Cemetery Photogrammetry: Historical Archaeology Data Collection Results from Oberlin Cemetery, Raleigh, North Carolina

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Abstract

Photogrammetry involves creating three-dimensional models using photographs of an object, which can provide more detailed documentation than the photographs alone. This technique could be used to record and assist in the future preservation of grave markers. This paper presents the results of photogrammetry in Oberlin Cemetery, located in the historic African American community of Oberlin Village in Raleigh, North Carolina. It has recently been mapped with geophysical tools by local professionals and rejuvenated by volunteer clean-up initiatives. The aim of this project is to contribute to the Oberlin community and the ongoing rehabilitation of Oberlin Cemetery through photogrammetry. This project resulted in 3D models and photographs of monuments in Oberlin Cemetery in addition to a How-To Guide for how to perform cemetery photogrammetry.

Introduction

Cemeteries are unique spaces that are found all over the world. Many in the United States have sprawling memorial parks lined with marble headstones, while others have small graveyards attached to churches. They contain a variety of meanings for different people. For most, it is a site they can visit to remember a loved one on the anniversary of their passing, birthday, or perhaps even holidays. However, for some, their cemetery is also a testament to their local history and heritage. This is true for Oberlin Cemetery in Raleigh, North Carolina. This is the final resting place of over 600 members of Oberlin Village, a historic Black community. Present-day descendants and residents of the community value this cemetery and use it as a way to honor the deceased and the rich past of the village. Cemeteries are able to “document the struggles and successes" (Rainville, 2009) of communities similar to Oberlin Village that need not be ignored or forgotten.

Due to compounding factors over the years, the state of Oberlin Cemetery began to decline. This is not uncommon for older cemeteries, especially African-American ones. African-American cemeteries face particular problems that are different from white cemeteries. Historically Black cemeteries have been demolished in order for the land to be used for construction. Development projects still threaten cemeteries even today (Dunnavant et al., 2021). These cemeteries are often forgotten or sometimes purposefully left off of city maps and property deeds due to historical racism and segregation (Rainville, 2009). This poses a huge risk for graves to be disturbed or destroyed if developers do not know the burials are there. There are many researchers and academics fighting for and proposing ideas to offer more protection and legislation regarding African-American cemeteries and burials (Dunnavant et al., 2021; Rainville, 2009). It is important to protect and preserve historic cemeteries, namely African-American cemeteries as focused on in my paper, as they serve as historical resources about the communities that surround them. Protecting these cemeteries is vital to a community's identity and heritage. Historic African-American cemeteries can be reminders of darker aspects of the past, such as inequality in burial practices (Rainville, 2009), but also the resilience and perseverance of a community that leads to the present day. The cemeteries can also provide opportunities for those outside of a particular community to learn about an area or group of people they may not be as familiar with.

Thanks to volunteers in the community, the cemetery has persisted and been given a new life. A local nonprofit organization, Friends of Oberlin Village (FOV), and nearby universities have been working on the grounds to rejuvenate and learn more about the cemetery (McGill et al., 2020; Wall et al., 2023). Data have been collected on the grave markers through pedestrian surveys and photography. The work presented here was carried out to build on these efforts by collecting data in the cemetery through photogrammetry, a process that creates three-dimensional models from photographs of an object. The process has been used by researchers and community members working on sites in places such as Banks Island, Canada (Haukaas & Hodgetts, 2016), and Alsace, France (Landes et al., 2013). Photogrammetry can allow one to capture and record the full, real-world view of grave markers, which differ from other archaeological artifacts since they cannot be manipulated or moved due to their fixed position (Landes et al., 2013).

Throughout this project, I was responsible for cleaning and photographing all grave markers, then modeling 75 of those markers to assist Friends of Oberlin Village in their work to maintain the cemetery. These project goals were agreed upon by FOV and myself, as they aligned with the needs of the community. This was very important for this project since Oberlin Village is a Black community and therefore has inherent sociopolitical factors that need to be taken into consideration by archaeologists (Flewellen et al., 2021). While my research was done as part of my graduate program capstone project, the fundamental purpose of this work is to benefit the Oberlin Village community. Afrodiasportic communities have been left out from archaeological work and knowledge creation about their own history. Collaborating with FOV and making sure they were the ones guiding the goals was vital to this project. "Ensuring that community archaeology is pursuing *community* needs is not only good archaeological practice but can be considered within the discourse of human and civil rights, recognizing people's inalienable rights to their culture" (Westmont & Clay, 2021). This quote encapsulates the fundamental heart of this project and hopefully the ultimate shift in all forms of archaeology to focus on and benefit the groups that the research is being done about in the first place. In this paper I will discuss the methods used to complete the project, its final results, and recommendations for similar historical archaeological projects in the future.

