research," which allowed him to both advance the knowledge of important sites in Afghanistan as well as discover previously unknown sites. The main issue that this study ran into was in regards to georectifying the Google Earth satellite imagery, particularly in mountainous regions. Another study that employed Google Earth was done by Contreras and Brodie (2010), who investigated the possibility of exclusively using free or open satellite imagery to identify signs of looting and site destruction. Contreras and Brodie (2010) looked at Jordan, where the uncertainty as to the scale of looting was exacerbated by the fact that most aerial photographs taken for archaeological purposes focused on archaeological remains that were visible from the air, while looters tended to target cemeteries (Contreras & Brodie, 2010). Satellite imagery, especially free satellite imagery like the one on Google Earth, offers a convenient and affordable solution to this problem (Contreras & Brodie, 2010). The only issue was that though signs of looting could be identified, the resolution for most areas was usually not high enough to allow individual looting pits to be counted (Contreras & Brodie, 2010). The images were, therefore, used primarily to identify signs of looting and marking the extent of visibly disturbed areas (Contreras & Brodie, 2010). Based on ground surveys and site visits at various locations, Contreras and Brodie (2010) were able to verify that the imagery-derived estimates of the looting damages of archaeological sites were reasonably accurate. Despite that, they suspect that the overall low resolution of the satellite imagery available biased the results to underestimate the true extent of site looting occurring in Jordan (Contreras & Brodie, 2010).

While free or open aerial imagery is advantageous, there are criteria that need to be considered if this data is to be incorporated into any type of work or research. The paper by McCoy (2017), which discusses the prospects and issues regarding the use of geospatial Big Data in archaeology, outlines three disciplinary goals which data needs to meet: it needs to be scientific, authentic, and ethical. One of the issues that are outlined is the fact that many geospatial datasets are dependent on users to assess their quality (McCoy, 2017). Another one is that most studies do not publish the underlying geospatial data alongside their research, which means it remains unavailable for others to use (McCoy, 2017). There is also the issue of privacy regarding those archaeological sites whose location is withheld in order to protect them from looting and vandalism (McCoy, 2017). Platforms like Google Earth, which currently provide aerial imagery for the entire world, place more emphasis on free dissemination of information than on privacy (Myers, 2010). Individuals and even governments do not have the choice on how their property or land is shared on Google Earth (Myers, 2010). This may put fragile sites at more risk of being damaged by careless visitors, vandals or looters. On the other hand, access to aerial imagery can be used to fight the looting of heritage sites, such as in Syria and Iraq, where high-resolution satellite imagery was used to evaluate the damages to archaeological sites (Casana, 2015; McCoy, 2017; Stone E. C., 2015). Apart from the study by Contreras and Brodie mentioned above, a more recent study by Casana (2015) used available high-resolution satellite imagery to examine over 1,200 sites. The goal was to uncover the scope and severity of looting across Syria since the armed conflict began in 2011. Aerial imagery was found even more useful than ground surveys at revealing signs of looting, digging and construction that may have been done on sites (Casana, 2015).

The problem is that though necessary data exists, or has the potential to exist through crowdsourcing, there needs to be a way to access the data (McCoy, 2017). The spread of drone use and other remote sensing technologies is continually increasing the volume of geospatial data that could be available to archaeology (McCoy, 2017). McCoy (2017) notes in his paper that the development of platforms connecting various geospatial datasets currently spread out across the web would be quite valuable in making these datasets more visible and accessible. Though a few archaeological databases do exist, they are only “small oases” in a “data desert” that have the potential to become “data oceans” as the data becomes easier to discover and access (McCoy, 2017).

3.2.3 Open Image Repositories

Open data repositories are platforms that aim to facilitate data access by gathering it together and allowing users to easily search through and access it. OpenAerialMap (OAM) is the main project that is dedicated to sharing open aerial imagery. OAM aims to provide a straightforward means for allowing various users to share aerial imagery that can then be used for a wide range of purposes. OAM is essentially catalogue of aerial images that are stored on the Open Imagery Network, which allows imagery to be shared online without needing a single site or server to host all the imagery (Chapman, OpenAerialMap: A Distributed Commons for Searching and Hosting Free Imagery, 2015; Open Imagery Network). It also makes all the collected aerial imagery available on OpenStreetMap (OSM). In addition to making imagery more accessible, OAM provides a free tool, the OpenAerialMap QGIS plugin, which can aid in analyzing the aerial imagery from OAM. This plugin enables OAM aerial imagery to be directly accessed on the free desktop GIS software QGIS. Using this plugin, users can relatively easily upload, search, and download aerial imagery from OAM (Humanitarian OSM Team, 2018). It can be useful in streamlining the image analysis process as one would not need to search for and download the imagery off OAM beforehand.

Mapillary is another open image repository; however, unlike OAM, it facilitates access to volunteered street-level imagery and map data (About us). Users contribute, view, and download the imagery shared on Mapillary either as individuals or as part of an organization. Mapillary is also capable of extracting map data, such as traffic signs, from the uploaded imagery. Unlike OAM, Mapillary images are licenced under the CC BY-SA 4.0, which still allows them to be shared and adapted for any purposes as long as appropriate credit is given, but they can be distributed only under the same share alike license as the original image.

OpenTopography is another open data repository that facilitates community access to free high-resolution topographic data. It is a National Science Foundation Earth Sciences funded data facility. It allows users to share aerial imagery in addition to LIDAR and point cloud data in the OpenTopography Community Dataspace. This community repository is geared towards allowing users to share small to moderate sized topographic datasets that are created using LIDAR or photogrammetry.

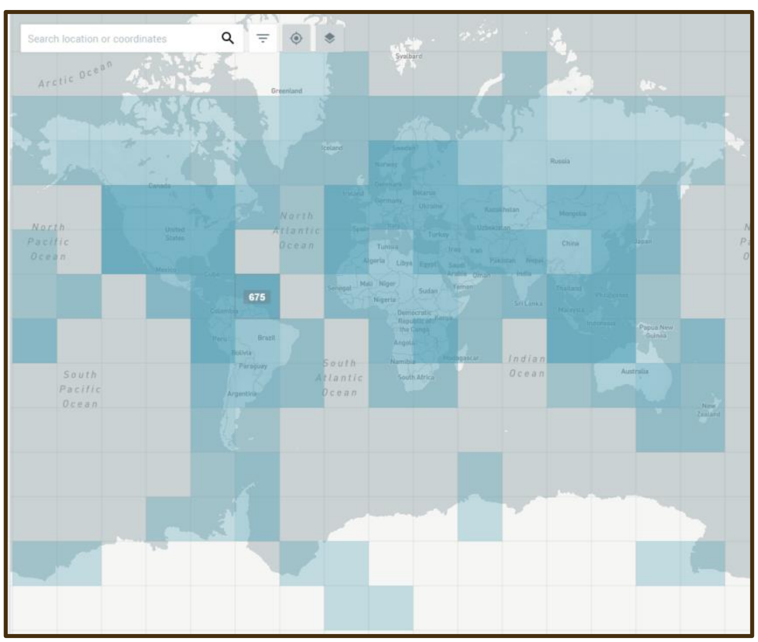


Figure 3.1: OAM explorer map illustrating aerial image availability by area – the darker the grid square the more available imagery there is. The clear grid squares indicate a lack of any aerial imagery for that particular area.

3.3 Research Methods / Methodology

The initial intent was to collect data through conducting semi-structured interviews with experts in the field of aerial archaeology as well as individuals involved in archaeological projects involving crowdsourcing. 10 invitations were sent out to academics who were found to be involved in aerial archaeology. This approach turned out to be unsuccessful as there were no replies to the interview invitation or to the follow-up letters. As an alternative way to collect necessary data, the interview questions were modified into a survey, which is presented in Appendix C. The survey consisted of 4 multiple choice questions and 9 open-ended or follow-up questions. The number of questions in the survey was limited so that the survey would not take more than 20 to 30 minutes to complete. The intent was to gather some empirical evidence to judge whether the archaeological community would be interested and willing to use OAM. Respondents were questioned regarding their knowledge and experiences of open data as well as what barriers they foresee in terms of creating and sharing aerial data online. This survey was distributed online using Qualtirics Insight Platform in accordance with the guidelines provided by the University of Waterloo's Office of Research Ethics. The link to the survey was shared on public Facebook groups concerned with archaeology: Archaeological Aerial Photography (over 1,000 members), Canadian Archaeological Exchange (over 2,800 members), and Archaeology (over 7,500 members). No other groups or websites outside of Facebook were found that would be suitable for sharing the survey. The survey responses were collected over a period of 5 days, from December 14, 2018 to December 19, 2018. This short time frame was due in partly to the time constraints of the project as well as due to the fact that the survey was generating a very high number of spam responses. Over 500 of the submitted survey were just spam – they contained answers composed of a nonsensical array of letters. Using the Data and Analysis tab on Qualtrics, these results were filtered out and the surveys deleted. There were also incomplete surveys composed of vague, one-word answers that did not really answer the questions provided. For this reason, surveys that had featured less than 3 of the textbox answer questions or which contained only one-word answers to these questions were removed. After filtering the survey responses, the resulting data pool consisted of 45 responses.

In addition to the survey responses, an examination was made of the aerial imagery available on OAM. The goal was to compare drone imagery with accessible satellite imagery, such as that found on Google Earth and Bing. Unfortunately, it was not feasible to do a thorough search of all the drone imagery found on OAM, not only due to the amount of imagery on OAM, but primarily due to the search restrictions. There is no option to search data by platform type or apply a filter on the OAM explorer that would show which areas have drone imagery available. It is also not possible to search images by cultural landmarks or sites they might feature, such as castles, ruins, etc. As of the beginning of 2019, OAM only offers the option to search images by location or coordinates as well as filter images by resolution or date added. Images can also be found through the OAM explorer, illustrated in Figure 3.1, which consists of a square grid overlaid on a world map. Using the explorer and resolution filter, a convenience random sampling method was used to find 3 aerial images showing heritage sites that could be used to assess whether OAM shows potential to be employed for archaeological purposes.

3.4 Results

3.4.1 Open Aerial Map

As illustrated by Figure 3.2, the last two years have seen a significant rise in the amount of aerial images on OAM as both the number of providers and images shared on OAM has more than tripled. As of April 2019, OAM had 339 contributors sharing around 9,522 images (HOT partners and Community). A month later, in May 2019, this number was already at 9,600 images. Thus both the Humanitarian Innovation Fund Final Report from 2018 and a current observation of OAM demonstrate that – at least as of 2019 – it is a successfully growing project.

