Increasing Accessibility for Hard-to-Reach Cultural Heritage Sites Using Low-Cost Drone Photogrammetry

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Increasing Accessibility for Hard-to-Reach Cultural Heritage Sites Using Low-Cost Drone Photogrammetry

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Anthropology

by

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ABSTRACT

New recording technologies have ushered in a transformative era in archaeological research, with drone photogrammetry emerging as a pioneering tool in this field. This innovative approach leverages unmanned aerial vehicles (UAVs) equipped with high-resolution cameras to capture precise aerial imagery of archaeological sites. Drone photogrammetry offers numerous advantages, such as cost-efficiency, rapid data collection, and the ability to access remote or challenging terrain. By seamlessly integrating photogrammetric techniques, these technologies offer archaeologists the ability to create highly detailed 3D models. This study delves into the principles and applications of low-cost drone photogrammetry in archaeology, highlighting its potential to enhance site documentation, analysis, and public outreach efforts. The case studies on the Marzuolo Archaeological Project (Italy) and at Zeb Edmiston House (Historic Cane Hill) show that low-cost drones are capable of capturing data at hard-to-reach sites and offer researchers an accessible and affordable tool for public engagement.
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CHAPTER 1: INTRODUCTION

In 1956, the initial application of photogrammetry in archaeology occurred in Italy when Castagnoli and Schmidt (1957) conducted a study on the urban layout of the Roman town of Norba. Despite this early application, Fussell (1982) and Anderson (1982) indicate that most archaeologists in the late 20th century avoided using photogrammetry techniques in their projects because they believed the method was expensive and required advanced technical skills that were time-consuming to master. In the 21st century, however, the field of archaeology has experienced a digital transformation in the way data is captured, visualized, analyzed, and disseminated (e.g., Huvila et al., 2018). Among the diverse digital technologies and practices that now make up an archaeologist’s toolkit, photogrammetry has become a popular and standard field recording technique due to its many advantages over traditional documentation methods, such as hand-drawn sketches and photographs.

Photogrammetry is a low-cost technique used to produce three-dimensional (3D) models of cultural sites and artifacts from two-dimensional (2D) images (e.g., Westobay et al., 2012; Kingsland, 2020). It is a faster, more accurate, and more cost-effective method of recording data in the field than hand drawing, and it allows archaeologists to create detailed and precise digital models of objects and sites. One of the main advantages of photogrammetry is that it allows archaeologists to capture data in 3D, which provides a more complete and accurate representation of an object or site than 2D methods. This is extremely important in archaeology, where objects and sites are often complex and challenging to capture in two dimensions. When the models are hosted on free online platforms (e.g., Sketchfab), the digital products can also be more accessible to a wider and more diverse global audience than traditional archaeological publications. Although there is a debate over whether photogrammetry can completely replace
traditional field recording methods, the digital 3D approach enables archaeologists to interpret
the sites in more detail and from different perspectives, which can enhance their understanding
of sites, structures, and artifacts (Campana, 2014).

The first photogrammetry applications in archaeology, by and large, were terrestrial
because of the available technology and its cost (Fussell, 1982). Unmanned Aerial Vehicle
(UAV) photogrammetry was a later development and it originated from aerial photography. Hot
air balloons were employed to capture the earliest known aerial images of ancient sites (e.g.,
Forum Romanum, Ostia, and Pompei) between 1899-1911 (Fig. 1) and at Stonehenge in 1906,
(Rączkowski, 2014; Capper, 1907), but photos taken by reconnaissance aircrafts in World War I
and World War II illustrated how aerial photographs could be used to discover new Greek and
Roman sites (Cowley & Stichelbaut, 2012; Bradford, 1957) (Fig. 2). Technology has made
significant strides since that time, and now UAVs, especially drones, have become an inevitable
tool for recording cultural sites with high-resolution cameras. Drones, the initial commercial
drone permits were released by the Federal Aviation Administration (FAA), are reliable, non-
invasive, and time-efficient tools for digitally recording and preserving cultural heritage sites
(Rao et al., 2016; Themistocleous, 2019).
Fig. 1: Aerial photographs (a photo mosaic) taken in 1911 from a balloon. Published by E.J. Shepherd in 2006.

Figure 2: Left: F24 camera installed in the side of a Westland Lysander aircraft, part of the RAF (Royal Air Force) published by R. Conyers Nesbit in 1996. Right: Aerial photo of Ostia Antica, Italy before 1938-40, ETA_post1924_149_168_566_384_0.

While aerial photogrammetry is not a new technique, recent developments and improvements in image processing software and hardware technology provide more opportunities and features (low-altitude imaging, long-endurance, built-in GPS and camera, remote controller, etc.) to collect and process data in high-resolution (Fig. 3). In this regard,
archaeological excavations that have difficulties in reaching out to the public can now open and introduce their data thanks to UAV's advanced features. As a result, it is now a commonly used tool for mapping and documenting archaeological sites, as well as for conducting spatial analyses and identifying new sites. In this instance, UAVs provide plenty of opportunities to capture data at hard-to-access cultural sites. Difficult-to-access sites can be defined as underwater, rural areas, and difficult to access due to physical and legal handicaps (e.g., mountains, slopes, and private lands).

Figure 3: UAV photogrammetric model of Insula IV at Ostia Antica, published in Sonnemann et al. 2015.

This thesis mainly aims to explore the use of UAV-based aerial photogrammetry at difficult-to-access archaeological sites, with a focus on its advantages, limitations, and potential for future directions. Even though there is a growing body of scholarship that deals with aerial photogrammetry applications in archaeology, the sources I have read neglect to provide practical approaches and workflows specific to UAV photogrammetry that include the entire pipeline.
from data capture to 3D modeling to data publishing. For this reason, my research aims to build a standard drone photogrammetry workflow for projects on tight budgets exploring inaccessible sites that require reliable, time-efficient, and easy-to-follow 3D modeling techniques. With the collaboration of the Marzuolo Archaeological Project (MAP) and the Arkansas Archaeological Society and Historic Cane Hill, Inc., I was able to apply my workflow to two cultural sites that are in rural areas, using two different types of DJI drones, to demonstrate the wide applicability and usefulness of UAVs. The Roman minor center at Podero Marzuolo (Cinigiano, GR, Italy) is in rural southcentral Tuscany at a distance from the well-traveled tourist paths along the coast and in the wine country surrounding Siena. It is also located on private land. In part to avoid high conservation costs and in part due to legal restrictions, MAP backfills its trenches at the end of every season. This means the site will never be open for researchers or the general public to visit. This makes it difficult for researchers and the local community to see the site – visits are only possible in July during the excavation season – and makes long-term engagement with the site challenging. While the Zeb Edmiston House is partially open to public visits, the house is located in rural Cane Hill, Arkansas, approximately 30 miles from the I49, the main traffic artery connecting the large urban centers in the NW part of the State. This, therefore, obstructs discovery of the site and limits the number of visitors. My goal with this research is to help break down barriers for the use of UAV photogrammetry in the field and to provide methods for disseminating the digital products so that the data can reach a wider public audience. In this regard, my research addresses how to create 3D models of inaccessible sites faster, more accurately, and at a lower cost with a drone and how to publish this data on Sketchfab, a free online platform where users can share 3D models for free, public use. Sketchfab also has an
annotation feature that allows researchers to add descriptive notes to their models to enhance learning and engagement with the sites (Sketchfab, 2023).

The first phase of this study was conducted between June 25- July 15, 2022. I joined MAP’s 2022 field season as a Topo Assistant to test my workflow on the site and record the excavations in the western half of Room D (Area 20000), which was located in the northern half of a large multi-craft production complex. Aerial photos were taken with a DJI Mavic Air 2 drone to create high-resolution 3D models that recorded the progression of work in this trench over the course of the season. These models, which act as a digital archive, are now being used by the directors in their interpretation of both the stratigraphy and the dynamic life activities that occurred in Room D. As part of my research, I have published a selection of the UAV models to Sketchfab with annotations and am currently tracking public engagement with the models.

To complete phase 2, the author was awarded a Tiffany Marcantonio Research Grant in Spring 2023 by the Graduate and Professional Students Congress at the University of Arkansas. This grant helped me purchase a DJI Mini 3 Pro drone with Fly More Combo to capture data in MAP’s 2023 season between July 1-25. The author was unable to join the excavations, but Dr. Vennarucci, MAP’s field director the advisor in this study, used the workflow I tested in the first phase to train staff and students in the capture of aerial photos of Areas 21000 and 22000 in the southwest area of the site, where another large masonry complex was discovered. Since one of this project’s goals is to break down barriers for the use of UAV photogrammetry in the field, her field back on the data capture process confirmed that my workflow is accessible for archaeologists not familiar with drone technology. MAP’s 2023 data also allowed me to compare both drones in terms of resolution, cost, and time efficiency.
To further prove the usefulness and wide applicability of the workflow, I modeled the Zeb Edmiston House at Historic Cane Hill, built in 1872 and restored in 2016, with a combination of UAV and terrestrial photogrammetry in September 2023. The DJI Mini 3 Pro drone and Sony Alpha 5000 handheld camera were employed during the data recording. By doing this, I tested the compatibility of two different types of photography methods to see if this hybridized approach might contribute to improving the model's resolution and facilitate capturing data in the narrow areas (under the deck) the drone cannot reach. The images were combined in Agisoft Metashape in order to cover possible holes in the model (Agisoft, 2023). The house has never been digitally recorded, and so my model will contribute to cultural heritage education and preservation efforts at Cane Hill, a difficult-to-access but important historic site for the history of this region of Arkansas.