Background

Oberlin Village/Cemetery

Oberlin Village is a historic African American neighborhood located near downtown Raleigh, North Carolina. The village began as a freedman's enclave founded by Jessie Pettiford. Pettiford was a free Black man originally from Virginia who purchased the land that became Oberlin Village in 1858 (Little, 2020), 12 years before the end of the Civil War in 1865. The enclave would grow into a blossoming village with schools, churches, stores, and homes (McGill et al., 2020). The cemetery was established in 1878 when members from prominent families in Oberlin, such as the Pettifords, began to sell and donate land to the community for this purpose (Little, 2020). The cemetery was a central part of Oberlin Village and has burials of community members as recently as 2017 (McGill et al., 2020). As Oberlin grew, so did the rest of Raleigh. Oberlin Village was eventually annexed by the City of Raleigh in 1922. Many families in the community would lose their homes due to the overall increase in property taxes from the city. As more people moved out of Oberlin, homes and buildings were lost due to the construction of new developments and the expansion of Wade Avenue through the community in 1958 (McGill et al., 2020). Through all of this, Oberlin Village persevered, and so did its community members.

My project was done through collaboration with FOV, an organization that was created in 2011 in response to damage to the area due to Hurricane Fran in 1996. Community improvement efforts were carried out for over a decade until the organization was formally established. Their mission was dedicated to the “preservation, commemoration, and education” (McGill et al., 2020) of and about Oberlin Village. FOV holds biannual cleanups where members of the community volunteer to clear debris and litter in the cemetery. The purpose of these clean-ups is twofold: to maintain the conditions of the cemetery and to educate about Oberlin Village. Each cleanup begins with the chair of the FOV cemetery committee giving an overview of Oberlin Village's history. The cemetery quickly becomes a classroom dedicated to the topic of a Raleigh community that is often overlooked. This provides an opportunity to teach Raleigh residents about Oberlin Village's importance to its community members and the surrounding city area (Friends of Oberlin Village, n.d.).

In recent years, Oberlin Cemetery has been the subject of research by many volunteers and professionals in the area. There have been geological surveys done of the cemetery to locate and identify unmarked burials. This work was done as a part of John Wall's PhD dissertation at North Carolina State University. A pedestrian survey was conducted to document surface-level features such as headstones. Each of these monuments was photographed, but many of the images are unclear and vary in quality. The engravings, such as names and dates, were transcribed (Wall et al., 2023) in addition to their geographic coordinates. These photos and attributes were entered into tables, which were used to aid this project. They noted fieldstones and depressions that might represent burials not marked by traditional headstones. The geophysical surveys were able to reveal where the unmarked graves were to give a more complete picture of the true number of burials in Oberlin Cemetery. Work continues at Oberlin based on community interest and needs, including the present project, which builds upon Wall's work.

Photogrammetry

Photogrammetry is a tool that allows one to make virtual 3D models of real-world items using photographs. The process begins with identifying an object to model. Next, one needs to photograph the object from various angles in order to capture what the object looks like on all sides and its physical textures. The photos are then run through photogrammetry software. The software will identify matching features from the pictures to form the 3D models or 2D maps (Marín-Buzón et al., 2021). There are several methods one can use to reach these results, from LiDAR and standard cameras to laser scanning and remote sensing via satellite (Marín-Buzón et al., 2021).

Photogrammetry is a process that has been used for cultural heritage preservation since the 1800s. Albrecht Meydenbauer created photogrammetry as a means to document objects and monuments while surveying buildings in Wetzlar, Germany (Albertz, 2007). He saw the importance of recording physical cultural heritage so that it could be reconstructed in the future if needed (Albertz, 2007). Since its invention, photogrammetry has seen much refinement and specialization in many fields of research, such as topography (Marín-Buzón et al., 2021). Archaeologists have been utilizing photogrammetry for data collection and analysis more frequently in recent years. It is mainly used to capture the physicality of archaeological artifacts, features, and landscapes.