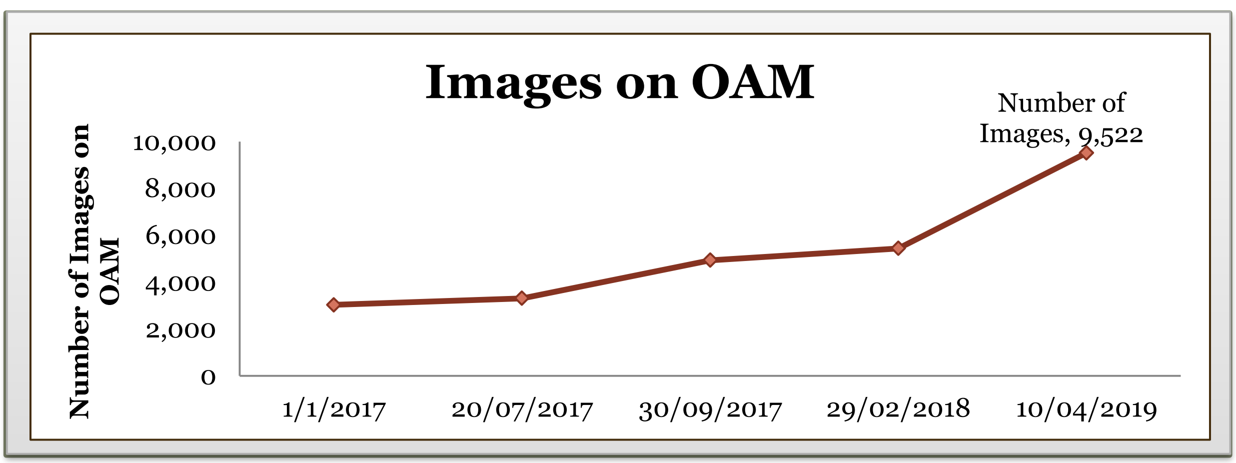


Figure 3.2: Number of images on OAM based on the Humanitarian Innovation Fund Final Report from 2018 and OAM status as of April 10, 2019.

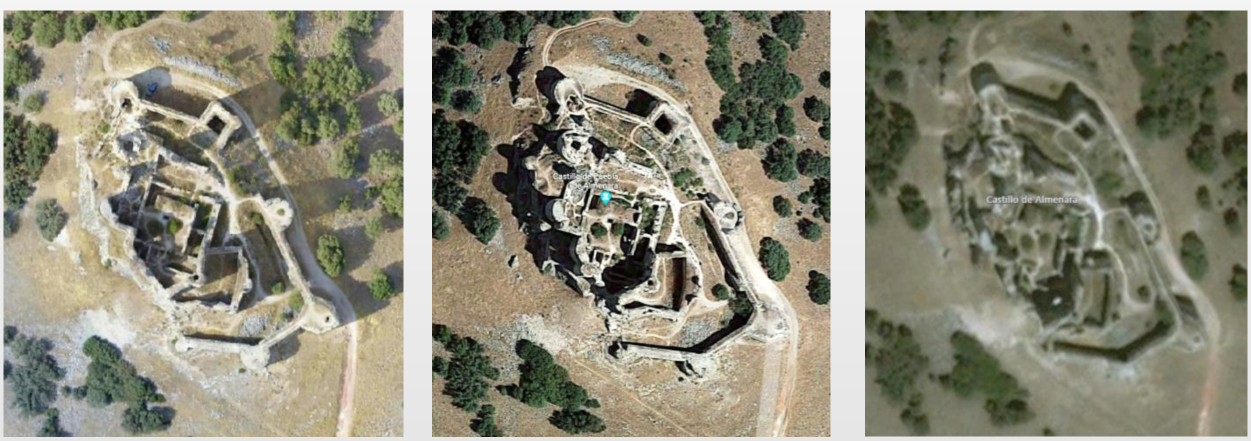
Though OAM does not yet support searching for imagery based on features or landmarks, such as cultural heritage sites, it is possible to find drone imagery of cultural heritage sites by manually looking through the available imagery as shown by the examples in Figures 3.3, 3.4 and 3.5. All three figures show high resolution drone images of heritage features that were shared on OAM. Alongside the images from OAM, the figures also show corresponding imagery from Google Earth and Bing maps. The images were assessed based on resolution, since high resolution is imperative for using the imagery in archaeology. In each instance, the images from OAM are superior to the satellites images in terms of resolution. The only exception is Figure 3.5, where the OAM image is close in resolution to the image from Google Earth; however, that is only because Google earth displays an image from the National Geographic Information Center in Spain versus the Digital Globe or HERE satellite imagery that it typically shows. Regardless, OAM still possesses the advantage of allowing each image to be downloaded and analyzed in QGIS or any other GIS software, unlike the Google or Bing images which are copyrighted and only viewable online.

Date: *2017-12-24*	Date: *unknown*	Date: *unknown*
Resolution: *2 cm*	Resolution: *unknown*	Resolution: *unknown*
Provider: *Sergey Kadomsky*	Provider: *Google Earth*	Provider: *Bing*
Sensor: *DJI Mavic Pro*	Sensor: *Digital Globe*	Sensor: *Digital Globe*
https://tiles.openaerialmap.org/5a40ed372553e6000ce5ab21/0/51e1788a-dc44-4704-8eae-e9dd41bfc10a/{z}/{x}/{y}.png		

Figure 3.3: Comparison of 3 images (from OAM, Google Earth and Bing) illustrating the Mir Castle Complex located in Mir, Belarus.

Date: *2017-09-12*	Date: *unknown*	Date: *unknown*
Resolution: *7 cm*	Resolution: *unknown*	Resolution: *unknown*
Provider: *Vitali Danilovich*	Provider: *Google Earth*	Provider: *Bing*
Sensor: *DJI Mavic Pro*	Sensor: *Digital Globe*	Sensor: *Digital Globe*

Figure 3.4: Comparison of 3 images (from OAM, Google Earth and Bing) illustrating the "Red Mill" in Losycki(Loshitskiy) Park, Minsk, Belarus.



Date: *2018-05-06*	Date: *unknown*	Date: *unknown*
Resolution: *2 cm*	Resolution: *unknown*	Resolution: *unknown*
Provider: *Aeracoop*	Provider: *Google Earth*	Provider: *Bing*
Sensor: *DJI Mavic Pro*	Sensor: *Instituto Geográfico Nacional*	Sensor: *Digital Globe, HERE*

Figure 3.5: Comparison of 3 images (from OAM, Google Earth and Bing) illustrating Castillo de Puebla de Almenara in Spain.

3.4.2 Survey Respondents

There were a total of 45 respondents to the online survey. All respondents seemed to be primarily from the US and Canada. They indicated having varying levels of experience in regards to using open data or open aerial imagery - some respondents indicated having a few years of experience, while others admitted having little practical experience. From the respondents with experience using open aerial imagery, some acknowledged having used it for research while others used it for archeological work such as excavations and surveys. There was one respondent in particular who specifically mentioned having used Open Aerial Map imagery.

Regarding the use of open aerial data in archaeology, 34 respondents were aware of instances where open aerial data had been employed. These respondents listed surveys, cultural resource management (CRM) reports, site discovery, research and 3D site modelling as some of the instances where open aerial data was employed. Of the 11 respondents who were not aware of any instances where open aerial imagery was used in archaeology, 8 respondents answered that they could foresee open aerial imagery being useful in archaeology, particularly in terms of locating sites, site surveys and providing a broader access to data.

Table 3.1: Table illustrating the responses gained from three of the multiple choice survey questions regarding user experience with open data and archaeology.

What is your experience in regards to open data, and specifically, open aerial imagery?	Positive experience (40)	Some experience (5)	Negative experience (0)	
Are you aware of any instances where open aerial data is used in archaeology?	Yes (34)	No (10)		
How valuable is data accuracy and precision in archaeology?	Extremely important (16)	Very important (25)	Moderately important (2)	Slightly important (1)

3.4.3 Benefits of Open Aerial Image Repositories

As presented in Table 3.1, all 45 respondents expressed having a positive experience in regards to open' data and open aerial imagery. The top reasons were the fact that open data is free as well as convenient and easy to use. A few individuals found it very useful in conducting research. A respondent wrote that "The use of such data is an extremely valuable part of the archaeological research process." In total, 4 respondents stated using it for research while 3 others used it for archaeological work. One of these respondents revealed the he was able to use open aerial data in conducting a land survey related to his work in CRM archaeology. He clarified that "We use them [aerial imagery] in CRM to show land use pattern over time and to plan survey." Looking ahead at possible real-world applications of volunteered open aerial data, 13 respondents mentioned archaeology alongside other applications such as VR, disaster relief, prospecting, and GIS.

As illustrated by Table 3.1, the majority of the respondents (41) agreed that data accuracy and precision were either extremely important (16) or very important (25). Only 1 respondent thought that data accuracy and precision was of slight importance to archaeology and, not surprisingly, no one thought that accuracy and precision were of no importance. As explained by a respondent, "Accuracy and precision is of great importance in archaeology because it allows us to create high-resolution maps. It allows us to create accurate/precise elevation datasets, topographic maps, hill shading, and hydrography maps that match the terrain." A different respondent pointed out that archaeologists "make claims about the past based on the data we collect. We also make decisions about where to survey and what survey results mean based on the accuracy of our data." Data inaccuracies can lead to the wrong conclusions and decisions being made.

3.4.4 Risks of Open Aerial Image Repositories

Openly sharing any data naturally brings with it some risks in terms of that data being misused. The question is whether those risks are low or high, and whether the benefits outweigh the risks. In the case of archaeology, this misuse of aerial data can result in archaeological work being impeded in various ways, for example through site vandalism or looting. As illustrated in Table 3.2, a majority of the respondents (33) were concerned that open aerial imagery either might or will impede archaeological work. At least in 15 cases, the concern lay in the fact that having aerial data openly available may facilitate archaeological looting by revealing site locations. As pointed out by a respondent, when thinking of the negative impacts relating to archaeology, "the quickest one that came to mind: looting and destruction of archaeological sites. There are "artifact hunters" out there who increasingly understand and using online open source resources to survey archaeological sites to pinpoint where they will find "treasure."". He explained that, in his experience, “With the patterns of humans seeking 'fun adventures' […] an open image repository may likely end up being a 'treasure map' for those young adventure seekers. They may vandalize the archaeological area (some cases like this exist, not from aerial data, but simply from sharing information […] that archaeologists are digging into the past in certain areas).” Another respondent stated that with open aerial repositories “certain members of the public with nefarious motivations (e.g., looting) could have more access to sensitive information about archaeological sites.” On the other hand, one respondent wrote that while he too sees exposing archaeological sites as a potential risk, he is not sure whether this risk is any higher than the one presented by Google Earth or Bing Maps.