In the second chapter, I offer a brief literature review that outlines the scholarship on aerial photogrammetry in archaeological research. I consider the benefits and limitations of using UAVs for recording, site documentation, and promoting public outreach of inaccessible archaeological studies, and I compare this method to traditional terrestrial photogrammetry, regarding cost-effectiveness, time efficiency, and data quality. In the next section, I outline my methodology for capturing UAV data in the field, processing the 3D models with Agisoft Metashape, and publishing them to Sketchfab. I then analyze the results of my work for the Marzuolo Archaeological Project and Cane Hill Historic, Inc. In the conclusion, I map future directions for this research and other potential applications of my workflow to fieldwork.
CHAPTER 2: AERIAL PHOTOGRAMMETRY IN ARCHAEOLOGY

Despite some limitation discussed below, photogrammetry is now a standard tool for recording archaeological sites. In the last two decades, photogrammetric studies in archaeology centered on terrestrial photogrammetry with a hand-held DSLR camera due to the high cost, strict regulations, and specialist experience (e.g., pilots license that started in 2015) associated with most aerial methods (Buzon et al., 2021). While certain research endeavors explored aerial photogrammetry, they primarily utilized helicopters, hot-air balloons, fixed-wing aircraft, or gliders. It was challenging to acquire high-resolution photographs of archaeological sites with these methods due to their limited top-down perspective and the inability to control flight speed (Themistocleous, 2020). In fact, before I introduced UAV photogrammetry to MAP, the local cultural ministry would send an aerial photographer to the site at the end of each season to take photos with a balloon, which the project would convert into orthophotos (Fig. 4). While this service was free of charge, the quality of the photographs varied because it was impossible to control the camera angle and difficult to control the flight speed or height of the balloon. The project could also only capture aerial photographs once a season instead of producing a progression of aerial photos to record the excavation process, which the drone allows.
Remarkable developments in Structure from Motion (SfM) algorithms and the wider availability of lightweight drones with onboard high-resolution cameras has transformed the way researchers record archaeological sites. UAVs, especially quadcopter drones, are more affordable than ever before (mid-level consumer models cost between $600 to $1,000) and provide more opportunities and features (low-altitude imaging, autonomous flight mode, long-endurance, built-in GPS, and remote controller, etc.) to collect data faster and process 3D images in high resolution (Fiz et al., 2022; Remondino et al., 2012). In this context, archaeological excavations, especially ones facing financial constraints and struggling to reach the public because of their hard-to-access locations, can now utilize UAVs’ advanced capabilities to share their data and findings.

This chapter explores the merits and drawbacks of employing drones at cultural sites, drawing from the author’s firsthand encounters on the Marzuolo Archaeological Project and Historic Cane Hill Arkansas as well as other archaeological undertakings. However, the main point of this research is to design a comprehensive workflow for researchers and students to
follow when they want to create reliable and detailed 3D models of archaeological sites for public engagement.

2.1. Advantages

While archaeological work is important for bringing unique historical remains to light and expanding our understanding of past peoples and cultures, excavation (and some forms of conservation and restoration) is an irreversible action that can cause the loss of data (Hornak, 2017). Most archaeological projects also face challenges with time and money that shape their fieldwork methods (e.g., salvage archaeology). Once exposed, the archaeological remains are vulnerable to destructive human activities (e.g., looting) and natural disasters (e.g., flooding, erosion). It may be true that an archeological site could be secured with fences, guards, and a protective roof like at the famous archaeological sites of Çatalhöyük in Turkey and Cacaxtla in Mexico, but these interventions are quite costly and not applicable for all archaeological sites (Aslan, 1997; Soria et al., 2017). Even at sites like Pompeii where access is strictly controlled, tourists and centuries of exposure have caused immense, irreversible damage to the remains. These considerations make affordable digital documentation vital for preservation, archiving, and sharing archaeological data. Employing drones for archaeological recording provides numerous advantages over other methods that can significantly improve the effectiveness, accuracy, and interpretation of archaeological surveys and makes it easier to reach the public. Some of the advantages include the following:

2.1.2. 3D Mapping and Modeling

The latest approach to employing UAV in archaeology involves their use in mapping and 3D photogrammetry capture. Drones can be used to capture a series of overlapping images from multiple angles that can be processed with imaging software like Agisoft Metashape to create
accurate, high-resolution 3D models of archaeological sites or features (e.g., Willis et al., 2016). This technology allows archaeologists to document, analyze, and visualize archaeological data in a more comprehensive and immersive way than traditional 2D methods. In addition, the collected data from a drone assists researchers in documenting plotting artifact distributions, visualizing soil profiles, and mapping topography and stratigraphic units. While traditional methods often limit researchers to ground-level observations, one of the most significant advantages of the drone is its ability to obtain an aerial perspective of the site and create precise maps from the air. When used over a period of time, this method can provide a more complete understanding of the spatial layout and development of a site than is possible to achieve from the ground-level observation alone.

UAV photogrammetry can also be combined with terrestrial photos to enhance the quality of the digital models and build orthoimages (Remondino, 2014). For instance, the studies in Italy at the so-called Temple of Neptune in Paestum and the Roman amphitheater at Avella proved that drone images (nadir and oblique) can be combined with terrestrial photos to enhance the model’s quality and close possible holes in the model (Barba et al., 2019; Remondino, 2014) (Fig. 5). I tested this method myself at Historic Cane Hill to model the Zeb Edmiston House, which has an overhanging roof and a covered front porch and back deck that were difficult to capture with a drone alone (See Chapter 4).
2.1.3. Time, Cost Efficiency, and Safety

Traditional archaeological field surveys can be time-consuming and labor-intensive (Themistocleous, 2020). Moreover, hand-drawing archaeological features to scale like walls or pavements is also extremely time-consuming. Drones, however, can cover large areas quickly and can be used to rapidly record and map contexts in the trench, reducing the time needed for data collection, which can lead to cost savings in terms of personnel, equipment, and logistics. This is especially advantageous for small projects like MAP, which works under both time and financial constraints.

In addition to cost savings, UAVs are also often more cost-effective than traditional aerial surveys using helicopters or fixed-wing aircraft, making them accessible to smaller research projects with limited budgets like MAP. For example, a case study conducted at the archaeological site of Vlochos in Thessaly, Greece, illustrated the sort of cost-effective and rapid
aerial photography facilitated by UAVs, further showcasing the economic advantages of employing UAVs in archaeological endeavors (Vaiopoulou et al., 2020). Reducing the expense associated with precise mapping and expediting fieldwork are both essential in order to increase the accessibility of this technology to a wider range of archaeological projects (Hill, 2019). In the last few years, DJI drones have become competitive in cost to hand-held cameras, used in terrestrial photogrammetry and field recording. Low-cost DJI drones like Mavic Air 2 and Mini 3 Pro cost between $800-1200 (DJI, 2023). Furthermore, archaeologists can use satellite imagery for free in their projects, but they do not have high resolution and multiple angles to produce 3D models. High-resolution satellite data, though available, can be expensive and often comes with large file sizes (Nikolakopoulos et al., 2019).

Early photogrammetric studies in the field were conducted on different platforms such as fireman’s ladders, lifts, and towers, which posed safety risks to the researchers (Fussell, 1982; Jeyapalan, 1980) (Fig. 6). Before I introduced UAV photogrammetry to the project, MAP excavators would climb on top of cars to capture aerial photos of a trench. If proper flight protocols are followed and the drone is flown in suitable conditions, UAVs offer a safer alternative.
2.1.4. Non-Invasive

Drones allow archaeologists to collect data without disturbing the archaeological site itself. This is particularly important for delicate or sensitive sites where physical access could cause damage. Wiseman et al. (2020) indicate, for example, that it is crucial to identify non-invasive techniques that can swiftly document the Hominin fossil site without causing any additional harm to the fossil beds at two prehistoric footprint sites: Formby Point and Happisburgh, United Kingdom. Existing 3D data capture methods like laser scanning or photogrammetry can sometimes be intrusive since they require the photographer to step in/around the area being recorded and sometimes involve setting up tripods, which in this case could disturb fragile sediment layers or cause inadvertent damage to the fossil material. Drones, however, can accomplish data capturing with a remote controller at different angles and altitudes from any location around the site (Castillo et al., 2019). For instance, the recent low-cost drones
have a strong antenna that can control the drone from a long-range (approx. 10-12 km) distance (DJI, 2023). Therefore, data can be collected without entering the site. Thanks to obstacle sensors built into the DJI drones, which alert the pilot if the drone is in danger of colliding with something, I was able to capture data at Podero Marzuolo and Zeb Edmiston House while standing at a distance from the trenches and House, following the flight of the drone on the remote controller’s screen. Furthermore, UAVs have a smaller environmental footprint compared to manned aircraft, making them a more environmentally friendly option (Park et al., 2018).

2.1.5. Inaccessible Sites

As previously mentioned, drones can be used to record inaccessible cultural heritage that might be difficult for researchers to explore on foot because of challenging terrain or in locations with limited accessibility. Castillo et al. (2019) highlight the use of drones in documenting archaeological sites on mountains and slopes, which are typically inaccessible. The archaeological ruins of the ancient port city of Syedra in Turkey, for instance, is located on a steep slope that can be challenging or even dangerous for researchers to access (Magnani et al., 2020) (Fig. 7). Marzuolo, on the other hand, has limited access because it is located on private land in a rural area of Tuscany that does not attract much tourism. Although Fentress (2022) calls Marzuolo, “a significant exception in the range of otherwise unexceptional peasant properties,” MAP’s “leave no trace” approach means that the trenches are backfilled at the end of every season so that at the end of the project the remains of the site will not be visible (Fig. 8). As a result, the detailed 3D models produced from UAV and terrestrial photogrammetry are extremely important records that can be shared with the public via platforms like Sketchfab to increase visibility for this exceptional Roman rural site.
Fig. 7: The ruins of ancient Syedra in Turkey extend down a steep, difficult to access slope. Photo by the Syedra Project.