Currently, there is no explicit standardization for implementing photogrammetry in the field of archaeology, but the general process remains relatively consistent across different projects (Haukaas & Hodgetts, 2016; Landes et al., 2013). Across the board, sources for this paper used varying software and materials to perform photogrammetry, but sources do point to Agisoft PhotoScan, a paid program, being the professional standard for archaeological photogrammetry. In “Do-It-Yourself Digital Archaeology” by Cerasoni and colleagues (2022), the researchers attempt to create different protocols for two types of photogrammetry. I used many of these steps to guide my research, but there were many aspects I had to alter to fit my project. While there do seem to be efforts to create photogrammetry standards for archaeology, my aim is to create a guide of best practices specifically for cemetery photogrammetry.

Methodology

Community

My project would not have been possible without the collaboration with Friends of Oberlin Village. After learning about Oberlin Village and its community, I thought the cemetery would be an ideal site to carry out my project. I wanted to provide something that would fill a need for the cemetery and the FOV organization. I was able to connect with FOV through Dr. Dru McGill at North Carolina State University initially. I had to first make sure that this was a project the non-profit deemed beneficial to the Oberlin community. I adjusted my original capstone project proposal to lay out my goals specifically for FOV. The proposal was sent to members of FOV's board to review and vet. They responded with an agreement with certain conditions to give me permission to carry out my project. First, FOV was to have first rights to all 3D models produced of the markers in the cemetery. Second, the models were not to be shared with individuals regardless of if they were an FOV member. Third, I was to spray and clean the monuments as a part of the project. I happily agreed to these terms, as the cemetery belongs to the Oberlin community and the members of FOV are the stewards of the cemetery. Any data or models should belong to that group for them to use at their own discretion. With the time restraints of a two-year graduate school capstone project, I let FOV know that I would not be able to complete models of the over 275 markers in the cemetery. I reached out for guidance on which graves FOV would like me to focus on for my sample of 75 markers. FOV requested that the monuments in the cemetery section dedicated to the heirs of John Manuel have priority for documentation. With the agreement and permission from Friends of Oberlin Village, I was able to begin working in the cemetery.

Materials

This project required the following equipment and supplies: Consumer-grade DSLR cameras are suitable for photogrammetry of this scale. A Canon EOS Rebel XS/1000D DSLR camera was used for this project. The lens was a Canon EF-S 18-55mm, so photos could be captured at a distance that was not too far or too close. A 32GB memory card was needed since that was the maximum storage capacity allotted for this particular camera. A 2TB external solid-state hard drive was used to store the images after each photography session. This drive is also the home to all models, images, and documents related to this project, which will be turned over to FOV after completion.

Lastly, five jugs of D/2 biological solution and garden pump sprayers were used to clean the monuments. It is important to note that cleaning the monuments was part of the agreement for my project with FOV. Cleaning is not a necessary step in cemetery photogrammetry. One can carry out photogrammetry of grave markers without cleaning them first without affecting the quality of the 3D models.

Image Acquisition

For photography related to the before-and-after cleaning photos, I took basic photos to represent all monuments in the cemetery. Data from a pedestrian survey conducted for John Wall's PhD dissertation about the topographic depressions within Oberlin Cemetery (Wall, 2018) was used for this project. It helped me locate most of the grave markers in addition to providing information about them. Most of Wall's photos were of the front or top of the marker where the engravings were located.

The photos I took before cleaning were the first ones I captured at Oberlin Cemetery for the project. Once those were complete, I sprayed the markers with D/2, a pH-neutral cleaning solution (more information about D/2 can be found at d2bio.com), which took roughly three hours to cover the almost 300 grave markers between myself and one volunteer. The solution had to be left for around one month to clean the markers. After one month, I photographed the monuments once more to show the aftereffects of the cleaning solution.

Most of the photography sessions had sunny or lightly cloudy weather. Having sunlight is helpful to take brightly lit pictures, especially since Oberlin Cemetery has a lot of shade from trees. Cloud coverage can decrease high-contrast shadows, but the exposure will need to be adjusted on the camera to capture more light. The camera should be in manual mode so that the settings can be adjusted according to the lighting. I tested photography in my backyard with Styrofoam headstones to see what the lighting would look like under trees with sunlight coming through the branches like in the cemetery. It was here that I experimented with changing the exposure time on the sides of the headstone that were receiving more shadows. I also took photos of a sample marker at Wake Monument Company that was in direct sunlight. The photos for that session were very different from the ones taken in the cemetery, but it showed me how a grave marker would need to be photographed in extremely sunny conditions.