Opinions were divided as to whether the risks posed by open aerial repositories might outweigh the benefits. While 19 respondents thought that the risks might outweigh the benefits, 14 thought that risks are greater. The remaining quarter of respondents (11), were unsure whether or not the risk have potential to outweigh the benefits. The reason some respondents were cautious regarding open data were due to the cost of data storage, issues around data accessibility, and the risks it might pose to archaeological work. Others were confident the benefits would outweigh the risks thanks to advancing technology and the financial advantages it can provide. One respondent seemed confident that the “risk may exist at the beginning, but as the technology matures, this is not a big risk.” Another respondent emphasized that, despite the risks, open aerial repositories provide “greater access to data [and] increased potential to find and better understand sites.”

Table 3.2: Survey responses regarding the benefits and limitations of open aerial imagery.

In your experience, how does the quality and quantity of volunteered imagery compare to data collected through traditional means (satellites, etc.)?	Better (30)	Equal (4)	Worse (4)	Uncertain (6) Valuable regardless of the quality (1)
Might it have the potential to impede archaeological work?	Yes (19)	Maybe (11)	No (14)	
Might the risks or negative effects of image repositories have the potential to outweigh the benefits?	Yes (19)	Maybe (11)	No (14)	

3.5 Discussion

3.5.1 Data Quality

The issues that persist in regards to free aerial imagery online are mainly related to the coverage, resolution and surface visibility of the aerial data available online (Contreras & Brodie, 2010). The drone imagery on OAM has potential to offset this limitation by providing access to very high resolution drone imagery. The main concern is that these drone images need to be accompanied by accurate data, including, but not limited to, accurate geographic coordinates. As stated by one of the respondents, accuracy and precision is important as it not only allows the creation of high-resolution maps, but it is necessary for the creation of accurate datasets that can be layered or combined with other types of spatial data. One respondent wrote that "the lack of quality control [...] can have a severe effect on the quality of volunteered imagery. [...] One must be cognizant of the limitations of this type of data when incorporating it into one's analysis." The main limitation lies in the nature of volunteered aerial imagery. It is a community-driven process and so it is not controlled by a single authority, which would guarantee the users quality and reliability.

The technology and camera sensors that many drones are equipped with are a great aid in ensuring the accuracy and precision of the collected data, provided the drone user knows how to take advantage of them. The accuracy of drone imagery is demonstrated by the high quality UAV images that can be found on OAM, three of which are illustrated in Figures 3.3, 3.4 and 3.5. One of the respondents, who had experience collecting drone imagery, confirmed that "a lot of aerial imagery accuracy relies on the current technologies and camera sensors that we use. That said, our current technology does a fairly good job, if the user is trained properly on how to exploit such technologies with high accuracy." Any remaining uncertainties regarding data quality that go beyond image resolution could be resolved by requiring a quality report to accompany the usual metadata that comes with the data (McCoy, 2017). Also, as mentioned another respondent, analysis and comparison of aerial images can also be used to ensure reliability.

3.5.2 Resolution

The study by Ciminale et al (2009) mentions that some of the factors that play a role whether an image can be used for site identification are: image resolution, ground characteristics, the time of year as well as the lighting and cloud cover. Resolution is an important aspect of image quality (Contreras & Brodie, 2010). In order for the images to be useful, the ground needs to be unobscured by things like cloud cover and the image resolution needs to be high enough to allow identification of ground features. Most available satellite imagery does not offer resolution as high as good quality aerial photographs (Contreras & Brodie, 2010). Images of low resolution can result in misidentification, such as in the case of Contreras and Brodie (2010) where two areas which were mistakenly identified as damaged by looting. This misidentification was revealed by site visits that were done afterwards to test the accuracy of the site evaluations that were founded on aerial imagery. Based on their research, Contreras and Brodie (2010) opt for a minimum resolution of at least one meter per pixel as best for successfully identifying looting or other site damages. The drone images on OAM far exceed that minimum. Modern technology allows drones to be equipped with relatively high resolution cameras and sensors. As a result, most drone images on OAM have a resolution of about 6 or 7 cm per pixel. Not surprisingly, therefore, 7 of the survey respondents mentioned that image clarity or resolution was one of the key advantages they saw in volunteered drone imagery. They believed drone imagery as being capable of producing higher resolution imagery than satellite imagery. This is also illustrated by the drone imagery available on OAM. As seen in the examples presented in Figures 3.3 and 3.4, the volunteered drone images have better resolution and quality than the free satellite imagery on Google Earth or Bing. It also features more detailed information, such as regarding the exact date the photos were taken.

3.5.3 Benefits of OAM for Archaeology

Historically, the cost of obtaining aerial images was relatively high, especially for regional scale projects (Contreras & Brodie, 2010). As of 2010, IKONOS or QuickBird satellite imagery, which came at a resolution of 60cm, cost $250 per square kilometer (Contreras & Brodie, 2010). Now, with more and more data becoming openly available online, cost is no longer an obstacle. This was also noted by a few of the survey respondents, who saw cost as one of the key benefits or advantages of volunteered aerial imagery. One respondent in particular explained that archaeologists “are always at the mercy to whoever funds us. And, we know how that goes.” There is a multitude of archaeological sites, which naturally leads to certain sites being prioritized over others. Whoever provides the funding will have the most say in choosing which sites to excavate. Limited funding can also restrict the scale of archaeological research. As a result, neglected sites may be subject to deterioration or destruction due to neglect. Aspects of cultural heritage may become irreversibly lost.

Producing digital records of archaeological heritage quickly, cheaply and relatively easily is a big advantage can be a big aid in conserving heritage and ancient sites. It is no surprise, therefore, that open data repositories appear to be a positive endeavour. One respondent pointed out that "the ability to quickly and easily obtain high-resolution aerial imagery will form an important starting point to spatial analysis and data management in archaeology." The free imagery on Google Earth has already proven useful to archaeologists in discovering large scale sites within a matter of hours instead of years as with traditional ground surveys (Thakuria, Padhan, Mohanty, & Smith, 2013). Non-commercial satellite imagery does not offer a high enough resolution to allow the detection of significant but less noticeable features (Wernke, et al., 2016). For example, in Peru, the ancient Inca Road stretches over distance of over 3,000 km, which makes it unfeasible to map the entire road network by survey (Wernke, et al., 2016). Drones offer a suitable alternative. Three of the survey respondents wrote that volunteered drone imagery can make up for the shortcomings of satellite imagery, which might not be able to capture certain areas that might have some archaeological significance. Another respondent wrote that having an open access repository of aerial imagery will aid in gathering data for areas where aerial data itself or access to aerial imagery may be currently limited.

An additional aspect worth considering is that the volunteered aerial imagery on OAM is shared under an open license, unlike Google or Bing satellite imagery, which is copyrighted. Another significant limitation of Google Earth is that it does not allow an analysis of imagery over time (Contreras & Brodie, 2010). Google Earth Pro does offer access to historic data; however, the range of historic imagery is once again limited due to the amount of storage space that would be required (Lazzari, 2019). For areas that do have historic imagery available, Google Earth Pro offers a time lapse tool that can be used to view landscape changes over time. An open data repository like OAM has the ability to potentially retain all historic data. OAM would be able to offer access to historic data, since it would not be replacing old aerial images with new ones. Instead, all the imagery would be available to view and download, making it easier to analyze and compare land changes over time. In addition to that, the images themselves might become useful records for archaeologists to use in the future. One of the respondents pointed out that these images of "change over time will also be an important historical record.

[...] Those of us who seek images from the early past, [...] understand the value of creating images and how they will be useful to future generations." He gave an example that "in the context of humans, we can see our material culture growth over time. We can see and analyze patterns of how fast humans populate an area and build structures. With a massive open aerial imagery database, we can even see the evolution of structures over time." If successful, therefore, OAM can prove to be a valuable data source for future archaeologists to use in their work and research.

3.5.4 Citizen Engagement in Archaeology

McCoy (2017) sees online access to archaeological data in an optimistic light and argues that big data or open data will bring about three key benefits to archaeology: data access, ethics, and a broader citizen engagement. Having access to high resolution aerial imagery at no cost will be the key benefit of OAM in terms of archaeology. It will allow archaeologists to easily search and analyse locations of interest before going out into the field. It will aid in determining what locations hold the most archaeological potential or what could be the most promising location in terms of conducting a primary ground survey. One of the respondents confirms this with his experience, where "analyzing aerial imagery is often one of the first steps of the consulting archaeology process." In terms of ethics, archaeologists have a responsibility to publish and share their findings not only with academics, but also with the general public. They need to balance the responsibility to protect archaeological sites with the responsibility towards local traditions and cultures. People have the right to be involved in the preservation of their cultural heritage. Cultural heritage can be a constructive part of people's identity and sense of place and heritage sites can communicate important symbolic meanings (Murzyn-Kupisz & Działek, 2013). Principle No. 4 of the SAA Principles of Archaeological Ethics states that "Archaeologists should reach out to, and participate in cooperative efforts with others interested in the archaeological record with the aim of improving the preservation, protection, and interpretation of the record. In particular, archaeologists should undertake to: 1) enlist public support for the stewardship of the archaeological record […]" (SAA, 1996). According to Smith, there are four primary ways in which archaeological research can do so and also benefit from crowdsourcing: 1) fieldwork using modern technologies (such as mobile phones or drones); 2) search of aerial image collections for site identification and monitoring; 3) crowdfunding; and 4) crowdsourced heritage data entry. There were a number of projects in each category that successfully employ crowdsourcing to further archaeological research, such as the Norfolk Medieval Graffiti Survey in the UK or the VeleHanden project in the Netherlands (Smith M. L., 2014). The study by Lin et al (2014) employed thousands of volunteers in searching through a vast area of high resolution aerial imagery in an attempt to find the tomb of Ghenghis Khan. No descriptions exist of Mongol imperial tombs, which meant that volunteers were just tasked with finding any unnatural or out of ordinary landscape features (Lin, Huynh, Lanckriet, & Barrington, 2014). The Valle of the Khans project allowed participants to register, learn the basics of identifying various features and then earn rakings through a proficiency index based on their contributions (Lin et al, 2014; Smith M. L., 2014). Based on the resulting crowdsourced map, a ground survey was conducted of the top 100 accessible locations. 55 of these locations were determined to have archaeological significance (Lin at al, 2014). Unlike these projects, OAM is not specifically devoted to archaeology. Nevertheless, it provides a platform whereby archaeologists could enlist the support of drone users willing to share aerial imagery of heritage sites or areas which might potentially feature buried archaeological sites. The potential is there, it is just a matter of how to coordinate and plan such crowdsourcing movements.