Fig. 8: Left: MAP’s Areas 21000 and 22000 at the end of excavation. Right: Areas 21000 and 22000 after backfilling.

2.1.6. Site Monitoring

Drones offer a distinctive bird's-eye view that enables archaeologists to capture all-encompassing observations of expansive archaeological sites, terrains, and characteristics that might be challenging to perceive from ground level. Although this task can be more readily accomplished using satellite imagery, drones provide real-time video monitoring that obtains high-quality data. Consequently, UAV photogrammetry can generate highly detailed cartographic materials that enable us to achieve the required precision for ongoing site
monitoring to track changes, erosion, and preservation efforts over time but also on a day-to-day basis. This can provide valuable information for planning future strategies in the field as well as more long-term conservation and management strategies. This realization has led to a transition from traditional methods (e.g., Total Stations, 2D photographs, field notebooks) to innovative photogrammetric techniques. Rinaudo et al. (2012), for instance, demonstrated the utility of daily monitoring of the excavations of a Roman villa in Aquileia, Italy with a low-cost aerial photogrammetry method and largely automated modeling process. The models produced at the end of each day were used to plan work and adjust excavation strategies for the following days. Starting in 2022, MAP also started using terrestrial and UAV photogrammetry on a daily and bi-weekly basis respectively during the excavation season to track the progression of work in the trench and guide plans and fieldwork strategies. These records have become important tools for trench-side analysis but also for interpreting data post-excavation, especially since the site is backfilled and cannot be revisited by researchers.

As 3D models have become an essential tool when cultural heritage sites are damaged due to intentional destruction, neglect, or natural disasters, drones are now being used to monitor at-risk sites, rescue data before a site is damaged, and guide conservation efforts after damage. For example, the recent earthquakes, wildfires, and floods in Turkey caused damage to cultural sites, and groups like the digital heritage nonprofit CyArk are using a combination of LIDAR and photogrammetry to monitor and digitally preserve these at-risk cultural heritage sites around the globe.

2.1.7. Public Engagement

UAV photogrammetry, as argued above, can be instrumental for scholars in documenting cultural heritage sites. Beyond simple 3D records or as fancy illustrations for publications,
however, the models created from drone imagery can also serve as a potent means to virtually experience the target location (Barba et al., 2019). Disseminating the models on free online platforms like Sketchfab or through virtual exhibits hosted on museum or project websites, are effective ways for researchers to share their data with a global audience, facilitating learning and enabling the remote exploration of lesser-known or challenging-to-access archaeological sites. The Sketchfab website provides a comment box for viewer impressions and tracker to count how many people viewed a model. This is useful for monitoring the level of public interaction with cultural heritage models. The platform is testing a new feature through Sketchfab Teams accounts that track also the viewer’s country, which will show the global reach.

Within public archaeology, the interconnection of method and theory assumes a pivotal role in shaping how we reveal, interpret, and convey historical narratives to the wider community. Conventional archaeological practices typically involve excavation, analysis, and the interpretation of material culture. The theoretical underpinnings guiding these practices have evolved over time, embracing methodologies such as processual archaeology, post-processual archaeology, and, more recently, public archaeology (Richardson & Sanchez, 2015).

Public archaeology, positioned as a sub-discipline, underscores the significance of involving the public in both the processes and interpretations of archaeological endeavors. This collaborative ethos recognizes that archaeology extends beyond the exclusive purview of academics, constituting an integral aspect of the collective memory and identity of communities. The theoretical frameworks in public archaeology often center around matters of representation, community engagement, and the ethical obligations of archaeologists (Schadla-Hall, 1999). In this context, digital archaeology has emerged as a transformative influence, providing novel tools and methodologies that facilitate inventive approaches to engaging the public. Technologies such
as 3D modeling, virtual reality, and interactive online platforms enable the development of immersive experiences that bring life to archaeological sites and artifacts. These digital tools not only amplify the accessibility of archaeological information but also create avenues for public involvement in research processes.

3D models created with UAV data, accessible via online platforms, provide an immersive visual experience, enabling users to virtually navigate archaeological sites and examine artifacts. This digital accessibility goes beyond geographical constraints, making cultural heritage more widely available. The integration of 3D models into public archaeology serves as an educational resource, enriching public comprehension and fostering greater appreciation for archaeological pursuits. Furthermore, the interactive functionalities of these models encourage active involvement, nurturing collaborative conversations between researchers and the general public. This process contributes to narrowing the divide between academia and the broader community, facilitating a joint exploration of our cultural history.

3D models can also be incorporated into other digital projects, such as virtual reconstructions and 3D printing (Calin et al., 2015). Two researchers are now working with MAP’s photogrammetry data to develop virtual reality applications. Cole Juckette, PhD candidate at the University of Glasgow, is designing an internal-facing Virtual Reality (VR) app for the project directors to use in exploring and interpreting their data. Virtual Reality is the utilization of computer modeling and simulation allows individuals to engage with a synthetic three-dimensional (3-D) visual or alternate sensory environment (Lowood, 2023). With mechanics like Minecraft, the VR app will allow the directors to test hypothetical reconstructions of the structures on site. Tom Keep, PhD candidate at the University of Melbourne, is creating a public-facing VR application, which visualizes Marzuolo’s blacksmith workshop at the time it
was in use in the mid-1st c. AD. This app will be used in local Italian schools for cultural heritage education (Fig. 9).

![Figure 9: Alpha version of Keep’s VR application of Marzuolo’s blacksmith workshop, which integrates photogrammetry models.](image)

### 2.2. Limitations

Despite the benefits, it is important to note that drone-based archaeological documentation also comes with challenges, such as regulatory considerations, the technical expertise required to effectively use the drone, and potential ethical concerns related to privacy and site preservation. However, this research mainly focuses on the drone side limitations in terms of hardware abilities and legal considerations.

#### 2.2.1. Camera Resolution

While drone camera technology has improved significantly, it may not have the same image quality as ground-based cameras, particularly in high-level light conditions. Terrestrial photogrammetry is conducted by handheld cameras in high-resolution quality thanks to changeable lenses. On the other hand, low-cost drones such as DJI Mavic 2 and DJI Mini 3 pro, the drones used in this study, have onboard cameras that are not modifiable and undetachable. For this reason, drones must fly at low altitudes to capture sharp photos (Seifert et al., 2019). DJI Mini 3 Pro has 1/1.3-inch sensor size and Mavic Air 2 has 1/2-inch sensor size and both drones
come with a maximum 48 MP photo resolution. The small sensor size results in less detail in the photos. Therefore, compact cameras can get higher quality by altitude and angle. However, low-cost drones have sufficient camera quality for analyzing archaeological sites in low-light conditions (Hamilton et al., 2016; Baker, 2019).

2.2.2. Regulation

UAVs are subject to a range of regulations worldwide to ensure their safe and responsible operation. These regulations vary from country to country, reflecting the diverse applications and concerns associated with UAVs. In general, common regulatory principles include rules related to drone registration, pilot licensing, flight altitude and airspace restrictions, and privacy and safety guidelines. Many countries have designated rules according to the purpose of flight, dimension, and weight. In the United States, regulations are categorized based on their purpose, whether for recreational or commercial use, while in Europe, they are classified according to the drone's weight (Remondino, 2014; Stöcker et al., 2017). Additionally, UAVs are often required to stay within the operator's visual line of sight, and nighttime and commercial drone operations may necessitate special permits (Cracknell, 2017). As technology and drone usage continue to evolve, governments around the world are adapting their regulations to strike a balance between promoting innovation and ensuring safety, privacy, and security for all citizens (Lee et al., 2022). It is crucial for drone operators to be aware of and comply with the specific regulations in their respective regions.

The drone pilots in the United States must follow Federal Aviation Administration (FAA) rules. The first step is to register the drone for the FAADroneZone, the official FAA website for drone services. The paper registration process should be used if the drone is 55 pounds or greater. Legislation mandates that individuals flying recreationally must undergo an aeronautical
knowledge and safety examination, and present evidence of successful completion if queried by law enforcement or FAA officials. The Recreational UAS Safety Test (TRUST) was created to fulfill this stipulation. TRUST delivers both education and assessment on crucial safety and regulatory details. For those operating drones recreationally under the Exception for Recreational Flyers, passing this test is a prerequisite before engaging in flight (FAA, 2023). The safety guidelines of the FAA must be complied with during the flight. The drone regulations are constantly updated, and the most recent information can be found at https://www.faa.gov/uas/recreational_flyers.

2.2.3. Stability and Maneuverability

While drones bring about numerous advantages, they also come with stability limitations which can impact their effectiveness in data collection. The stability of drones in archaeological sites is highly contingent on the territorial archaeological context (Pecci, 2020). Variables such as wind conditions, the ruggedness of the terrain, and the presence of obstacles like trees, poles, and buildings can greatly affect the stability and maneuverability of drones, especially low-cost ones which might lack advanced stabilization features found in more expensive models. These external factors can cause drones to veer off course, potentially leading to crashes or inaccurate data collection, which in turn could impede the archaeological documentation process.

The Zeb Edmiston House in Cane Hill, for instance, sits in a small clearing surrounded by large trees, which made flying the drone challenging. While capturing photogrammetry of the House, the DJI Mini 3 Pro drone collided with a small tree branch that I suspect was not large enough to set off the drone’s obstacle sensors. Another limitation I faced was capturing data in narrow and darker areas such as the ceilings on the back deck and front porch, which resulted in
some distortion in the model. The drone is not suitable for taking photos of sharp points because of its maneuverability and camera angle.