The main setting that I needed to adjust during photography was the exposure time. The photos with less sunlight had exposure times that ranged from 1/30 sec to 1/1250 sec. The photos with more sunlight had exposure times that ranged from 1/1600 sec to 1/4000 sec. Many of the photos had similar exposure times because many photos were taken from such small increments of changes in angles. The range of exposure ranged so greatly due to the amount of light reaching a marker through the trees in the cemetery. Some faces were in bright light while others were in dark shadows. Adjusting the exposure time helped even out the lighting for all faces of a monument. The rest of the settings for the photos were consistent as follows: ISO speed of 800 and F-stop of 5.6. The quality of the photos was set to RAW. The photos will end up being CR2 files (Canon Raw 2) once uploaded to the computer.

After adjusting the settings, I was able to begin photography in the agreed-upon section in Oberlin Cemetery after the initial test sessions. Starting at the front of this section, I photographed 77 markers mostly from right to left, facing west. I recorded the photography duration for each monument, which totaled six hours and 45 minutes over the course of five separate trips to the cemetery. It took an average of about five minutes to complete photographing an individual monument. Larger monuments took a little longer to capture every detail, while smaller, simpler ones typically took closer to the average five minutes. I took photos from various angles to capture all surfaces and details for each of the 77 markers. It is important to take at least two photographs of each surface to successfully create a complete 3D model (Cerasoni et al., 2022). Most markers fell in the range of having 30-100 photos taken, while the largest monuments had over 100.

I downloaded the images from the camera's SD card after each day of photography to make sure they were securely saved. SD cards are very small and can be lost or damaged easily. I wanted to make sure that I backed up the photos as soon as possible after every photography session. My project required thousands of photos and files that were captured and created over the course of several months. I kept the files on both a desktop computer in the archaeology lab at NCSU and a hard drive to ensure that if something happened to one or the other, there would always be at least one backup.

I moved the photos from the memory card over to the external solid-state drive and divided them into folders for the individual markers and the before-and-after photos. Separating the photos into these folders as I went made them much easier to navigate from the rest of the project rather than having to determine which images belonged to which monument. Once the photos were here, they were ready to be used in the model creation process.

Model Creation

For the next step in my project, I needed software that could process photos of the grave markers and create models from them. There are several photogrammetry applications available, both paid and free. Some of the paid options to create models are Agisoft Metashape (Haukaas & Hodgetts, 2016; Magnani et al., 2016; Marín-Buzón et al., 2021), Adobe Photoshop, and Affinity Photo (Cerasoni et al., 2022). Cerasoni et al. also suggested RealityCapture, which is now free but required payment at the time I made my software decision. The free and open-source options I found were GIMP, Krita, and Meshroom (Cerasoni et al., 2022). I knew I wanted to use a free application for this project in order for the steps to be replicated by anyone; therefore, I looked into those options. I decided on Meshroom because, after my own research, I found that GIMP and Krita cannot actually create the models, only edit them. Meshroom is free software used for 3D reconstruction created by AliceVision, a non-profit organization (“AliceVision | Photogrammetric Computer Vision Framework,” n.d.). The software I used to edit the models is called Blender. A quick Google search led me to Blender, which is used by many 3D technology professionals. It is another free and open-source software dedicated to editing and creating all sorts of 3D projects (Blender Foundation, n.d.). Both softwares offer different sets of tools that, when used in collaboration, result in clean, photorealistic models.

Meshroom is the software that processes photos to form 3D models. To do this, I uploaded the photos to the application. Most of the process is automated in the software. The steps in the creation can be seen as nodes at the bottom of the application window and can be adjusted by the user as needed. For my project, I kept all of the default node settings. The process simply needs to be started by the user, and Meshroom takes care of the rest. The time it took for Meshroom to create a model ranged from 11 minutes to 2.5 hours, with an average duration of about 41 minutes. Similarly to the photography process, more detailed markers took the most time to create. Occasionally there were models that had holes or were missing the back side. This was typically fixed by adding additional photos with better lighting. There were a couple of models that still did not render correctly after the new photos. It might be expected for one or two models to contain holes here and there. The final product of the application is a folder with every piece of the model, such as the points, mesh, faces, and textures. From here, I could now use the Blender application to polish the textured mesh 3D file.