3.5.5 Drawbacks and Limitations of Open Crowdsourced Imagery for Archaeology

According to respondents, the key challenges of using volunteered aerial data for archaeological research are verification and availability. Image availability is certainly a valid limitation right now in regards to the amount of aerial imagery currently on OAM. Though as illustrated in Figures 3.3, 3.4 and 3.5, it is possible to find some archaeological sites on OAM, there are still too many blank areas on OAM with no drone imagery available. The likelihood of finding imagery for a particular site is slim. Even once there is more imagery on OAM, two respondents mentioned that finding and identifying data that could contribute to existing archaeological collections as well as finding aerial imagery that would be useful for archaeology might be difficult. In regards to accuracy verification, that is always an issue with crowdsourced data. Anyone can contribute data, which means the imagery will be coming both from amateur drone users as well as experts (Coleman, Georgiadou, & Labonte, 2009). Nevertheless, the majority of the survey respondents (34) saw volunteered aerial imagery as being of high quality. This may be thanks to modern drones, which come equipped with technologies ensuring data accuracy, such as GPS, image stabilization, altitude hold and ability to pre-program the desired flight pattern.

In addition to quality, image extent is another significant consideration. Very high resolution (VHR) satellite imagery is capable of being used for identifying large scale cultural features, such as land use patterns and roads (Ciminale et al, 2009). Most drone images, however, might not show such a large extent. This might be limiting to archaeologists interested in a large geographic area. On the other hand, if there is enough drone imagery on OAM, this limitation might be relatively easily overcome by downloading and then stitching the aerial images using appropriate computer software.

One of the respondents with previous experience in collecting and sharing aerial imagery on OAM mentioned current legislation surrounding the operation of UAVs as an important barrier that needs to be taken under consideration. He mentioned that the legislation can present an impediment to the collection of data in many areas. For example, the respondent's university passed a policy banning the use of drones on-campus in order to avoid them being used for malicious purposes. Though the intention was good, the respondent pointed out that such a complete drone ban inhibits aerial data research as it prohibits people (in this case even academics) from using new technologies altogether due to fear that they may be used for harm. The current drone regulations differ widely from country to country, even from place to place. They put a number of restrictions on drone users regarding flight altitude, distance and areas where drones can be flown. This can certainly affect the amount of imagery that will be available from various places – even with an open aerial repository like OAM, aerial data may continue to remain scarce for countries like India, Bangladesh, Egypt, Syria, North Korea and Cuba where flying drones is altogether prohibited.

One of the drawbacks that were expressed in the research was that the dominance of digital archaeological record could impede the interaction with the physical archaeological record and primary data collection (Caraher, 2016; Myers, 2010; Wernke, et al., 2016). As the digital record continues to grow, archaeologists might rely more on the digital records instead of on the sensory experience of archaeological features and artifacts (Wernke, et al., 2016). Research may become predominately done virtually, without coming into contact with the artifacts or the landscape being analyzed. There is a risk that this provides an impersonal perspective that may lead archaeologists to dehumanize the peoples being studied (Myers, 2010). Another drawback of an aerial image repository is that it is very data rich and without labels or landmarks it can be overwhelming and make it hard to know where to look (Contreras & Brodie, 2010). One of the respondents mentioned that combining various aerial images and integrating them with satellite imagery might be a challenge. This could be especially true of archaeologists who might not be experts in GIS.

3.5.6 Open Aerial Imagery and Privacy

Sharing data, especially in the archaeological context, is a balance between privacy, data quality, and the benefits of sharing archaeological findings with the rest of society (McCoy, 2017). This is a difficult matter as, on the one hand, the whole idea of open data is based on the notion that information should not be censored to fit with what someone thinks the rest of the population should or should not have access to; people also have the right to the cultural knowledge that can be offered by archaeological sites. On the other hand though, open imagery of archaeological sites will make their locations more widely known and thus might make them more vulnerable, particularly to looting. This concern was already indicated by a few scholars who worried that using aerial imagery could draw unwanted attention to archaeological site locations (Contreras & Brodie, 2010). Around 11 of the survey respondents also expressed the concern that the looting of archaeological sites may be one of the negative effects of open aerial imagery. Even when publishing research, archaeologists have routinely withheld the location of archaeological sites that were not open to the public for visiting in order to protect these sites (McCoy, 2017). Contreras and Brodie (2010), however, who performed a study examining the extent of looting, did not think that publishing aerial images of the archaeological sites they examined would benefit looters. Based on their findings, they thought that the advantage open aerial imagery brings to those working to protect and monitor archaeological sites and cultural heritage is greater than the opportunities it might provide to looters.

Looting of archaeological sites is an old problem that has been occurring long before aerial imagery was widely available. It can result in the loss of an extensive amount of valuable information and is difficult to prevent (Cunlliffe, 2014). One respondent aptly stated that “we can outweigh the risks if we get funding to protect resources. But, there is no guarantee that clever humans won't find a way to exploit.” Having enough resources is a significant factor in lessening site vulnerability to destruction. Openly accessible imagery might not actually pose a considerable threat to the security or archaeological sites. Google Earth has been offering an aerial view of the world since 2005. There is no literature that would indicate it poses a significant risk to archaeological sites. There are, however, multiple studies that found Google or Bing aerial images useful to their research, such as the study of Contreras and Brodie (2018), Cunlliffe (2014), Hamer et al (2018) and Thakuria et al (2013). As of right now, it is hard to predict what effects on archaeological sites the images from OAM will have. OAM is still in a very early stage of development and does not yet contain a high number of imagery.

The imagery on OAM might end up having little impact on the overall looting rates. On the other hand though, it can certainly be a valuable resource to researchers or those in charge of preserving cultural heritage in monitoring remote sites. Not only will open aerial imagery allow archaeologists to track looting, it will also allow archaeologists to monitor and even predict future damage to sites resulting from other factors such as urban or agricultural expansion, commercial activities like mining, and even military developments (Hammer et al, 2018). The study by Hammer et al (2018) pointed out that the lack of free high-resolution aerial imagery before the launch of Google Earth in 2005 made it difficult to track the destruction to archaeological sites in an affordable manner. Archaeologists had to purchase the necessary satellite imagery or conduct time-intensive field surveys. The benefits that OAM brings by making aerial imagery freely and easily accessible seems to outweigh the potential risks associated with everyone having access to high resolution aerial imagery.

3.6 Conclusion

This research illustrates the advantages in archaeological research that can be gained through an open aerial image repository like OAM. The key benefits it identifies are lower cost, higher resolution, easier data access, and broader citizen engagement in archaeology. Aerial images have a history of use in archaeology. Now, OAM presents archaeologists with the potential of easily obtaining these images for free, from a single online repository. Google Earth has already shown potential in this regard. Previous studies illustrated that free aerial imagery can be advantageous, particularly in terms of remotely monitoring sites. The volunteered drone images on OAM can be even more useful thanks to the extremely high resolution imagery that can be obtained from drones. As of yet, there have been no studies uses of an open aerial repository like OAM in archaeology. OAM is still a growing project, but as more images continue to be shared on OAM, so does OAM’s potential to affect archaeological work.

Currently, the key challenges of employing open aerial imagery in archaeology are image availability, data accuracy and drone legislation. Image availability on OAM is still a significant issue, especially in regards to cultural sites. This can easily change in the nearby future if people continue to contribute data. In order to maintain a high rate of contributions, OAM needs to continue reaching out and informing the public on its progress. It should also incorporate more tools that would facilitate both the uploading and finding of data, making it not only straightforward, but also engaging. Previous studies advocated that geospatial cyberinfrastructure should be allowed to evolve based on the uses and contributions of the community (McCoy, 2017; Snow, et al., 2006). In terms of archaeology, this could include providing more search or tag options so that it would be easier to find archaeological sites. Having more options in terms of the information attached to the imagery can also improve data accuracy. Accuracy is an issue with most crowdsourced data since there is no guarantee that it was collected in an accurate manor or that the associated metadata is correct. According to this research, most of the individuals expressed no concerns with crowdsourced imagery, which the view being of high or good quality. Despite that, looking into methods that would safeguard aerial image quality in the future, as more images continue to be added, will make them a more reliable source of data. It will give them more credibility and allow them to be used in both in research or archaeological excavations.

Another important consideration in regards to the growth of OAM is how such a repository can impact archaeological sites. The idea of open data is great, but it entails the risk that some individuals may use it to cause harm. In terms of archaeology, this could be using the open aerial imagery to locate and then loot or vandalize archaeological sites. So far, studies have not shown free aerial imagery, like the ones on Google Earth, to be correlated to increased rates of looting. The images currently on OAM are also unlikely to cause any issues in this regards as most areas are still lacking imagery. As OAM continues to grow, the high resolution imagery may compromise the security of certain sites. Research would be needed to assess to whether that does end up occurring and what mitigations measures can be put in place.

Despite the risks and challenges, this research reveals that having access to free aerial imagery can be advantageous to archaeology. It enables more research to be done at lower costs and, with enough imagery, landscape analysis over time. It can be used to discover new sites as well as remotely monitor known sites. It can also promote citizen engagement in archaeology. If

OAM achieves its goal to provide aerial imagery for the entire world, it can be a valuable resource to the field of archaeology.

CHAPTER 4: CONCLUDING REMARKS AND FUTURE RESEARCH

4.1 Summary of Conclusions

This research evaluates the potential benefits and challenges of developing an open aerial image repository like OAM, which would rely primarily on volunteered data. It examines OAM in a general context as well as in the specific context of archaeology, drawing wide-ranging conclusions about the strengths and weaknesses of volunteered aerial imagery for these end user communities. This analysis provides a deeper understanding of the barriers that face the continued development of OAM.

The findings in Chapter 2 indicate that OAM is a promising open data project that can satisfy the need for free and accessible high resolution aerial imagery. It is currently the only platform that is dedicated to crowdsourcing aerial imagery. Though there are still many areas in the world which lack aerial imagery, a review of the numbers shows that since OAM started the number of contributors and images on OAM continues to increase. The interviews and online surveys indicate that in general people approve of the idea of making aerial imagery open and accessible online. OAM provides the prospect of having aerial imagery both affordable and easily available. This can be very beneficial to many undertakings, especially those which are often limited by funding such as conservation efforts, humanitarian aid efforts, or archaeological research. Other benefits of OAM include the capability for rapid mapping, for up-to-date aerial imagery as well as for the retention of historic aerial imagery. On the other hand, there are still issues relating to image quality and technical difficulties that need to be addressed as OAM continues to expand. There is also a concern among the interviewees and respondents that some individuals might use the aerial imagery for non-desirable purposes. Right now, the relative lack of data on OAM appears to be the largest constraint. Despite that, the there are people who have already found it a useful platform for sharing georeferenced images. OAM allows citizens to quickly and easily obtain high resolution imagery, making it a valuable platform for a wide array of uses.