The size of the drone is also a consideration when traveling. For MAP director Dr. Vennarucci, the small size of the DJI Mini 3 Pro (249 g) was an advantage since she was transporting a lot of other technology and equipment with her on an intercontinental flight to Italy. Since lithium batteries cannot go in checked bags, all the technology had to fit inside her carry-on suitcase. The drone’s small size, however, meant that MAP was not able to fly it on windy days. The wind pushed the drone around while taking photographs which caused distortion in the model. The DJI drone company is striving to enhance drone stability in windy conditions, yet this remains a challenge.

There are some mobile applications available that track flight conditions for the drone. The FAA, for instance, has created the B4UFLY app that gives the operator a clear “status” indicator on whether it is safe to fly or not in a specific location. It also shows restricted flying zones and allows registered users to upload their flight status such as flight time and area so that other operators can take precautions (FAA, 2023).

To sum up, despite some limitations, UAVs have revolutionized the field of archaeology. Capturing photogrammetry with a drone provides new ways to document a site and the 3D models produced with drone imagery are offering researchers new insights on their site and innovative ways to share information with the public, ultimately leading to a deeper understanding of cultural history.
CHAPTER 3: METHODOLOGY

This chapter focuses on the drone photogrammetry workflow to open inaccessible archaeological sites to the public. While MAP was already using terrestrial photogrammetry in the field, I introduced UAV photogrammetry to the project’s digital recording methodologies. As stated above, before 2022, the project only took aerial photographs once at the end of each season using a balloon. The 3D modeling workflow I designed closely adheres to workflows developed by other archaeological projects (Prins, 2016; Buzon et al., 2021; Over et al., 2021; Callieri et al., 2011); however, I made some modifications to update the workflow’s steps to account for aerial photogrammetry tools and tailored it to fit MAP’s field strategies and research goals. Consequently, the workflow is best suited for recording large archaeological trenches that have the walls and profiles. Depending on the specific project requirements, the researchers may need to modify and adapt it accordingly. This workflow aims to provide researchers who have limited to no experience with UAV photogrammetry with the practical details they need to do the following (Fig. 10):

1. **Preparation:** prepare for UAV photogrammetry

2. **Data Collection:** obtain faster, more reliable photogrammetric data of the excavation areas on a more regular basis (daily or bi-weekly) to closely monitor the progression of work on site and make better-informed work plans.

3. **Data Processing:** process the UAV data into high-quality 3D models, which serve as detailed digital records of the site.

4. **Model Publishing:** online publishing of the 3D models with descriptive annotations to drive public engagement with the site.
The data in this project were collected with two different types of DJI drones, which is the world leader in drone technology, controlling ca. 70% of the market share worldwide (Simmie, 2017). The DJI Mavic Air 2, an affordable mid-level drone, was employed in 2022. The data used as an example in the workflow outlined in this chapter was collected at Marzuolo in Area 20000 on July 15, 2022, with the Mavic Air 2. Since the DJI Mavic Air 2 is no longer in production and MAP project directors wanted a drone <250g to comply with recreational drone laws in Italy, a DJI Mini 3 Pro, which has been reviewed as the best affordable compact drone for beginners, was used the following year to capture data at Marzuolo. The same drone was also used to model the Zeb Edmiston House at Historic Cane Hill in 2023. Both drones have a CMOS (Complementary Metal-Oxide Semiconductor) camera sensor that can take between 12MP and 48 MP photos and can fly up to 34 minutes on one battery as well as other features that make them well-suited to photogrammetry capture (Table 1).
<table>
<thead>
<tr>
<th>DJI Mavic Air 2</th>
<th>DJI Mini 3 Pro</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="DJI Mavic Air 2" /></td>
<td><img src="image2" alt="DJI Mini 3 Pro" /></td>
</tr>
<tr>
<td>• Out of production</td>
<td>• $759-1,084</td>
</tr>
<tr>
<td>• 570 g</td>
<td>• 249g</td>
</tr>
<tr>
<td>• 42.5 mph</td>
<td>• 36 mph</td>
</tr>
<tr>
<td>• 34-min flight time (11.5 miles)</td>
<td>• 34-min flight time (11 miles)</td>
</tr>
<tr>
<td>• ½” CMOS sensor, 48MP images and 4K/60p video</td>
<td>• 1/1.3” CMOS sensor, 48 MP images and 4K/60p video</td>
</tr>
<tr>
<td>• 1080@p30fps image transmission up to 6.2 Miles</td>
<td>• 1080@p30fps image transmission up to 7.4 miles</td>
</tr>
<tr>
<td>• HDR video, images, &amp; panoramas</td>
<td>• HDR video and images (24/25/30fps)</td>
</tr>
<tr>
<td>• APAS 3.0 Obstacle Avoidance</td>
<td>• Three-way obstacle avoidance (front, back, bottom)</td>
</tr>
<tr>
<td>• FocusTracking – Point of Interest</td>
<td>• FocusTracking – Point of Interest</td>
</tr>
<tr>
<td>• GPS + GLONASS</td>
<td>• GPS + Galileo + BeiDou</td>
</tr>
<tr>
<td>• Return to Home &amp; Precision Landing</td>
<td>• Return to Home &amp; Precision Landing</td>
</tr>
<tr>
<td>• RC-N1 remote requires smartphone intermediary</td>
<td>• DJI RC remote</td>
</tr>
</tbody>
</table>

Table 1: Left: DJI Mavic Air 2. Right: DJI Mini 3 Pro.

3.1 Preparation

Before starting the data acquisition, the area to be photographed must be cleaned well and all tools and equipment should be removed from the trench. Operators should check the wind speed to ensure that it is safe to fly the drone and consult with the field supervisor or director on what needs to be modeled and the flight plan. The UAV models in this project were all georeferenced using Ringed Automatically Detected (RAD) targets placed around the edge of the trench or structure. The positions of the targets were recorded with a total station prior to flying the drone.
3.1.1 Lighting

The most important factor to take into account prior to data capture, but one that is also very difficult to control in the field, is the lighting situation. It is advisable to prioritize data collection when sunlight is low or there is cloudy weather because light reflecting off the ground can cause distortions in the model (Gasparini et al., 2020; Hamilton, 2016). As can be seen in Figure 11 below, the data used to process the first model was collected in the low light of the morning, resulting in a higher resolution of the walls, drain stones, and soil deposits. The model below was processed with data collected on the same day at noon in high light after the drain stones had been removed from its ditch. This resulted in some distortions in the model because of the light reflecting off the soil. Therefore, images should be taken in as low light as possible.
Figure 11: Models produced with photogrammetry captured on the same day. Above: data captured in the morning in low light. Below: data captured at noon in high light.

3.2. Data Collection

Data should be captured frequently to monitor work in progress during an excavation. As stated above, the models produced can help shape work plans on subsequent days, inform field strategies, and be used in post excavation interpretations. During the 2022 excavation season at Marzuolo, I recorded Area 20000 at the end of every working day, which was adjusted to bi-weekly recording in 2023.

In addition to the regularity of data capture, researchers must carefully consider the three essential components that are required to create high quality 3D models with a drone: flying altitude over the trench, flight patterns, and the steadiness of the flight are all crucial for producing spatially accurate, high-resolution models (Mozas-Calvache et al., 2012; Ruzgiene et al., 2015). Poor planning in any one of those categories may cause the photos to fail to align or a poor-quality model with holes and distortion.

3.2.1 Altitude

Drones must be operated at the most effective altitude to achieve the highest level of ground sample distance. Due to the camera resolution of low-cost drones, data should be collected between 5 and 15 meters (m) from the ground. There is a positive correlation between image resolution and camera height (Castillo et al., 2020: Hamilton, 2016), as the images in Figure 12 below illustrate. The photo taken from a height of 7m produced a blurry photo while the details in the photo taken from 3m are clearer and easier to read.
Figure 12: Displaying part of a stone drain (SU 20105) in Area 20000. Above: This photo has been taken from 7m in altitude. Below: This image was captured from 3m in altitude. Both models were taken at 70% zoom.

3.2.2 Flight Pattern

Since Agisoft Metashape builds a point cloud (the basis of the 3D model) by matching pixel groups between images, a thick coverage of photos (ca. 50-75% overlap between photos) from a diverse range of angles is necessary to generate a high-quality 3D representation of a trench or structure. A point cloud consists of discrete data points located in space, representing a 3D shape or object. If there are too few photos or not enough overlap between photos, there will be holes and distortions in the final model. This makes planning the flight pattern of the drone important to make certain there is good coverage of the target area.
Operators on this project used FocusTracking – Point of Interest (PoI) mode on the drone. This feature lets operators designate a certain area of interest (e.g., a trench) on the DJI RC remote. The drone will then automatically circle the perimeter of this designated area at a specified speed, which allows the operator to capture photogrammetry with a 360-degree view of the PoI area (Fig. 13). In this example, the center of Area 20000 was marked on the DJI RC’s screen as the PoI and the flight speed was set to slow-medium (Fig. 14).