Blender required more manual steps to be taken to clean up the model created in Meshroom. It was important for me to assign all the correct texture files to the mesh outline of the models, so the materials show up correctly. I did this before making any edits. The models typically had excess coverage (grass, leaves on the ground around the markers) included that was captured in the photographs. I cropped that material out in Blender to focus solely on the monuments. After cropping, I decimated the models, a process that scales down the number of faces in the model's mesh and can reduce overall file size. The final step was to pack all of the texture files into the Blender file. This makes it so the model file can be shared, and the textures will still be with it. Blender will not have to pull from the texture files located in the model's MeshroomCache folder. Once all of this was done for the 77 models, they were finally complete and saved to the external solid-state hard drive as Blender files for FOV. This way, they can be opened in Blender and used by FOV as they please in the future.

File Organization

After finishing photography and modeling, I organized the files on the solid-state drive. I wanted to make the hard drive as easy to navigate as possible for FOV once I shared it with them. I created three folders to divide the files: Before-and-After Cleaning Photos, Models, and Monuments. The first folder houses the Before-and-After Photos for all the grave markers in Oberlin Cemetery. It also contains a spreadsheet that lists the makers and their corresponding image file names so they can be located easily in the folder. There is also a README document with directions for locating a grave marker's photos. The Models folder contains the .blend files of the 77 models created of the monuments. There is a README document with instructions on how to download Blender and access the .blend files. The Monuments folder has subfolders for each of the 77 makers that were modeled. In each subfolder is the monument's MeshroomCache folder, photos used for the model, the model .blend file, and PNGs of the model with and without texture. The Monument folder also has a spreadsheet with information about the 77 markers and a README file describing everything in the folder. With the help of the README files, anyone in FOV who plugs in the hard drive into their computer should be able to navigate and access the files on it.

Results

Monument Cleaning

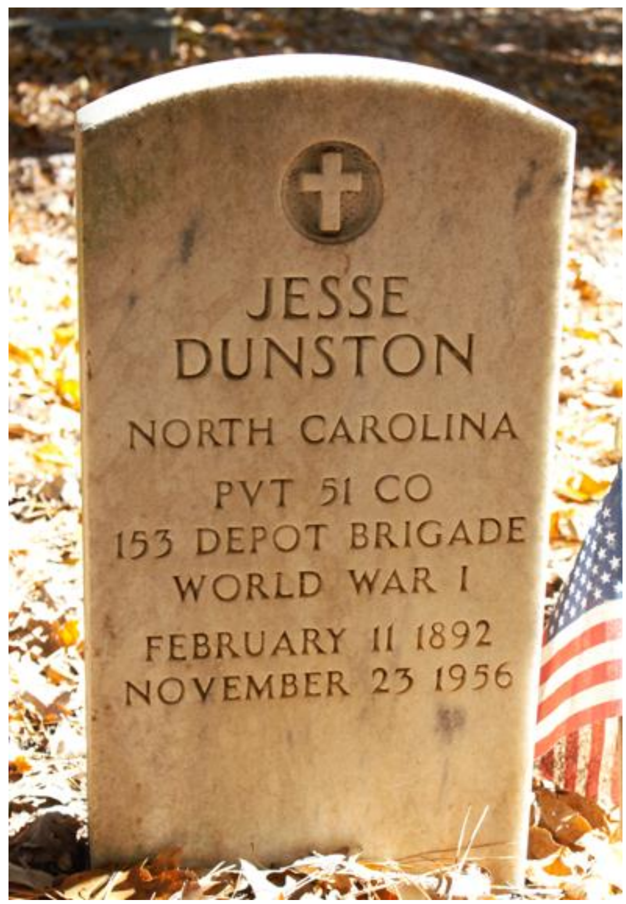
The purpose of my project was to fulfill the goals of Friends of Oberlin Village for Oberlin Cemetery while also gaining experience and knowledge of photogrammetry as a form of archaeological data collection. One of the goals I discussed with FOV was to clean the grave markers in the cemetery. Before cleaning, I photographed all the monuments in order to show the difference the cleaning made. Afterward, they were left to sit with the solution for up to a month. Once the solution had set and cleaned the monuments, I photographed them once more in a consistent manner for FOV's records.

Figure 1

Headstone of Jesse Dunston before cleaning with D/2 solution.

Figure 2

Headstone of Jesse Dunston after cleaning with D/2 solution.