Chapter 3 examines one of these potential uses of OAM by looking at its potential in the field of archaeology. Aerial photographs are a valuable source of data in archaeology, allowing archaeologists to examine and analyze archaeological sites. The online survey used the main source of data presents a snapshot of how the archaeological community currently views the idea of open aerial imagery. One of the key benefits OAM would bring is lowering the cost of obtaining aerial imagery. This could allow archaeologists with limited funding more freedom in terms of their work and research. Other advantages are easier data access and more citizen engagement in archaeology or cultural heritage. The leading concern among the interviewees is that the open aerial imagery might facilitate the looting of archaeological sites. This is a difficult matter as on the one hand, citizen engagement in archaeology is desired. On the other hand, having the locations of archaeological sites publicly could draw unwanted attention to the sites. There are also challenges with image quality verification and availability.

4.2 Key Research Contributions

Drones allow people to easily obtain an aerial view of the surrounding landscape and capture it in the form of photographs and videos. The fact that drones allow for a wider range of individuals to collect aerial imagery delivers considerable potential in terms of remote sensing. People are able to create their own datasets using drones. This creates numerous advantages; however, it is be limited to the amount of imagery or data that one is able to collect. A collaborative project gathering all the imagery in the same format and stitching it together to form a worldwide map would traverse that limitation. If users contribute imagery to an open online repository on a fairly regular basis, such a repository could be a source of current, high resolution aerial imagery that would be available to anyone for free.

That is what OAM aims to do. To create a platform that would be dedicated to the sharing of aerial imagery and which provides a catalogue of all available open aerial imagery. It allows open aerial imagery to be visually searched through a web map. This creates considerable potential for the growth of open data in general. It increases both the accessibility and distribution of open aerial imagery. It also eliminates the expenses or restrictions that used to limit the availability and usability of aerial images.

As of right now, regular or frequent contributions are still a challenge as drones are still a relatively novel technology. Though OAM remains limited by the comparatively low number of imagery it offers, nonetheless, this research indicates that OAM is growing and is seen by people as a useful endeavor. There is potential for this collaborative project to flourish in the future.

People have already found it a useful platform for sharing georeferenced images. There are domains that would really benefit from free access to aerial imagery, particularly non-profit endeavors with limited funding such as archaeology, humanitarian aid and conservation efforts. This knowledge contributes to the broader pursuit of understanding the value of Open Data in today's digital world. Of course this research also shows that there are risks and issues that need to be considered. This is a valuable starting point in opening a discussion on the future goals of open aerial imagery and the path that OAM should take to develop into a valued open data repository.

4.3 Recommendations

As OAM continues to grow, there is room for improvements that would ensure the project is successful and sustainable in the future.

Attracting Contributors

Volunteer motivation is an important aspect to consider in regards to the continued growth of OAM is. The more users are involved in OAM, the more likely it is to be successful. Though this particular matter was not really brought up by any of the interviewees or survey respondents, it is a key concern to ensure the sustainability of OAM. People need to feel drawn to contribute imagery for one reason or another. It would be unwise to assume that simply the increase in drone availability and drone ownership will automatically result in an increase of images contributed to OAM.

Creating more of a sense of community on OAM would be a good start. A review of previous literature and other VGI projects such as OSM and Mapillary shows that the sense of community is one of the primary factors motivating people to contribute. In regards to OAM, the first step in this direction should be providing some means through which OAM users can communicate. In OSM, users can communicate using a forum, questions and answers site or through comments on OSM changesets. Any of these means of communication can be easily selected and applied to OAM. It would not only aid in connecting users to one another, but it would also allow novice drone users or new contributors to get assistance from more experienced users.

Based on the findings coming from the interviews, the amount of data on OAM and its ease of use are also important aspects that can either attract or deter users. The interviews revealed that the limited number of images, restricted interface and occasional bugs on OAM discouraged some individuals from using OAM. Though not explicitly stated, individuals seemed more willing to join and contribute to a platform that is already proving to be successful. OAM has still a way to go in this regard, but if it could convince the online community that it can be a successful and sustainable platform, it would attract contributions from more and more users. The interviewees generally thought OAM could be a useful undertaking and expressed a willingness to share their aerial imagery on OAM if it became more popular.

Another important aspect that needs to be addressed is the social realization that this repository offers more benefits than an aerial image repository like Google Earth, which many have become accustomed to using. Cristiano Giovando and Tyler Radford (2016) commented on the fact that many people are unware of the difference between openly licenced imagery and other types of free imagery available online. Free aerial imagery, like the one offered by Google Maps or Bing, cannot be legally used for every purpose as it is copyrighted. Openly licensed imagery, as offered by OAM, can be legally used for almost any purpose and anyone can contribute or access the imagery. Raising awareness about this key difference is an important factor in making people more aware of the significance of open data repositories.

Quality

OAM cannot guarantee image quality; however, this is not an insurmountable challenge. Overall, the drone imagery on OAM tends to be of high quality and resolution. Once OAM amasses enough imagery, that itself can aid in ensuring quality, as it will allow users to compare imagery and assess its quality. There are additional strategies, however, that can be implemented to confirm data quality and accuracy. Tools allowing for community surveillance and control can be one way to ensure the quality control of the images on OAM. Even having a simple rating or comment system could be a useful tool in gauging image quality.

Another solution to ensure the quality of the imagery submitted on OAM could be the development of an app that drone users could use to collect and share aerial images. Not all drones are accompanied by software that enables autonomous flight or pre-programmed waypoints at which the drone would take photos. This can make it difficult for inexperienced drone users to capture high quality aerial photos. An app that would autonomously fly a drone and capture images suitable for mapping could thus be a useful tool that would ensure image quality. The Fly4Fall project in 2017 successfully implemented this type of solution with the

Hangar 360 app for DJI drones (Lyons, 2017; Press, 2017). A similar idea can be applied to creating an app geared towards aiding drone users to collect imagery for OAM.

Privacy

Further research is needed to determine the effects of high resolution aerial imagery in regards to privacy. The goal of OAM is to provide a free high resolution map of the entire world that anyone will be able to use. This has a multitude of benefits; however, it is problematic in regards to privacy. Theoretically, everyone has a right to privacy. This right entails obtaining an owner's permission before publicly sharing aerial imagery of private residences; however, in larger residential or metropolitan areas this is unfeasible. In other instances, where it is possible to ask for permission, some individuals or communities might refuse to have images of their land shared online. Aerial images shared online by outsiders may be unintentionally putting some indigenous communities at risk for various reasons. It is worth noting that Google Earth and Bing already share a worldwide aerial view of the world. All OAM would be doing is sharing similar data without the copyright that restricts the use of both Google's and Bing's imagery. Nevertheless, as OAM imagery has potential to be higher resolution and more up-to-date, it would be constructive to examine how it can impact the privacy of individuals, communities and even places. Knowing exactly what areas are most at risk will be helpful in devising strategies to mitigate those risks. The surveys indicate that the archaeological community is concerned about the privacy and security of archaeological sites. As of right now, it is hard to predict what effects on archaeological sites open aerial data will have. OAM is still in a very early stage of development and does not yet contain a high number of imagery. At the same time, looting of archaeological sites is an old problem that has been occurring long before aerial imagery was widely available. Openly available aerial imagery might end up having little impact on the overall looting rates. Research is necessary to examine whether drone imagery would have an impact on looting rates or not. Perhaps research may indicate areas for which aerial data should not be shared. In that case, this idea of having a complete, publicly available high resolution map of the entire globe may never be fully accomplished. An option can be implemented of restricting access to certain datasets to users with a specific license. Despite the appeal of democratizing spatial data, it is better to ensure that OAM is a beneficial and ethical project that cannot be easily used to harm others.

4.4 Limitations

This study is not without its limitations. The primary limitations are the small sample size resulting from the difficulties in attracting participants for this research. Although 50 interview requests were sent out to companies, organizations and experts somehow involved with drones and aerial data collection, most of the interview invitations remained unanswered. Follow up emails were equally unsuccessful. In total, only 5 positive responses came back agreeing to the interview. The sample of 5 individuals is by no means representative of the entire community of drone users. Nevertheless, the respondents were able to provide valuable information based on their years of experience in the field of drone use and aerial imagery collection. A more significant barrier was encountered when attempting to contact archaeologists whose expertise involved aerial archaeology. There were no responses to the interview invitation or the follow up letters. In order to continue researching the possibilities of using open aerial imagery in archaeology, the alternative was to gather information from the archaeological community in general by means of an online survey that could be distributed via a link. The number of questions was limited down to 13, of which 4 were further modified into multiple choice questions. This was a necessary compromise so that the survey would be easier to complete. Since it was difficult to get in touch with experts, the survey was shared on Facebook groups concerned with aerial archaeology and archaeology in Canada and the United States. This means the respondents might not necessarily be experts. There may also be limitations in participants' ability to describe their experiences in writing. Some misinformation is also possible as there is no way to ascertain whether respondents wrote the truth. Though the respondents had little motivation to lie, there were, after all, many spam survey responses that had to be manually filtered out.

In addition to the limitations associated with the difficulties around contacting experts, the study also suffers from the inability to get in touch with OAM contributors. As mentioned in Chapter 2, OAM currently does not feature any option that would allow users to easily get in touch with one another. The fact that the OAM username does not have to reflect the user's real name allows OAM users to stay anonymous. Though there is room for OAM users to offer some information about themselves in the "bio" section of their public profile, using that section to provide contact information is entirely optional and totally dependent on the user. For the most part, it was found that OAM users did not really provide much or any information regarding themselves in their bios. Combined with the use of usernames instead of actual names on OAM, it was impossible to contact OAM users to invite them to participate in either the interview or the online survey.

Another possible limitation of this study is the selection of imagery chosen for analysis. Due to the time constraints of the project as well as the fact that new images continue to be shared on OAM, it would not be feasible to do a thorough analysis of all the drone imagery on OAM. Due to the limited query capabilities currently on OAM, convenience sampling was used to find the appropriate images. The images selected needed to fit certain criteria that would illustrate the points touched upon in the analysis, such as image quality, image inaccuracies as well as cultural heritage features. The OAM world explorer would be used to find these images. A grid square would be randomly selected in order to see the aerial imagery found in that region. The first two or three images that were found to fit the criteria were then selected for analysis in this research. This may have presented some bias in terms of which images were selected as the images listed at first would be more likely to be selected. Since the analysis focused more on pointing out the benefits and limitations of OAM instead of finding an overall trend in OAM imagery, this sampling technique was sufficient for the purpose of this research, especially since a probability sampling technique was not possible.