Figure 13: The drone’s flying pattern over Area 20000 in PoI mode. (Photo by Eray Can)
Although PoI mode allows the operator to automatically fly over the focused area, it only supports a single shot camera mode with 12MP resolution. Therefore, the 167 images collected for the July 15 model were taken at a relatively low altitude (5-12m) by rotating the camera for top-down and oblique angles. The oblique (45°-50°) and nadir (vertical) images are vital for producing accurate and high-resolution models. To avoid the drone’s shadow in the photos, flights were conducted at a minimum height of 5 m, which does not compromise the resolution. By adjusting the angle and altitude of the camera, the operator can ensure a thick coverage of photographs (Fig. 15).
3.2.3. Steady Flight

To obtain high-quality photos, the drone must fly in good weather conditions. Even though our DJI drones have gimbal-lock features that automatically adjust the camera to ensure the footage is always stable, the wind may cause vibrations that can result in blurriness in the images. The DJI Mini 3 Pro can handle wind speeds up to 24 mph (level 5 - moderate wind resistance). While as mentioned above, there are mobile apps that track weather conditions for drone flying, as a general rule, follow the chart below (Fig. 16):

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean Wind Speed</th>
<th>Appearance of Wind Effects On a Tree</th>
<th>On Land</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm</td>
<td>&lt; 1 knot &lt; 2 km/h</td>
<td>Still</td>
<td>Smoke rises vertically</td>
</tr>
<tr>
<td>Light Air</td>
<td>1 – 3 knots 1 – 5 km/h</td>
<td>Leaves rustle</td>
<td>Smoke drifts, wind varies are still</td>
</tr>
<tr>
<td>Light</td>
<td>4 – 6 knots 6 – 11 km/h</td>
<td>Leaves rustle</td>
<td>Wind felt on face, vanes begin to move</td>
</tr>
<tr>
<td>Gentle</td>
<td>7 – 10 knots 12 – 19 km/h</td>
<td>Leaves and small twigs move</td>
<td>Flags flap</td>
</tr>
<tr>
<td>Moderate</td>
<td>11 – 16 knots 20 – 28 km/h</td>
<td>Small branches move</td>
<td>Dust and loose paper lifted</td>
</tr>
<tr>
<td>Fresh</td>
<td>17 – 21 knots 29 – 38 km/h</td>
<td>Small trees in leaf begin to sway</td>
<td>Flags fully extended</td>
</tr>
<tr>
<td>Strong</td>
<td>22 – 27 knots 38 – 49 km/h</td>
<td>Larger branches shake</td>
<td>Whistling in wires, umbrellas become difficult to use</td>
</tr>
</tbody>
</table>

Fig. 16: Wind chart from https://www.droneblog.com/dji-mini-3-pro-wind-resistance/.
3.3. Data Processing

The collected photogrammetry data were processed in Agisoft Metashape with an educational license for the professional edition version 2.0.2 ($549.00). The professional edition has georeferencing capabilities. Metashape uses Structure from Motion (SfM) technique, which is a photogrammetric method to produce 3D models from 2D images. I largely followed the steps laid out in the “General Workflow” section of Metashape’s User Manual (Agisoft, 2023) with a few adjustments (see Fig. 10 above). Processing 3D models requires a computer with significant RAM (32 gigs preferred) and a powerful graphics card. The recommended system requirements can be found at https://www.agisoft.com/downloads/system-requirements/. I used a Windows 10 operating system laptop with Intel Core i7 9750H 2.69GHz Processor and 16 GB Memory RAM.

3.3.1. Importing Photos: Workflow > Add Photos

Importing photos into Metashape is the first step in data processing. To build the model of Area 20000 at Marzuolo, captured on July 15, 2022, I imported 167 images taken from different angles with the DJI Mavic Air 2. To add photos to the Workspace chunk, click **Workflow** in the top toolbar then select **Add Photos** to browse to the folder that includes the images you want to import. The photos can also be dragged from the origin folder into the Workspace chunk. Note that the number of photos impacts the processing time and size of the model.

3.3.2. Estimate Image Quality: View > Photos > Estimate Image Quality

Low-quality photographs can have a detrimental impact on the alignment outcomes and the overall texture quality. To address this issue and remove poorly focused images during processing, Metashape recommends utilizing its automatic image quality estimation feature. Removing the images with a quality score lower than 0.5 units from the alignment and texture
generation procedures is advisable. To check image quality, right click on a photo under Camera in the Workspace’s chunk or open the Photos pane (View > Photos) right click on one of the photos in this pane to select **Estimate Image Quality**. The analysis should be applied to **All Images**, and then click **OK**. After completing the analysis procedure, a number representing the estimated image quality will appear in the quality column of the Photos pane.

**3.3.3. Alignment**

Once the photos are imported to the Workspace, align them. In this step, Metashape tries to calculate camera positions and orientations and to match common points between the imported photos to establish how the photos relate to each other in 3D space. Properly overlapping photos are critical for successful alignment. In the **Workflow** menu, select **Align Photos** and accept the default parameters in the **Align Photos** dialog box (**Fig. 17**). These parameters are set to “high:” the higher the accuracy the more accurate the camera positions estimate will be, but the longer the alignment process will take. Once the alignment process is finished, the calculated camera positions and a cloud of tie points (matching points between photos) will be shown in the Model window (**Fig. 18**).

![Fig. 17: Metashape’s default parameters for the photo alignment step.](image-url)
Figure 18: Tie point cloud produced after the alignment step.

3.3.4. *Optimize Alignment: Tools > Optimize Cameras*

The optimize alignment function is an essential step in the photogrammetric workflow. The main purpose is to refine the alignment of photos and accurately position them in a common coordinate system, creating a dense point cloud that forms the basis for the 3D model. Go to the *Tools* and select *Optimize Cameras*, then click OK with default parameters selected (f, cx, cy, k1, k2, k3, p1, p2).

3.3.5. *Building Dense Cloud: Workflow > Build Dense Cloud*

Once the alignment step is done, Metashape is ready to generate a dense point cloud, a dense concentration of data points in 3D space that represent the physical environment captured by UAV photogrammetry in the field. Each point in the dense cloud has an X, Y, and Z coordinate. To build the dense cloud, click *Workflow* and select *Build Dense Cloud*, set the quality to *High* to obtain a high-resolution model. After processing, the dense cloud will appear in the Model window (Fig. 19). Once the dense cloud is processed, it is possible to crop the
cloud and delete any unnecessary points using the selection tools under Model. Doing this will speed up the processing time in the next step.

![Figure 19: The screenshot shows the dense cloud of the Area 20000 model.](image)

3.3.6. **Building Mesh: Workflow > Build Mesh**

Metashape is capable of generating a polygonal mesh using the point cloud data. The mesh is composed of a set of vertices (single point in 3D space), edges (line connecting two vertices) and a face (a closed loop of edges) and defines the shape of the trench or structure. To build a mesh, Click Workflow and Select Build Mesh. Source data should be Dense Cloud and Surface type Arbitrary (3D).

3.3.7. **Building Texture: Workflow > Build Texture**

The next step involves laying the original photos over the 3D mesh as textures to give the model a realistic appearance. Select the Build Texture from the Workflow menu. In the Build Texture dialog box run processing with default parameters. When processing is complete, textured model will appear in the Model window (Fig. 20).
Figure 20: Above: default parameters in texture processing. Below: the completed texture of the Area 20000 model.

3.3.8. Decimate Mesh: Tools > Decimate Mesh

Decimation is a technique employed to reduce the level of detail in a model by substituting a high-resolution mesh with a lower-resolution alternative while still effectively preserving the object's shape. Metashape typically generates 3D models with overly intricate details, so it is often beneficial to follow up the geometry calculation with a decimation process. Decimating the model serves another purpose, which is to reduce the file size for uploading to Sketchfab, as the platform enforces a maximum model file size of 100MB for free accounts. Additionally, this helps improve the model's loading speed for viewers.
To decimate the model, Click **Tools** and then Select **Decimate Mesh**. In the Decimate Mesh dialog box, target face count should be between 50,000-100,000. The model in this workflow has been decimated by 50,000 face counts. The texture atlas is eliminated as part of the decimation procedure. After decimation is done, the texture must be rebuilt (see 3.3.7 above). The final texture of this Area 20000 model was rebuilt with default parameters.

### 3.3.9. Exporting to Model

Before exporting the model, clean it up again by removing in remaining unnecessary point using **Free-Form Selection** under **Model**. Utilize the Resize Region and Rotate Region toolbar buttons to modify the dimensions and alignment of the bounding box. After aligning the bounding box to your specifications, you can proceed to generate a new animation track, either horizontal or vertical. When the model is ready, click **File** and then select **Export Model**. The model should be exported as .fbx file with Jpeg file format for the texture.

### 3.3.10. Data Storage

MAP’s photogrammetry data is stored on Box, a secure, cloud-based, content management system with unlimited storage provided by University of Arkansas's IT team. The data is also backed up on external hard drives. When the project finishes, this data will be deposited in a disciplinary or institutional repository (e.g., Open Context) that can ensure the long-term sustainable discovery, access to, and preservation of these data for use by other researchers, educators, and interested members of the public.

### 3.4. Model Publishing

Sketchfab is a free-to-access online platform that has revolutionized the way 3D content is created, shared, and experienced. With its functional interface and robust features, Sketchfab simplifies the process of 3D content creation, curation, and collaboration, making it an essential
tool for professionals in various industries, like archaeology, architecture, 3D design and art, game development, and virtual reality (Sketchfab, 2022). The models hosted on Sketchfab are also being used as pedagogical tools to immerse students in cultural heritage. By integrating Sketchfab into this workflow, I aim to enhance the visibility of hard-to-access cultural heritage sites and help viewers, with not much archaeological knowledge, learn about the archaeological process.