It is apparent in many of the before-and-after photos that the solution helped greatly to revive the appearance of many of the monuments. Many of the white marble and granite markers were covered in green algae. Figures 1-4 show far less algae covering the stones after allowing time for the D/2 solution to work. Some markers, but not all, were much cleaner and brighter in

Figure 3

Headstone of Powell Peebles before cleaning with D/2 solution.

Figure 4

Headstone of Powell Peebles after cleaning with D/2 solution.

color overall. The variation in the effectiveness of the cleaning solution could be attributed to several factors. The color of the material a monument is made of could make it more difficult to see the result of the cleaning. Darker granite stones show less discoloration than the lighter ones, making it difficult to assess the difference after cleaning. Additionally, D/2 is effective against stains such as mold and lichen, but it is unable to remove rust stains ("Use D/2 — D/2," n.d.). While D/2 is effective at removing many types of growths and dirt, the markers might still have other signs of age and deterioration that are difficult or impossible to reverse. After seeing the outcome of cleaning the monuments, I believe it is worth the short amount of time and effort it takes to apply the solution to refresh the appearance of a cemetery.

Photography

It took several sessions to photograph the monuments designated for modeling by FOV. In total, I photographed 77 grave markers to be modeled instead of the 75 originally planned. Two footstones associated with modeled headstones were not visible during the original photography days; therefore, they were added to the sample for consistency. I soon learned that it is important to make sure the lens is focused on the marker and not the ground or background, which can be difficult to determine in the field for each and every photograph. There are typically enough photos that capture the surfaces to make up for ones that end up being out of focus. I expected there to be some small variations in the lighting of photos due to either time of day or shadows. This did not seem to affect the quality of the models, especially considering lighting can be adjusted in Blender.

The Final Models

The photogrammetry software used for this project, Meshroom, produced extremely clear and detailed models for the 77 chosen monuments. The models were so detailed that I had to decimate them, which reduced the file sizes greatly, making them much more reasonable to store. The detailed original models contained excess material of grass and objects in close proximity to the markers. Cropping that out resulted in more polished models that were solely focused on the grave markers as well as smaller file sizes. Before cropping and decimating, the model files ranged from over 500 to 100 megabytes. After cropping and decimating, the models now range from under 200 megabytes to two megabytes in file size. In addition to the 3D mesh of the model, Meshroom also created texture files that are applied to the mesh, giving it a fully fleshed, realistic appearance. Within the Blender software used for editing, one can add and remove textures to view the models' structures in different ways. Stripping the texture will leave a blank, grey version of the model, and adding it back will show what the monument looks like in the real world. One can also adjust shadows and lighting to view the models in ways that might not be possible in the cemetery. By doing this, it was possible for me to read engravings on four monuments that were previously illegible (Wall, 2018).

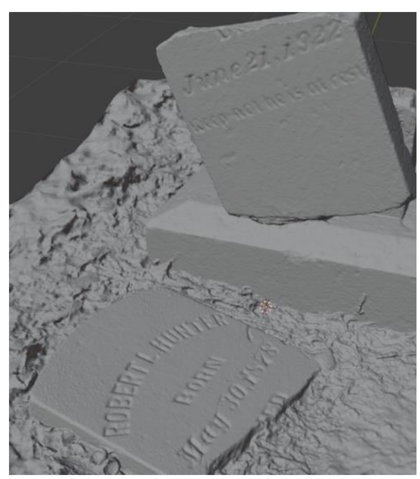
Figure 6

Headstone of Robert L Hunter.

Note: Difficult to read line under date of death.

Figure 7

Untextured model of Robert L Hunter stone.



Note: Engraving under date of death can now be read as "Weep not he is at rest."

The final models can be easily accessed as Blender files as long as the viewer has the Blender application installed on their computer.

Challenges

Photography Issues

As with many projects, I ran into a number of obstacles along the way. The main issue regarding photography was the size of the SD card to hold the photos on the camera. The initial SD card used for the project had a storage capacity of 128 gigabytes. This one was purchased with the anticipation of taking over 1,000 photos in a given session at the cemetery. The goal was to have one SD card to hold all the photos necessary for the project. When this card was inserted, I quickly discovered that it could not be formatted for this particular camera. The camera I used in this project was only compatible with SD cards up to 32 gigabytes of storage. This issue was solved by ordering two 32 GB SD cards. In the meantime, I cycled several low-capacity storage cards to avoid losing any time. The new 32 GB cards proved to be suitable for the number of photos taken as long as they were offloaded onto the external hard drive once the photography session was completed.