4.5 Future Research

As the number of images on OAM continues to grow, future research is needed into how open high-resolution aerial imagery will affect the varying levels of privacy, from individual privacy to that of communities and entire countries. Future research into ensuring aerial data quality would also be constructive. It would help determine not only what could be the most effective measures to safeguard data quality, but also how volunteered image quality compares to authoritative aerial imagery. That would allow users to have a better awareness of the strengths and weaknesses of the data, allowing them to use the data with more confidence.

It would also be beneficial to investigate what motivates drone enthusiasts to collect and contribute imagery specifically to OAM. As stated by Brabham (2010), “Unlocking the reasons why crowds give their creative energy […] is crucial for being able to develop best practices for governments and non-profits hoping to take the genius of crowdsourcing further into the service of the public good.” This research was unable to look into OAM motivations due to the inability to reach out to OAM users. Once there is a way to contact users or reach out to them through a forum or wiki, looking deeper into what motivates them and combining that knowledge with the academic literature looking at other VGI projects would be aid OAM in evolving into a sustainable project that is able to maintain its pool of contributors.

In addition to issues directly related to OAM, there are also issues surrounding drone legislation that may influence the growth of OAM. Drone regulations can discourage drone enthusiasts from collecting imagery or even acquiring drones. The ICAO expected the demand for small drones to continue to grow; however, it saw the lack of appropriate regulatory frameworks as limiting the UAV market (ICAO, 2011). The current regulations differ widely from country to country and place a number of restrictions on drone users regarding flight altitude, distance and areas where drones can be flown. Though drone regulations can impede the collection of aerial data, it is important to remember that they typically aim to protect the citizen's privacy as well as the security of areas that may be sensitive in nature. One way that could make drone regulations less discouraging to people wishing to collect data using drones would be to standardize these regulations and make them more transparent to citizens. There already are international efforts to address this issue. The Small UAV Coalition, The UAViators and AUVSI are examples of a few of these international efforts to promote and advance the use of UAVs worldwide. What remains to be done is to join these efforts with the knowledge that can be gained from further research. Combined, it can guide future government policies relating to drone legislation.

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APPENDIX A: TABLES

Table 1: List of open data sites offering aerial imagery.

	Website	Description	Metadata
AAPG Datapages	http://www.datapages.com/gis-map-publishing-program/gis-open-files	Spatial library offering access to peer-reviewed Global Framework, Geothematic and Geographic themed projects.	yes
Copernicus Open Access Hub	https://scihub.copernicus.eu	Provides high spatial resolution data and access to Sentinel-1, Sentinel-2 and Sentinel-3 user products.	yes
DIVA-GIS	http://www.diva-gis.org/gdata	A collection of data that includes administrative areas, population, transportation, waterways, elevation, land cover, and climate.	limited
Earth Stat	http://www.earthstat.org	A number of GIS datasets regarding agriculture, including global cropland and pasture from 1700 to 2007.	yes
ESPON Database Portal	http://database.espon.eu	Various datasets from across Europe relating to human geography.	yes
ESRI Open Data	http://hub.arcgis.com/pages/open-data	Provides access to over 67,310 open data sets from 4,092 organizations worldwide (as of 2017).	yes
EU Catchment Characterisation and Modelling	http://ccm.jrc.ec.europa.eu/php/index.php?action=view&id=23	The CCM2 database covers the entire European continent and includes a hierarchical set of river segments and catchments based on the Strahler order.	yes
EU Science Hub	https://ec.europa.eu/jrc/en/scientific-tools	A collection of a variety of data portals on different subjects, including, but not limited to, hydrology, environment, climate, and soil.	yes
European Environment Agency	https://www.eea.europa.eu	The EEA offers data and assessments on a wide range of topics related to the environment.	yes
GADM	http://gadm.org/	GADM is a spatial database of the world's administrative areas, mainly countries and lower level subdivisions.	limited
GeoNetwork	http://www.fao.org/geonetwork/srv/en/main.home	Includes a wide range of spatial data pertaining to various thematic categories.	yes
Global Forest Change 2000–2014	http://earthenginepartners.appspot.com/science-2013-global-forest	Offers a global reaster dataset, based on a time-series analysis of Landsat images, that illustrates forest extent as well as the losses and gains in tree cover between 2000 and 2014 .	yes
Global Land Cover Facility	http://glcf.umd.edu/data	GLCF provides earth science data that comes from satellite imagery. It provides access to both satellited imagery as well as data that was derived from satellite imagery.	yes
Global Map data archives	https://globalmaps.github.io	A database encompassing the entire globe at 1km resolution that was produced by the International Steering Committee on Global Mapping.	yes

Globe Land 30	http://www.globallandcover.com	Provides 30-meter resolution land cover rasters showing global distribution of 10 major land cover classes.	yes
Harmonized World Soil Database	https://webarchive.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html?sb=1	Raster datasets combining numerous regional and national soil databases.	yes
History Database of the Global Environment	http://themasites.pbl.nl/tridion/en/themasites/hyde	HYDE offers time series data of population and land use for the last 12,000 years. It also presents various other datasets regarding the field of human geography for the last century.	yes
Humanitarian Data Exchange	https://www.humanitarianresponse.info/applications/data/country-region	Extensive list of over 500 datasets at the national, regional, and global level that is provided by the UN Humanitarian Response programme.	yes
IPUMS Terra	https://www.terrapop.org	IPUMS Terra combines population census data (from over 160 countries) with global environmental data, describing land cover, land use, and climate.	yes
Koordinates	https://koordinates.com	Provides a wide range of global and national data, such as elevation, environment, climate etc.	yes
Last Glacial Maximum Vegetation	http://anthro.unige.ch/lgmvegetation/download_page_js.htm	Broad-scale map of the world showing vegetation cover at the Last Glacial Maximum (25,000 - 15,000 BP)	yes
MapCruzin	http://www.mapcruzin.com	Includes a wide range of data for various areas of the world.	limited
Natural Earth	http://www.naturalearthdata.com	Supported by the North American Cartographic Information Society (NACIS).	no
NEO	https://neo.sci.gsfc.nasa.gov	NASA's Earth Observations (NEO) focuses on global satellite imagery and provides around 50 different global datasets accessible in JPEG, PNG, Google Earth and GeoTIFF formats.	limited
Nils Weidmann Projects	http://nils.weidmann.ws/projects.html	Provides dataset showing historical state boundaries and capitals in the post-World War II period. Another dataset that is provided illustrates ethnic groups worldwide.	yes
Nordpil	https://nordpil.com/resources	Nordpil offers Tectonic plates GIS data as well as a world database of administrative and urban areas.	yes
OneGeology Portal	http://portal.onegeology.org	Combined geological data from various organisations across the world. Levels of detail vary globally.	yes
Open Aerial Map	https://openaerialmap.org	Crowd-sourced aerial imagery.	yes
Open DEM	http://www.opendem.info	OpenDEM Project is a repository of free DEM data.	limited
Open Street Map	https://www.openstreetmap.org	Crowd-sourced data for the whole world.	no
Open Topography	http://opentopo.sdsc.edu/datasets	A community-based site that provides high-resolution topography data available both as DEM and dense point cloud.	yes

Open Topography	http://www.opentopography.org	Offers high spatial resolution topographic data and tools for various locations worldwide.	yes
SAGE	http://nelson.wisc.edu/sage/data-and-models/datasets.php	Center for Sustainability and the Global Environment (SAGE) includes datasets that are of interest in examining the connections between human activity and the natural environment.	yes
SEDAC	http://sedac.ciesin.columbia.edu/	Socioeconomic Data and Applications Center (SEDAC) provides various datasets (including historical data) that are seperated into themes.	yes
Soil Grids	https://soilgrids.org	Datasets of soil types worldwide, including both topsoil and subsoil. Level of detail varies globally.	yes
Spatial Data Repository	https://spatialdata.dhsprogram.com	The Spatial Data Repository provides geographically-linked health and demographic data from The DHS Program and the U.S. Census Bureau.	yes
Thematic Mapping	http://thematicmapping.org/downloads	National borders along with attributes including country codes, area, and population (based on 2005 stats).	limited
UNEP Environmental Data Explorer	http://geodata.grid.unep.ch	A wide range of data from the United Nations Environment Programme, which includes Global Forest Cover, Global Potential Evapotranspiration, Global Average Monthly Temperatures, Dams, Watershed Boundaries and many more.	yes
UNEP GEOdata	http://geodata.grid.unep.ch	A wide range of environmental data from the United Nations Environment Programme	yes
USGS Earth Explorer	https://earthexplorer.usgs.gov	USGS's Earth Explorer provides an extensive database of satellite and aerial imagery.	yes
USGS HydroSHEDS	https://hydrosheds.cr.usgs.gov	Hydrological data based on STRM elevation data that includes global river networks, watershed boundaries, drainage directions and flow accumulations.	yes
USGS Land Cover Institute	https://landcover.usgs.gov/landcoverdata.php	Wide range of land cover datasets.	limited
Water Isotopes	http://wateriso.utah.edu/waterisotopes/pages/data_access/da_main.html	Global and regional water isotope distribution, which includes data site locations and raster datasets in ArcGIS Grid format.	yes
World Pop	http://www.worldpop.org.uk	Provides spatial demographic datasets for Central and South America, Africa and Asia with the intent to aid in development, disaster response and health applications. It uses documented and peer-reviewed methods in creating datasets which include metadata and measures of uncertainty.	yes
World Resources Institute	http://www.wri.org/dataset	WRI is committed to producing high-quality research, including reports, issue briefs, working papers, and technical notes. Among other topics, publications include grassland extent data, Percentage tree-cover, population density and tree cover, share of wood in fuel consumption	yes

		etc.	
WWF World Ecoregions	https://www.worldwildlife.org/pages/conservation-science-data-and-tools	Various shapefiles of global ecoregions as defined by the WWF Conservation Science Program.	yes

Table 2: List of drone models available on the market as of 2018.