3.4.1. Uploading 3D Model to Sketchfab

Sketchfab allows free account holders to upload 3D models up to 100Mb file size and to include up to 10 annotations per model. I published my models on a professional account ($180/yr) that allowed me to upload models up to 200MB in size and to add up to 20 annotations per model. After signing into the account, initiate the process by selecting the orange Upload button located at the upper-right corner. Then, simply drag and drop your decimated model's .fbx file and its texture file (.jpg or .png) into the designated upload box (Fig. 21)

Figure 21: Uploading the Area 20000 model to Sketchfab.
### 3.4.2. Editing 3D Settings

After the model is successfully uploaded, it is visible in a window on the left side of the screen. To make edits, Click **Edit 3D Settings**. If the model is darker than usual, in the **General Settings**, pick **Shadeless** from the **Shading** option (Fig. 22).

![Editing the Area 20000 model’s 3D settings in Sketchfab.](image)

**Figure 22:** Editing the Area 20000 model’s 3D settings in Sketchfab.

Under 3D Settings, it is also possible to add descriptive annotations. Click the lightbulb annotation icon and double click on the desired point on the model to add annotation (Fig. 23). A number in a circle will appear in that spot linked to a text box where you can add a title for the annotation and short description. Notes should be written with a public audience in mind and should provide key information to help viewers interpret the model and its significance.

![Adding annotations to the Area 20000 model on Sketchfab.](image)

**Figure 23:** Adding annotations to the Area 20000 model on Sketchfab.
Sketchfab also has a VR mode that transports any viewer with an Oculus Quest, Oculus Rift, HTC Vive, or Microsoft Mixed Reality headset to the trench’s edge, where they can explore the model in a 1:1 scale (Fig. 24). To set the scale for the VR experience, click on AR/VR, and adjust the scale to 1. It is possible to position the model anywhere in your model by using the green and red arrows and blue wheel. Wherever the model is positioned, this is where the VR experience begins.

![Fig. 24: Editing AR/VR settings of the Area 20000 model in Sketchfab.](image)

### 3.4.3. Publishing 3D Model

Once finished, save settings and click **Publish** to make the model available to view. Now the model is only available to view, but it is also possible to make the model free to download.
CHAPTER 4: CASE STUDIES

This chapter presents two case studies that illustrate the application of the photogrammetry workflow in this research (See Chapter 3). The case studies were conducted in two very different cultural heritage sites: the Roman settlement at Marzuolo in Italy and the Zeb Edmiston House in Historic Cane Hill, Arkansas. Both cultural sites are located on private land and/or in rural areas, making them difficult for researchers and the public to access. These case studies demonstrate my workflow's versatility and the potential for UAV to improve field documentation, data analysis, and public outreach with cultural heritage sites. This chapter also highlights the project-specific challenges I encountered, emphasizing the importance of being able to improvise the workflow to respond to a project’s priorities or unexpected obstacles (e.g., terrain, weather) during aerial photogrammetry.

4.1. Marzuolo Archaeological Project (MAP)

MAP explores the Roman-period minor center at Podero Marzuolo, which is located approximately 35 km from the coast in a rural area of Southern Tuscany, Italy (Fig. 25). The archaeological site is situated on an alluvial plateau overlooking the Orcia river in the northernmost part of the present-day municipality of Cinigiano, whose hilly landscape in Roman times would have been characterize by scattered small-scale farming. Marzuolo was first excavated in 2012 and 2013 by the Roman Peasant Project (Bowes et al. 2021) but work later resumed in 2016 under the directors of MAP. The project’s primary objective is to reconstruct the intricate details of this nucleated settlement with precision and contextualize its development within the local context of its rural community, as highlighted by Van Oyen et al. (2021).
Marzuolo has a long history of occupation, spanning from the Late Republican era (the first century BC) to the Medieval period (Eleventh-Twelfth century AD). During the first century AD, the northwestern part of the site was occupied by a significant masonry complex dedicated to diverse crafts, including metalworking, woodworking, and pottery production. While still actively in use, the complex was destroyed by a fire in the middle of the first century AD, providing a unique chance to examine how the different crafts were organized within the workshops (Van Oyen et al., 2022) and how their spatial arrangement might have supported cross-craft interactions (Vennarucci et al., 2018). Located in a small-scale peasant landscape, recent excavations emphasize that the site served its rural community as a center of production and re-distribution of products (metal objects, terra sigillata pottery, wine) (Van Oyen et al., 2021). According to esteemed archaeologist Elizabeth Fentress, “the site at Podere Marzuolo is something genuinely new” with the potential to reshape how we think about the Roman countryside (Fentress, 2022).
Because the site is located on private property, MAP is required to backfill the site at the end of each season. The site will never be open to researchers or the public to visit. For this reason, I was invited to join MAP’s team in 2022 to help evolve their digital recording methodologies by designing a UAV photogrammetry workflow and train staff and directors on how to use it. The project’s 3D models are crucial evidence of the site and one of the best means for sharing the site with a wider global audience.

4.2. MAP 2022

In its 2022 season, MAP focused on completing the excavations of Room B (Area 17000) and Room D (Area 20000) in the northern part of the large multi-craft workshop complex mentioned above (Fig. 26). The project also opened a new Area 21000 in the southwest part of the plateau where magnetometry showed the remains of another large masonry structure. In consultation with Dr. Vennarucci, we decided to test and refine my workflow by capturing daily photogrammetry of the western half of room D in Area 20000. When the eastern half of this room was excavated in 2018, two large cylindrical wine tanks were discovered that were used in wine production. MAP directors hoped to find more evidence of wine production or multi-craft production in the other half of the room, and so this trench was given special priority. Directors also wanted a detailed record of the stratigraphic sequence of this complex.
4.2.1 Discussion of Data Capture Methods – MAP 2022

In 2022 I used a DJI Mavic Air 2 to capture a total of 14 photo sets of the trench in Area 20000 between June 28 to July 15, following the steps I outlined in Chapter 2.1.2. The trench I recorded was approximately 3 m x 5 m in size (Fig. 27), which meant that I could capture the entire area with PoI mode. By way of example, Table 2 shows the flight details of five end-of-day models from Area 20000 that I selected to publish on Sketchfab (see 3.2.2 below). I took on average between 150-250 photographs per model, and the flight time was usually between 15-20 minutes, well below the 34-minute maximum that the battery pack allows.
Fig. 27: Plan of the trench in the western half of Room D in Area 20000. (Shared with MAP’s permission.)

<table>
<thead>
<tr>
<th>Date (dd/mm)</th>
<th>Photos (n)</th>
<th>Flight Time (min)</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29/06</td>
<td>141</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>01/07</td>
<td>198</td>
<td>18</td>
<td>6</td>
</tr>
<tr>
<td>05/07</td>
<td>159</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>08/07</td>
<td>248</td>
<td>23</td>
<td>14</td>
</tr>
<tr>
<td>15/07</td>
<td>167</td>
<td>21</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2: This table shows the flight details for five of Area 20000’s end-of-day models published to Sketchfab.

The weather and terrain (the site is located in an open plateau) caused no problems for flying the DJI Mavic Air 2 (570 g) but I did encounter challenges with lighting. Although cloudy weather or early morning is the best time to capture data, I usually took my end-of-day model around noon in high light. The soil has a high clay content and the light reflecting off it impacted the quality of some of the models, but the directors made this sacrifice. Since MAP has short 4-week seasons, they work at a fast pace. The project combines open area archaeology with rescue archaeology techniques, to reach natural geology before they must backfill the trenches at the end of the season. For this reason, doing aerial photogrammetry first thing in the morning when
the team arrived on site was not ideal because the team had to wait to start work. At the end of the day, photogrammetry could be captured while the team packed up artifacts, tools, and equipment.

4.2.2. Discussion of 3D Modeling Results – MAP 2022

The 3D models I produced from the UAV data in 2022 were processed according to the steps outlined in Chapter 2.3 and are already being used in various ways. The sequence of end-of-day models provided opportunities to see the progression of work in the trench, which helped the directors in their post-excavation analysis of the stratigraphy. For example, the aerial imagery captured details that were not easily seen on the ground during excavation, especially in the heat and bright light. A simple drain, made by filling a ditch (SU 20103) with stones and tiles (SU 20102), was discovered in the eastern half of the trench on July 12, 2022; however, the model of July 5th shows a line of brown soil on the same N-S alignment as the drain below (Fig. 28-29). This brown soil may represent the soil fill that covered the deposit of stones and tiles in the drain channel, but it was not easy to see in the trench. As a result, the drain was not detected until July 12. Thanks to the UAV models, directors can now adjust the stratigraphic relationships to show that the drain was probably inserted in the room later.

Fig. 28: Compare photographs of SU 20093 in Area 20000. The aerial photo on the left captured a line of brown soil in the eastern half of the trench (end-of-day July 4, 2022), which is not clear in the terrestrial photo on the right (July 5, 2022). (Shared with MAP’s permission.)
As stated above, one goal of this project was to improve MAP’s public communication by publishing 3D models online. I created a stacked layout of a selection of five end-of-day models from Area 20000, which were published to Vennarucci’s Sketchfab professional account in October 2023 (Fig. 30). This digital product was designed in Autodesk 3ds Max software to facilitate the understanding of MAP’s archaeological methods and techniques for both the general public and scholars. Presenting the models in a vertical stack in chronological order from the newest (top) to the oldest (bottom) imitates the stratigraphic sequence and enables viewers who may not be well-versed in archaeology to better grasp MAP’s approach to single-context excavation. This arrangement also allows the viewer to observe the evolution of a trench over time (moving from top to bottom as the trench was excavated or bottom to top as the trench was formed), effectively introducing the concept of time as the fourth dimension into the 3D experience. This comparative method also proves to be valuable for the viewer with more expertise in the field, since the stacked layout allows the viewer to switch between the models to formulate assessments and interpretations regarding the contents and characteristics captured in
each model. To minimize the light differences across the models, it is advisable to collect consistently at similar times during the day.