In regard to the before-and-after photos, several monuments are missing from either the before or after photos. I was able to locate some of the missing ones while taking photos after cleaning, so there is photo documentation of those. I was unable to locate seven monuments for these photos after several attempts to find them using a map with GPS coordinates from the original data from John Wall. The markers missing in the after photos were likely unable to be located due to foliage debris. The state of the cemetery can vary depending on the time of year and if there has been a recent cleanup. During cleanups, large branches and debris are removed, but most everything is left in place at the request of FOV. While it was my intention to record every monument, I did end up having several holes in my own data, whether it be from human error or conditions such as obscured markers.

Model Creation Difficulties

This section of the project was where I experienced the most challenges. The majority of the models turned out very well, but some did not fully render. Typically, this means that the photos of the missing section were not accepted by Meshroom. After rephotographing the respective monuments, I re-ran the models in the software with the new photos added. For most of the markers, this was able to fix the holes, creating a more complete model. However, there were some that were unable to be improved. In these cases, it seems that the back side of the monument was the section of the model that was missing, perhaps due to lighting or focus in the photos.

The biggest hurdle was ensuring that the textures that accompanied the models' meshes were directly connected to a single file. Meshroom produces texture files along with the mesh, but when the mesh file is opened in a 3D viewer, the textures are not attached. I worked with Colin Keenan, an experiential learning services librarian at NC State University Libraries, to solve this issue. He was able to assist in working with the models in Blender. The first line of action was to bake the texture into the model. This allows the textures from the images to be applied as the base texture of the model's mesh ("Render Baking - Blender 4.4 Manual," n.d.). After multiple meetings with Keenan, the attempts to texture bake were fruitless. The textures failed to properly map onto the models each time.

The next option was to manually add the texture files in Blender to the corresponding material slots. This way, the texture files were within the Blender file, and the materials would be visible when the file was opened. Now that everything was all under one Blender file, the models could be either exported as various file types or uploaded to 3D model hosting platforms. These Blender files are the easiest way for FOV to view the models without having to upload them to a hosting platform, but they will have access to the texture and mesh files from Meshroom as well.

Storage Concerns

Over the course of this project, I accumulated a substantial amount of very important files, over 500 GB worth. Those files include before-and-after cleaning photos, photos of 77 markers from various angles for models, MeshroomCache folders, model Blender files, and PNGs of each model. The textured mesh files produced by Meshroom were very large in size; hence, the models were eventually decimated in Blender. Most 3D model hosting platforms have file size limitations that many of the models would have exceeded. The decimation step in the model creation process solved this issue for most of the models.

As for the storage of the entire project's worth of files, it was clear that a large amount of space was required. This called for an external hard drive to store the files that I would eventually share with FOV for their records. The most appropriate storage option was a two-terabyte capacity external solid-state hard drive to avoid losing data if it were to be damaged.

Final Thoughts

Discussion

The goals of this project were certainly met over the last year. Contributions to Oberlin Cemetery's upkeep were made through the cleaning of all grave markers. By photographing the monuments before and after the cleanings, comparisons can be made to show the effectiveness of the D/2 solution spraying and sitting approach. This information could aid FOV in the future when considering how often to clean the markers by seeing how the state of the stones' appearance has changed. I was able to acquire the solution thanks to Dr. Dru McGill of NCSU and an Archaeological Institute of America Site Preservation Grant. The funding from this grant goes to supporting “a site preservation, education, and training program” (Archaeological Institute of America, 2025) for Oberlin Cemetery. While spraying monuments is not a necessary step for cemetery photogrammetry, it does produce a cleaner marker to be modeled. The cleanliness of a marker does not affect the outcome of a 3D model. This step can be optional depending on if an organization has the means to purchase the cleaning supplies. I included this as part of my project, as it was part of my agreement for collaboration with FOV.

My project required collaboration with Friends of Oberlin Village in order to work within the cemetery. There were some aspects of my initial ideas for the project that were altered to coincide with the needs of FOV. I originally wanted to make the models accessible to viewers online, but FOV was not ready to have them publicly published. It was important to put the organization’s and community’s needs and wants first. The project is meant to benefit the community, and to do that I needed to honor the requests from those whose sole purpose is to take care of the cemetery, Friends of Oberlin Village. One of the most important aspects of this project was to make sure the data and files I share with FOV are not only useful but also useable. This is why I made a point to use software programs that were not restricted by paid subscriptions and gave full documentation of how to access every file. The deliverables from the project will do FOV and the Oberlin Village no good if they cannot access them (Davis & Sanger, 2021).