Drone Company	Drone model	Image	Video	Battery Time		Size	Price range
	8807w Foldable RC Drone	2 MP	720p	10 min	Wi-Fi	14"	$79.99
	Altair AA108		720p	10 min	Wi-Fi, altitude hold	7"	$149.80
	Aurelio Tech (002BKQCP0)	2 MP	720p	15 min	Wi-Fi, foldable wings	10"	$105.99
	Blade Chroma			30 min	GPS, Aerial Photography Mode	13"	
DJI https://www.dji.com/company	DJI Inspire 1 Pro	16 MP	4K @ 30fps		GPS, remote focus, point of interest waypoints, course lock		$2,699.00
	DJI Inspire 2	20.8 MP	HD 4096×2160 @ 60fps, 4K @ 60 FPS	27 min	GPS, FlightAutonomy, Cinecore 2.0 image processing system	17"	$8,059.99
	DJI Inspire 1 RAW	16 MP	4K, 4096 x 2160	18 min		5"	$8,099.00
	DJI Mavic Air	12 MP	4K 30 FPS; slow-motion in 1080p 120 FPS	21 min	FlightAutonomy 2.0		$1,079.99 - $1,349.99
	DJI Mavic Pro Aircraft	12.4 MP	4K	30 min	GPS, Wi-Fi	11"	$987 - $1,489.00
	DJI MAVIC PRO Foldable Quadcopter Drone	12.4 MP	4K 30 FPS	27 min	GPS, Wi-Fi, 4 vision sensors, Front Obstacle Avoidance	10"	$1299.99 - $1749.00
	DJI P4P Obsidian	20 MP	4K @ 60fps				
	DJI Phantom 3 4K	12 MP	4K	25 min	GPS, Wi-Fi	18"	
	DJI Phantom 3 Standard	12 MP	2.7K @ 30 FPS	25 min	GPS, Wi-Fi	15"	$1,049.97
	DJI Phantom 4	12 MP	4K @ 30 FPS, 1080p @ 120 FPS	28 min	GPS, vision positioning, visual tracking		$1,389.99
	DJI Phantom 4 Advance	20 MP	4K @ 60 FPS	30 min	GPS, Wi-Fi, FlightAutonomy, 5 vision sensors	14"	$1,619.99

	DJI Phantom 4 Pro	20 MP	4K 60 FPS	30 min	infrared, visual tracking, FlightAutonomy	11"	$2029.99 - $2,429.00
	DJI Phantom 4 Special Edition	12 MP	4K @ 30 fps	28 min	Wi-Fi; Lightbridge	11"	$1,199.97
	DJI S1000 Plus	36 MP	HD 1920×1080 @ 60 or 25fps				
	DJI Spark	12 MP	1080p @ 30 FPS	16 min	GPS, Wi-Fi, visual tracking, FlightAutonomy, UltraSmooth technology to reduce camera movement	5.6"	$484.89 - $799.99
	DJI Zenmuse XT	13 mm	640×512 @ 30fps				
DROCON https://drocon.co	DROCON Bugs 6			12 min		15"	
	DROCON Cyclone X708	0.3 MP	720p		Wi-Fi	17"	$75.99 - $167.74
	DROCON Hacker		720p	6 min		1.5"	
	DROCON U31W Navigator		720p	7 min	Altitude hold, custom flight route	7"	
	DROCON U818A PLUS		720p	15 min	Wi-Fi, altitude hold	13"	$249.95
	DROCON UDI U818A WiFi FPV RC	2 MP	720p, 1280 × 720 @ 30 FPS		Wi-Fi, altitude hold	14"	$199.95
EACHINE	EACHINE E012HW	0.3 MP		5 min	Wi-Fi, altitude hold	2.5"	$46.99
	EACHINE E10C Mini Quadcopter	2 MP		6 min		2"	$49.99
	EACHINE E58 WIFI FPV Quadcopter	2 MP	720p	9 min	Wi-Fi, Altitude hold, foldable wings	11"	$102.99
	FADER Drone with HD Video Camera				Wi-Fi	9"	$87.99
FlyAbility	FlyAbility ELIOS		HD 1920×1080 @ 30fps; HD 160×120 @ 9fps				
	GBlife Mini Pocket Foldable RC		720p	7 min	Wi-Fi	5"	$52.99
	GoPro Karma Drone	12 MP	4K @ 60 FPS, 1080x240	20 min	GPS, Wi-Fi, Bluetooth		$1,199.99 - $1,299.99
	Hexo+ Drone				Bluetooth	17"	$499.88
Holy Stone	Holy Stone F183W FPV RC Quadcopter Drone		1280 x 720p @ 30 FPS	10 min	Wi-Fi	12"	$149.90
	Holy Stone HS100 GPS FPV RC Drone		720p	15 min	GPS, Wi-Fi, Altitude hold		$339.99
	Holy Stone HS110 FPV Drone	2 MP	720p HD	9 min	Altitude hold	13"	$99.99
	Holy Stone HS160 Shadow		720p	9 min	Wi-Fi, Altitude	6"	$129.99

	FPV RC Drone				Hold		
	Holy Stone HS200 FPV Quadcopter Drone	2 MP	720p HD		Wi-Fi, Altitude Hold	13"	$164.99
http://www.holystone.com/AboutUs	Holy Stone HS230 5.8G FPV RC Racing Drone		720p			19"	$229.90
	Holy Stone HS300 RC Drone	5 MP	1920x1080P, 30 FPS	10 min	Automatic Altitude Hold		$255.99
	Holy Stone HS400 FPV Drone		720p HD		Wi-Fi, Automatic Altitude Hold	21"	$232.47
	Hubsan H109S X4 Pro		1080p	21 min	GPS, altitude hold	11"	
Hubsan	Hubsan H216A X4 Desire		1080p	11 min	GPS, Wi-Fi, altitude hold, waypoints	7"	
http://www.hubsanus.com	Husan H507A Star Pro		720p	9 min	GPS, Wi-Fi, waypoints	7"	
	Hubsan H510M X4 Waypoints FPV		720p	20 min	GPS, Wi-Fi, waypoints	9"	
	Intel Falcon 8 Plus	36 MP	HD 1920×1080 @ 60 or 25fps and 14-bit RAW thermal				
	LiteHawk BURST		320 @ 30 FPS	5 min		7"	$99.97
	LiteHawk Click		30 FPS				
LiteHawk	LiteHawk FOCUS		720p HD @ 30 FPS	8 min		6"	$199.99
	LiteHawk OPTIX				Wi-Fi, repositionable camera angle		
	LiteHawk QUATTRO LENS		30 FPS				
http://www.litehawk.ca/	LiteHawk QUATTRO SNAP		30 FPS		16-bit audio		
	LiteHawk Snap Auto		640 x 480, 360p @ 30 FPS	8 min		6"	$99.99
	Parrot 2.0 Drone		720p HD				$199.99 - $329.99
	Parrot Airborne Cargo Drone						$139.99
	Parrot Airborne Night Drone			9 min	Bluetooth, 2 headlights, pressure sensor, ultrasound sensor	7"	$99.97 - $179.99
Parrot	Parrot AR.Drone 2.0		1280 x 720 @ 30 FPS	12 min	Wi-Fi	20"	$299.97
	Parrot Bebop 2	14 MP	1080p HD, 30 FPS	25 min	GPS, Wi-Fi, 300m signal range	12.9 "	$559.83 - $799.99
	Parrot Bebop Blue Area 1 Drone	14 MP	1080p				$699.99
	Parrot Bebop-Pro 3D Modeling	14 MP	1920 x 1080p @ 30 FPS	25 min	Wi-Fi, Pix4Dmodel software	8"	$1,499.99
	Parrot Disco	14 MP	1080p @ 30	45 min	Wi-Fi	45"	$799.99

https://www.parrot.com/ca			FPS				
	Parrot Mambo Fly		60 FPS	9 min	Bluetooth, attachable camera	5"	$139.99
	Parrot Mambo FPV		60 FPS	10 min	Bluetooth		$229.99
	Parrot Mambo Minidrone	0.3 MP		8 min	Bluetooth	7"	$89.97
	Parrot Swing	0.3 MP	60 FPS	8 min	Bluetooth	13"	$89.97 - $99.97
	Polaroid PL100		480p	5 min	Wi-Fi, Radio Frequency	2.5"	$99.99
	POWPRO Cair PP- XS809	2 MP		10 min	Wi-Fi, altitude hold	13"	$89.99
	PrecisionHawk Lancaster 5	18.4 MP					
	Ryze Tech Tello	5 MP	720p	13 min	Wi-Fi	4"	$129.00 - $135
	SHR/C SH5 RC Drone	2 MP	1080p	10 min	Wi-Fi, altitude hold, waypoints	12"	$99.99
	Sky-Hero PX8 Spyder 1000 Plus						
Aeryon www.aeryon.com	SkyRanger R60	20 MP; 13 MP	1080p60 H.264 HD; 640×512, 8.33 FPS	50 min	Wi-Fi, 30x zoom, automatic in-air replacement		
	SkyRanger R80			50 min	GPS, automatic in-air replacement		
	SwellPro Splash Drone 3	14 MP	4K @ 25fps				
Syma http://www.symatoys.com	Syma RC D700WH Wi-Fi Drone					22"	$249.99
	Syma RCD5500W Drone		720P HD				$129.99
	Syma X21W quadcopter drone	0.3 MP		5 min	Altitude hold	7"	$49.90
	Syma X5SW FPV	0.3 MP	640x480p @ 30 FPS	7 min	Wi-Fi	12"	$69.99
	Syma X5UW		720p @ 30 FPS	9 min	Wi-Fi	17"	$99.90
	Syma X8G	5 MP		7 min		19"	
	Syma Z1			7 min	Gravity and optical flow sensors, foldable	10"	
Tenergy (TDR) www.tdrworld.com	Tenergy Sky Beetle				Wi-Fi, Auto hovering, orbit flying, foldable	3.8"	
	Tenergy Syma X5UW	1280x720, 640x480	720p, 480p	7 min	Wi-Fi	13"	$99.95
	Tenergy TDR Phoenix Wifi	0.3 MP		7 min	Wi-Fi, auto hover, collision avoidance	13"	$149.99
	Tenergy TDR Robin Pro	2 MP	720p @ 30 FPS	6 min	Altitude hold, orbit video	4"	$124.99