Figure 30: Stacked layout of Area 20000 models as published on Sketchfab. (Model by Eray Can.)

Having all the models consolidated in a single location simplifies the process for viewers who want to examine multiple models and gain a more comprehensive understanding of the trench and excavation progress. If the models were uploaded individually, viewers would face the inconvenience of having to navigate through numerous models by repeatedly clicking in and out of each one and waiting for each new one to load. This may cause viewers to become disinterested and to stop engaging after viewing just one or two models, resulting in them only grasping a fragmented narrative of the trench's development. When using separate models, the viewer is also required to mentally superimpose the models on top of each other to reconstruct the stratigraphy and chronology in the trench. This would be difficult for the average viewer with no archaeological experience.
Despite the merits of the stacked layout, MAP’s directors found it difficult to move between the models. When rotating the model in 3D space, the viewer is limited to a certain zoom and field of vision to avoid the model above obstructing the view of the model below (Fig. 31). For this reason, I also created a terraced layout for the five end-of-day models from Area 20000. The terraced layout still maintains the chronological progression of models (newest on top and oldest on bottom) but spreads them out so that the viewers can move between the models with fewer viewing obstacles (Fig. 32). Annotations were added to help the viewer understand MAP’s excavation methods and interpret the features and stratigraphy visible in each model.

Fig. 31: In the stacked layout, the model above obstructs the viewing of the model below. (Model by Eray Can.)

Figure 32: Terraced layout of Area 20000 models as published to Sketchfab.com. (Model by Eray Can.)
Sketchfab’s VR mode feature transports viewers with VR headsets into MAP’s trench where they can step into the role of the archaeologist to explore the trench models at a 1:1 scale. In this study, MAP directors tested the VR mode of the Area 20000 models with the Oculus Quest 2 VR headset, a lightweight, untethered headset that tracks the viewer’s body movements in real time. The viewer can move across the surface of the trench by puddle jumping around and between the models using the hand-held controllers (Fig. 33). While the trenches at Marzuolo may be buried, this feature allows MAP researchers to return to the trench at any moment from the convenience of their office to check data and interpretations. It also provides an engaging, immersive experience for the public, who cannot visit Marzuolo otherwise. Furthermore, this VR feature can be used in the classroom to train students in archaeological methods and single context recording in preparation for fieldwork (Sanders, 1999; Hodgson et al., 2019). Vennarucci plans to test my models in her Roman Art and Archaeology course in spring 2024.

Figure 33: Exploring Area 20000 models in VR mode on Sketchfab.
4.2.3. Discussion of Data Capture Methods – MAP 2023

In July 2023, the MAP team embarked on their 6\textsuperscript{th} season of excavation, revisiting Area 21000 where the previous year they had uncovered a circular structure made of large limestones held together with plenty of mortar, nested within a room in a larger masonry structure that is on the same NW-SE alignment as the multi-craft complex to the north. Work this year confirmed that this circular feature served as a Roman well, exhibiting a rectangular exterior and a circular interior, with a diameter of around 1 meter. Concurrently, a new Area 22000 was opened just west of Area 21000 to expand the scope of investigation of this new structure and determine its phases of development and functions (Fig. 34). The excavation crew unearthed three new rooms west of the well room, all sharing a single back wall and opening to the south. The structure appeared to have undergone two distinct phases: 1. Its initial construction before ca. 20 B.C. to A.D. 20, and a later phase post the early 1\textsuperscript{st} century A.D. during which the rooms were filled with rubbish materials from a dump (e.g., large animal bones, large fragments of ceramic, discarded metal objects), likely to elevate the floor levels. In this later phase, the walls of the structure were also rebuilt with mortar.

![Fig. 34: Plan of Areas 21000 and 22000 at the end of excavation in 2023. (Shared with MAP’s permission.)](image)
I was unable to join MAP’s 2023 season, but the project directors implemented my UAV methodology, which I tested on site in 2022. I received a technology grant from the Graduate Professional Student Congress (GPSC) at the University of Arkansas to purchase the DJI Mini 3 Pro drone that was used to capture data this season, and I held a training session with Dr. Vennarucci to teach her how to fly the drone and capture photogrammetry before she left for Italy. Dr. Vennarucci consulted with MAP’s GIS specialist, Matteo Faraoni (University of Siena) and 3D modeling specialist, Tom Keep (University of Melbourne), on how to best implement my UAV workflow into the project’s broader digital methodologies (since in 2022 I focused on testing the workflow on one trench only). It was decided that the Topo Team assistant, Daniel Sanders, who was a Master's student of Classical Studies from Radboud University, would oversee the UAV photogrammetry because he had previous experience flying a DJI Mini 3 Pro while working on the Via Appia Project. Since MAP is committed to training students and young professionals in state-of-the-art excavation methods and techniques, Vennarucci had Sanders teach any interested students my UAV photogrammetry data capture workflow (Fig. 35).

Figure 35: MAP student learns the UAV photogrammetry data capture workflow. (Photo by Vennarucci.)
I advised Dr. Vennarucci to reduce the amount of UAV recording from daily to biweekly: Wednesdays and Fridays of each week. It was also decided to focus the UAV photogrammetry on Areas 21000 and 22000, which combined measured approximately 168 m² (Fig. 36).

Producing high quality models for such a large, open area was more time consuming and more challenging with terrestrial photogrammetry than with the drone. The large size of the areas also influenced the drone’s flight pattern. In addition to the PoI flight mode, the drone executed an S (snake) pattern across the Areas to guarantee thorough photo coverage and a more precise and accurate model. This added additional time to the data capture (approximately 30-40 minutes) and the processing (because there were more photos), but this extra time investment was balanced by the biweekly capturing schedule.

Figure 36: The DJI Mini 3 Pro in flight over Area 22000 at Marzuolo. (Photo by Vennarucci.)

I also advised Dr. Vennarucci to have the crew capture photogrammetry in the early morning while the light was still low (around 6:00 am), but, as in 2022, the directors decided to sacrifice optimal lighting conditions for work efficiency. Except for one early morning model, all others were taken in the afternoon at the end of the workday (around noon). The weather in 2023 created a few problems for the drone, which weighed less than half (249 g) of what the DJI
Mavic Air 2 (570 g) weighed. The wind, which grew stronger in the afternoons, would cause the drone to vibrate in the air, and one day was so strong that it was unsafe to fly the drone.

4.2.4 Discussion of 3D Modeling Results – MAP 2023

The UAV data collected during the 2023 season was processed in Agisoft Metashape according to the steps outlined in Chapter 2.3. Due to the large size of the area and larger photosets, the models produced were also very large and their sizes had to be reduced using Metashape’s Decimate Model feature before they could be uploaded to Sketchfab. I have published the final model of Area 21000 and Area 22000 to Sketchfab (Fig. 37).

![Figure 37: The final model of Area 21000 and Area 22000 as published to Sketchfab.](image)

4.3. Zeb Edmiston House

The Zeb Edmiston House is one of several buildings in Cane Hill listed on the National Register of Historic Places (NHRP) with 82000948 reference no. A small, rural township in Northwest Arkansas, Cane Hill was established by European settlers in 1827 as Washington County’s earliest settlement. Like Marzuolo, Cane Hill supported its rural community as a center of industry and trade. In fact, the Arkansas Archaeological Survey (ARAS) has been conducting
a study at the J. D. Wilbur Pottery Factory in Cane Hill, which produced and sold stoneware pottery from 1868 to 1889 (Pebworth & Evans, 2023). The town also acted as an educational center, notably hosting Arkansas’ first college to open its doors to women, and was the scene of combat prior to the Battle of Prairie Grove on December 7, 1862 in the Civil War (Historic Cane Hill, n.d.). Despite the town’s historic importance, it does not attract many tourists since it is located approximately 30 miles from the major traffic arteries (I49) and urban centers (e.g., Fayetteville) in Northwest Arkansas. For this reason, I received permission to record photogrammetry of the Zeb Edmiston House, which has never been modeled before, to create an accurate 3D record that could be used to increase public communication about this rich cultural heritage site.

The Zeb Edmiston House is a one-story house built in 1872 by a businessman from a wealthy local Cane Hill family. The house’s yellow-and-white-painted wood frame stands on a stone foundation and has a side gable roof and front porch designed in the Greek Revival style. The back of the house has an L-shaped deck. Unfortunately, the house was subjected to flash floods from the nearby Jordan Creek, which happen at regular intervals every several years, with significant occurrences noted in 1985, 2006, and 2015. Having fallen into serious disrepair, in 2016 the exterior of the house was raised by five feet to prevent damage by future flooding and its exterior was restored (Historic Cane Hill, n.d.) (Fig. 38).
4.3.1: Discussion of Data Capture Methods – Zeb Edmiston House 2023

The Zeb Edmiston House was recorded on a partly cloudy day in September 2023 using a workflow improvised from the one outlined in Chapter 3.2 to include both aerial and terrestrial photogrammetry. I decided to test a combined methodology at this site for two reasons. First, the building is located close to the main road in a small grassy clearing surrounded by tall trees with overhanging branches and electrical poles. These obstacles around the house inhibited data collection with the drone, and, in fact, the drone collided with a tree branch during data capture. Secondly, capturing photogrammetry of a standing structure required a different approach than the one used to record open area trenches at Marzuolo. While a drone is great for taking photos of the top of the house, it is more difficult to fly a drone under covered areas and in narrow spaces. As a result, the DJI Mini 3 Pro was used to take images of the roof from high altitudes and a Sony Alpha 6000 DSLR camera with a 16-50 mm lens was employed to capture data underneath the front porch, back deck, and other areas where it was not safe to fly the drone (Fig. 39). Although the combination of aerial and terrestrial images may not enhance the model’s quality, I was curious to see if the drone’s capability to take top-down (nadir) and oblique angle
shots could help close holes in the terrestrial model. Instead of capturing photos with Point of
Interest mode, the flight was made manually keeping the drone in a visual line to avoid crashing
it into trees or poles. A total of 290 photos were taken during data collection, 168 aerial and 122
terrestrial photos. Before processing the data, 32 photos were filtered out due to blurring and the
quality of light. In the Metashape workspace pane, the photos were categorized into two chunks:
aerial and terrestrial.