Veho	Veho Muvi Quadcopter X-Drone	16 MP	1080p @ 30 FPS	20 min	GPS, Wi-Fi	9"	$1099.98 - $1,199.95
Virhuck http://www.virhuck.com	Virhuck 516 Wifi FPV Drone	0.3 MP		15 min	Wi-Fi, altitude hold	15"	
	Virhuck T905F		720p		Altitude hold		
	Virhuck XS809W RC Quadcopter		720p	10 min	Wi-Fi, altitude hold, foldable wings	13"	$89.99
	WIFI DRONE RC	0.3 MP	720p HD @ 30 FPS	10 min	Wi-Fi	13"	$159.93
Wingsland https://wingsland.com/	Wingsland M5		720p @ 250FPS	17 min	GPS, altitude hold, optical flow, point of interest		
	Wingsland Minivet	12 MP	1080p	25 min			
	Wingsland S6 4K30	13 MP	4K @ 30 FPS, 1080p @ 60 FPS	10 min	GPS, Wi-Fi, infrared and optical flow sensors	6"	$349.99
	Wingsland X1 FPV Racing Drone	0.3 MP	640 x 368	7 min	Wi-Fi		$149.99
Zero Tech (Xiro)	Xiro Xplorer Mini Discovery	13 MP	4K, 1920 x 1080 @ 30 FPS	15 min			$599.97
	Xiro Xplorer 4K	12 MP	4K @ 24 FPS, 1080p @ 120 FPS	20 min	Wi-Fi, waypoints		
Xtreme www.xtremecables.net	Xtreme Raptor		720p	10 min		13.5"	$53.98
	Xtreme Xflyer	0.3 MP	640 x 480	10 min			
Yuneec http://us.yuneec.com/	Yuneec Breeze 4K	13 MP	720p HD, 4K 30 FPS	12 min	GPS, Wi-Fi, flow and infrared positioning sensors, orbit mode	7.7"	$392.52 - $499.99
	Yuneec H920	16 MP	4K @ 30 FPS	24 min	Orbit mode, pint of interest, waypoints, foldable	36"	
	Yuneec Q50 Typhoon	12 MP	4K @ 30 FPS, 1080p @ 120 FPS	20 min		22"	$1,499.98
	Yuneec Typhoon H	12 MP	4K	28 min	GPS, Wi-Fi	18"	$1,249.00 - $1,299.97
Zero Tech	ZeroTech Dobby Standard Pocket Size Selfie Drone	13 MP	4K	9 min	GPS, Wi-Fi	3"	$379.97

APPENDIX B: INTERVIEW QUESTIONS

General questions:

1. How did you become involved in [name of NGO/business] and working with aerial data?
2. Based on the work that is done at [name of NGO/business], what is your experience in regards to open data, and specifically, open aerial imagery?
3. What are the main or most valuable outcomes that you see from both your use of imagery and the wider distribution of imagery?
4. Who do you see as your target end user?
5. What is your role in supporting or developing a community of imagery contributors? What actions has your organization taken to build this community?
6. In your opinion, what is the future of volunteered raster data in terms of real-world applications?
7. Why are you gathering/enabling the contribution of drone imagery?
8. What have you heard regarding Open Aerial Map?
9. In your experience, how does the quality and quantity of volunteered imagery compare to data collected through traditional means? How valuable is data accuracy and precision to your users and/or NGO/product/business?
10. What barriers and/or issues are there with using the imagery that has been donated?
    a. Who owns the data?
    b. What may be some of the issues regarding data ownership?
    c. What issues might contributors have with donating imagery?
11. What might be some risks of distributing volunteered aerial imagery?
    a. Are there any risks in terms of personal security? What about in terms of community or national security?
    b. Might the risks or negative effects of image repositories have the potential to outweigh the benefits?

Questions for respondents whose work relates to archaeology:

1. Are you aware of any instances where open aerial data is used in archaeology?

[If yes:] What are some of the ways in which open aerial images have been used in archaeology?

[If no:] Would you foresee open aerial imagery as being useful in archaeology? Why or why not?

2. In your opinion, what is the potential of open aerial data in archaeology?
    a. Would open aerial data repositories facilitate archaeological work?
    b. To what degree might open aerial repositories be of assistance?
    c. What might be some of the benefits from having access to aerial repositories?
3. What are some of the key challenges or barriers in using user-contributed aerial data for archaeological projects or research?
4. What may be the negative effects of open image repositories on archaeology? Might it have the potential to impede archaeological work?

Concluding question:

1. Thank you for the interview as well as all the valuable information. Is there anything else you'd like to add regarding to open aerial data before we end?

Appendix C: Survey Questions

Online Survey Form

Welcome to the research study! We are interested in understanding the potential of open aerial image repositories in archaeology. You will be asked to answer some questions regarding the use of aerial imagery in archaeology. Excerpts from this questionnaire may be included in the thesis and/or any publications to come from this research. You may withdraw my consent at any time without penalty by contacting the researcher. You can also contact the researchers before papers have been submitted for publication to withdraw your data.

The study should take you around 20-40 min to complete, and you will receive a $10 Amazon gift card for your participation. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the Principal Investigator in the study to discuss this research, please contact Veronika Jorz at vjorz@uwaterloo.ca or Dr. Peter Johnson at peter.johnson@uwaterloo.ca.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE#32112). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or oreceo@uwaterloo.ca.

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

- ☐ I consent, of my own free will, to participate in this study.
    - ☐ I agree to the use of anonymous quotations in any thesis or publication that comes of this research.
    - ☐ I do not agree to the use of attributable or anonymous quotations in any thesis or publication that comes of this research.
- ☐ I do not consent, I do not wish to participate

1. What is your experience in regards to open data, and specifically, open aerial imagery?

2. In your opinion, what is the future of volunteered raster data in terms of real-world applications?

3. Are you aware of any instances where open aerial data is used in archaeology?
   - ☐ Yes
   - ☐ No
4. What are some of the ways in which open aerial images have been used in archaeology?

5. Would you foresee open aerial imagery as being useful in archaeology?

6. How valuable is data accuracy and precision in archaeology?
   - ☐ Not important
   - ☐ Slightly important
   - ☐ Moderately important
   - ☐ Very important
   - ☐ Extremely important
7. Why is that?

8. In your experience, how does the quality and quantity of volunteered imagery compare to data collected through traditional means (satellites, etc.)?

9. What are some of the key challenges or barriers in using user-contributed aerial data for archaeological projects or research?

10. What may be the negative effects of an open image repository on archaeology?

11. Might it have the potential to impede archaeological work?
    - ☐ Yes
    - ☐ Maybe

- ☐ No

12. Might the risks or negative effects of image repositories have the potential to outweigh the benefits?
    - ☐ Yes
    - ☐ Maybe
    - ☐ No
13. Why is that?

Thank you for taking the time to complete the survey as well as for your contributions to my research investigating the implications of user contributed open aerial data in archaeology. Your feedback is extremely valuable.

If you have any general comments or questions related to this study, please contact Veronika Jorz, vjorz@edu.uwaterloo.ca, or Dr. Peter Johnson, peter.johnson@uwaterloo.ca, Department of Geography and Environmental Management, University of Waterloo.

We would like to assure you once again that this study has been reviewed by, and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE # 32112). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

APPENDIX D: HUMANITARIAN UAV NETWORK CODE OF CONDUCT

Unmanned Aerial Vehicles (UAVs) offer the potential to improve humanitarian assistance and disaster reduction. As such, they offer the possibility to better meet the needs of those affected by humanitarian crises. This can only be realized if UAVs are employed in a responsible and ethical manner. This Code of Conduct, aims to guide all actors involved in the use of UAVs to support the delivery of humanitarian assistance in disasters and situations of conflict. Acceptance and adherence to this Code will contribute to safety, professionalism and increased impact while building public confidence in the use of UAVs. The Code of Conduct will be revisited as experience grows and technology further develops. The UAViators Best Practice Report will also be updated as needed. Note that this Code of Conduct is a standalone document. The supporting, theme-based Guidelines are separate and distinct from this Code of Conduct.

The use of UAVs to support humanitarian action should be carried out for humanitarian purposes only and with the best interest of affected people and communities in mind, and should adhere to the humanitarian imperative of doing no harm. Naturally, how the guidelines below are applied may differ depending on whether UAVs are used to support humanitarian action in response to a natural disaster or armed conflict. That being said, UAV deployments in either context must observe the humanitarian principles of humanity, neutrality, impartiality and independence. UAV missions must also be legal, safe and have adequate insurance.

1. Prioritize safety above all other concerns: humanitarian benefits should clearly outweigh risks to persons or properties.
2. Only operate UAVs when more effective means are not available and when humanitarian purposes are clear, such as the assessment of needs and the response thereto. UAV missions should be informed by humanitarian professionals and experts in UAV operations with direct knowledge of the local context.
3. Respect the humanitarian principles of humanity, neutrality, impartiality and independence: prioritize UAV missions based on needs and vulnerabilities, make sure actions are not, and not perceived as being, politically or economically influenced; do not

discriminate or make distinctions on the basis of nationality, race, gender, religious belief, class or political opinions.

4. Do no harm: assess and mitigate potential unintended consequences that UAV operations may have on affected communities and humanitarian action.
5. Operate with relevant permissions: UAV operations must be in compliance with relevant international and domestic law, and applicable regulatory frameworks including customs, aviation, liability and insurance, telecoms, data protection and others. Where national laws do not exist, operators shall adhere to the ICAO RPAS Circular 328-AN/1901 with the approval of national authorities.
6. Engage with communities: community engagement is important and obligatory. Developing trust and engaging local communities encourages active partnership, builds local capacities and leadership and enhances the impact of your mission. Information should continuously be provided to communities regarding the intent and use of UAVs. Refer to Humanitarian UAV Network Community Engagement Guidelines.
7. Be responsible: contingency plans should always be in place for unintended consequences. UAV teams must take responsibility for and resolve any issues involving harm to people and property, including liability.
8. Coordinate to increase effectiveness: seek out and liaise with relevant local and international actors and authorities. UAV teams must not interfere with and always seek to complement formal humanitarian coordination mechanisms or operations.
9. Consider environmental implications: operating UAVs should not pose undue risk to the natural environment and wildlife. UAV operators must take responsibility for any negative environmental impact their mission causes.
10. Be conflict sensitive: all interventions in conflict zones become part of conflict dynamics and can result in very serious unintended consequences, including the loss of life. Extraordinary caution must be used in deploying UAVs in conflict zones. Refer to Humanitarian UAV Network Conflict Zones Guidelines.
11. Collect, use, manage and store data responsibly: collect, store, share and discard data ethically using a needs-based approach, applying informed consent where possible and employing mitigation measures where it is not. The potential for information to put individuals or communities at risk if shared or lost must be assessed and measures taken

to mitigate that risk (e.g. limit or cease collection or sharing). Refer to Humanitarian UAV Network Data Ethics Guidelines.

12. Develop effective partnerships in preparation and for and in response to crises: work with groups that offer complementary skill sets (humanitarian action, UAV operations, local context, data analysis, communications) during, and preferably in advance of crises. Refer to Humanitarian UAV Network Effective Partnerships Guidelines.
13. Be transparent: share flight activities as widely as possible, ideally publicly, as appropriate to the context. Convey lessons or issues to communities, relevant authorities and coordinating bodies as early as possible.
14. Contribute to learning: carry out and share any evaluations and after action reviews to inform the betterment of UAV use for humanitarian action.
15. Be open and collaborative: Coordination is a multi-stakeholder process. This means that lessons learned and best practices on the use and coordination of UAVs in humanitarian settings must remain open and transparent along with any related workshops, trainings and simulations.