Fig. 39: Above: Capturing UAV photogrammetry of the House’s roof. Below: Capturing
terrestrial photogrammetry of the House’s back porch.
4.3.2 Discussion of Modeling Results – Zeb Edmiston House 2023

Since a house is a more complicated shape than a trench, I was required to take a considerably larger number of images than I did for MAP’s models to prevent gaps in the dataset and enhance the accuracy of image matching and alignment. However, the larger the data set the more processing time is required. The model was processed in Metashape following the steps outlined in Chapter 2.3. The combination method was partially successful in closing holes in the model, but the software was not able to properly combine aerial and terrestrial photos because of the light and resolution differences in the photos taken with the different cameras. Also, there are image gaps in the ceilings of the front porch and back deck, caused by poor lighting and a lack of thick photo coverage of these hard to capture spaces so that the software could not recognize the points. While imperfections exist, this first photogrammetric study of the Zeb Edmiston House allowed me to test an improvised version of my workflow on a standing structure and demonstrates the potential of 3D models for improving engagement with the historic structures at Cane Hill. The model was published to Sketchfab and could be linked to Historic Cane Hill’s official website, which currently contains few images and brief descriptions, to encourage more public engagement (Fig. 40).

Figure 40: The Zeb Edmiston House model as published on Sketchfab. (Model by Eray Can)
DISCUSSION AND CONCLUSION

Increased access to affordable consumer drones and user-friendly imaging software in the last 15 years has encouraged more archaeological projects to add UAV photogrammetry into their digital recording workflows, but many project directors still view this groundbreaking technique as too expensive or needing specialized technical skills to execute. This study aimed to create a low-cost and easy-to-follow workflow for implementing UAV photogrammetry in the digital recording of hard-to-access cultural heritage sites, like the Roman settlement at Marzuolo in Italy and the Zeb Edmiston House at Cane Hill in Arkansas. My workflow outlines how to capture imagery with a DJI drone in the field, how to process the 2D aerial images into spatially accurate 3D models using Metashape software, and how to use the models in public communication by publishing them to Sketchfab.

My work contributed to improving MAP’s 3D recording methods in terms of quality and efficiency. The project had never used UAV photogrammetry before and relied on aerial photographs captured from a balloon at the end of every season. I tested the workflow in the field in 2022 to record the excavation of Room D in Area 20000, part of a Roman multi-craft production complex. MAP in 2023 used my workflow to record another Roman structure with a well in Areas 21000 and 22000 and to train students on the project. Drone photogrammetry provided MAP with an efficient way to capture high-quality aerial imagery on a regular basis to monitor the progress of work over the season. The models produced are also a useful interpretative tool, and have helped directors notice new details, like the fact that the cut and top fill of a drain in Area 20000 was visible higher up in the stratigraphy than excavators on the ground realized.
This project also highlighted the importance of having a flexible UAV photogrammetry workflow that can be changed to respond to the priorities of the project or the unique conditions of the site being recorded. The biggest problem I encountered when testing the workflow was adverse light conditions. When processing the UAV data collected in 2022, I discovered that the light reflecting off the ground around noon caused distortions in the Area 20000 models. As Roncella et al. (2021) and Burdziakowski et al. (2021) indicate, a low-light environment is crucial for accurate and high-quality models. The best time to collect data is in cloudy weather or before sunrise. However, on MAP I had to capture data at the end of every workday instead of in the morning due to the directors’ concerns about time. Even though the drone was efficient, the time it took to clean the trench, set up for photogrammetry, and record would have pushed back the start of work 30 to 60 minutes. This demonstrates the compromise that is often required between best practices in UAV photogrammetry and project priorities and resources. The directors were willing to sacrifice a little on the visual quality of the model to have more time to work. While it was not a problem in 2022 with the heavier DJI Mavic Air 2, the wind was a problem in 2023 with the lighter DJI Mini 3 Pro, and recording was canceled one day due to unsafe flying conditions. In this case, the director sacrificed wind resistance for ease of transportation on flights and to stay in the open category of Italy’s drone laws.

To show the applicability of my workflow, I adapted my UAV methodology to record a local cultural heritage site, the Zeb Edmiston House in Historic Cane Hill, Arkansas, which had never been digitally recorded before. While the open area trenches at Marzuolo were mostly flat, the house is a standing structure. Therefore, it offered different challenges to capture data. For instance, while we used PoI mode on MAP supplemented by an S-pattern to cover the larger combined Areas 21000 and 22000 in 2023, I flew the drone manually in a spiral pattern at the
Zeb Edmiston House due to the danger of obstacles (tree branches, electric wires) surrounding the structure. I also used a combination of terrestrial and aerial photos at the house to capture areas like the covered porches that were difficult to fly a drone under. Although I think the combination improved the model, it also extended the processing time in Metashape, which had trouble matching points between the imagery from the different cameras.

3D models shared online can be an engaging and effective form of public communication for projects, especially those that investigate little known or difficult-to-access cultural heritage sites. I chose to publish my 3D models of Marzuolo and the Zeb Edmiston House to Sketchfab, a free online platform for sharing 3D content with a global audience. Sketchfab has an annotation feature that allowed me to add descriptive notes to the models to help viewers interpret the 3D record. For Marzuolo I combined five end-of-day models of Area 20000 into two different layouts in 3ds Max software, stacked and terraced. By organizing the 3D models in chronological order, both layouts introduce viewers to the 4th dimension in archaeological interpretation and can be useful for teaching students about stratigraphy and single context recording methods. However, the terraced layout eases viewing and moving between models. The VR mode in Sketchfab transports the viewer to the cultural heritage site where they can investigate MAP’s trenches or the Zeb Edminston House at a 1:1 scale. This immersive viewing experience can enhance engagement and learning. Since Sketchfab tracks the number of viewers and allows them to leave comments, the projects can check traffic to see how many people are engaging with their models. Moreover, 3D models are crucial in public archaeology, offering immersive and accessible means to involve audiences in cultural heritage. These digital representations not only improve public understanding of archaeological sites but also encourage
wider participation and appreciation, fostering a more inclusive and dynamic approach to preserving and sharing cultural sites.
**FUTURE DIRECTIONS**

There are future directions I would like to explore with this project. This study focused on improving the visibility of hard-to-reach archaeological sites by sharing 3D models at Sketchfab because it provides various tools and modes to edit the models to enhance public engagement like the annotation and VR features. Publishing models to Sketchfab also helps raise visibility for these sites by contextualizing them with a larger global cultural heritage context since the platform has over 100,000 3D models in its Cultural Heritage & History category. However, I have started to design a WordPress website (marzuolo.uark.edu) for MAP, which does not currently have a project website, that will include a virtual exhibit of a selection of the project’s aerial, terrestrial, and object 3D models. The project’s website will provide viewers with a more comprehensive history of the project and site so that the 3D models can be integrated with the project’s online database, maps, plans, artifacts, excavation reports, etc.

Research has shown that 3D models are effective educational tools and enhance experiences with cultural heritage (e.g., Malik et al. 2021). Sketchfab and WordPress sites both use algorithms to track the number of people who view the 3D models, but the number of viewers does not reflect the length or quality of engagement with the cultural heritage or the amount of learning that happens. To address these questions, I would need to apply subject testing to this study, but due to time constraints, I was not able to apply for IRB approval in time to do this. In the future, MAP directors could seek IRB approval to invite volunteers to interact with the 3D models published to Sketchfab and answer a set of survey questions afterward to measure the subjects’ level of interest and ask what the subjects learned through their interaction with the models.
Last spring, for example, I was involved in hosting a set of 3D modeling workshops for Dr. Vennarucci’s CLST 4003H: Shopping in Ancient Rome course at the University of Arkansas. Although the data sets the students worked with were captured by the Virtual Roman Retail project with terrestrial photogrammetry, the 3D modeling workflow in Metashape was similar to my own and we used my workflow for publishing models to Sketchfab. At the end of the project, the students took a survey, and their feedback, shared here with Dr. Vennarucci’s permission, supports the view that models are effective tools for making the past more accessible (see Vennarucci 2023). There were twelve students in the classroom and none of them had produced a 3D model before this class. After completing the project, 75% of the students felt confident about producing 3D models on their own using the workflow they were taught. Moreover, when asked what key things, lessons, or skills they learned in the process, several students commented that they learned the importance of 3D modeling in making the past more tangible and accessible and many indicated that they gained a valuable digital skill that they looked forward to using in other courses and future careers. All twelve students in the class found the Sketchfab workflow easy to use and commented on their pride in seeing their 3D models published online. This example shows how my UAV photogrammetry workflow might be integrated into a classroom setting to enhance education and experience with cultural heritage.

This research will appear in part in the methodology section of the Marzuolo Archaeological Project’s final monography at the end of the project. Dr. Vennarucci has also invited me to contribute to a co-authored article planned on the evolution of MAP’s digital recording methodologies.
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