Additionally, the photography and model creation will give FOV documentation of the state of the monuments now. Some of the models even made it possible to read inscriptions from markers that are illegible to the naked eye. The cemetery contains many more markers that were not included in this sample size, and which have engravings that cannot be read. Members of the FOV can use the How-To Guide attached to this project to decipher the remaining illegible monuments. With the How-To Guide provided at the end of my project, I believe that someone who is a beginner at photogrammetry would be able to create models for grave markers in virtually any cemetery. I was not a beginner to photogrammetry when I started this project. I had the time and experience to use trial and error for much of this project. Through this, I found the steps that worked for cemetery photogrammetry. I used the high-resolution "DIY" photogrammetry—HRP—protocol V.2 from “Do-It-Yourself Archaeology” by Cerasoni et al. (2022) to guide myself in this project. Their protocol is aimed at smaller, movable artifacts that can be photographed in a lab. I was able to use the steps applicable for the cemetery markers in my guide but left out the ones that would be best used in a laboratory environment, such as using a solid color backdrop or turntable. A beginner would not have to go through all of these steps again since they will be able to follow the best practices I have laid out.

One of my goals with this project was to make the How-To Guide as detailed as possible so that someone without photogrammetry experience could carry out the process on their own. This guide could be used by other nonprofit organizations working with historical cemeteries, not just researchers or archaeologists. Groups such as these should be able to take this type of documentation into their own hands. Projects such as the Ikaahuk Archaeological Project, which invited collaboration with local people, showed “models could be readily generated by community members themselves, including children or users without significant training with technology” (Haukaas & Hodgetts, 2016). Though they could collaborate with researchers, I believe my guide could provide autonomy when it comes to a community’s knowledge creation. This would make it so that the community could not simply engage with the archaeological process but create and conduct their own projects (Westmont & Clay, 2021).

I believe that using photogrammetry as a form of data collection and documentation would benefit almost any cemetery. The 3D models were able to capture more detail of grave markers than only photographs. Models allow views from all sides and angles, showing the viewer a more complete picture of a monument. Models such as these can aid in comparisons of a marker's appearance over time to determine any sort of preservation or restoration efforts. During my project, I was able to read engravings of previously illegible monuments by adjusting the lighting and material texture of their models. Photogrammetry can provide names, dates, or epitaphs back to makers that have experienced weathering and fill in the blanks for previously unknown data entries in more recent cemetery research efforts. Losing names and dates on gravestones is more than simply losing cemetery data, though. These engravings are a part of the biographies of real people who deserve to be memorialized. Documenting and discovering the information on the monuments ensures that these individuals will not be forgotten even after years of wear and tear on a cemetery. Ultimately, collaborative community archaeology projects such as this one with Oberlin Cemetery can not only aid in memorializing understudied groups (Davis & Sanger, 2021) but also raise awareness and potentially funding for future research or preservation efforts in the community (Rainsville, 2009).

Conclusion

Overall, the process for image acquisition and model creation worked successfully in producing realistic three-dimensional models. I have documented both of these processes in a How-To Guide so others, such as volunteers with Friends of Oberlin Village, can replicate them. This guide can serve as documentation of the best practices for cemetery photogrammetry since there is no true standardization for these specific projects. The models in this project will serve as documentation of 77 grave markers in Oberlin Cemetery. Due to the size of the cemetery, the number of monuments recorded had to be scaled back for the project, but FOV can choose to finish out modeling the remaining markers using the How-To Guide. These models show what the monuments look like at a certain time. Hopefully, the detailed models can be used as a record of what the markers looked like in late 2024 and assist in any maintenance or restoration measures. The grave markers in Oberlin Cemetery are important memorials of the people who helped create and continue Oberlin Village. Documenting these monuments contributes to the remembrance of a thriving historic community and ensures that its contributing residents are not forgotten over time.

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References Cited

Albertz, J. (2007). A Look Back: 140 years of 'Photogrammetry.' Some remarks on the history of photogrammetry. *Photogrammetric Engineering & Remote Sensing*, *73*(5), 504–506.

AliceVision | Photogrammetric Computer Vision Framework. (n.d.). https://alicevision.org/#meshroom

Archaeological Institute of America. (2025). *AIA Site Preservation Projects - Oberlin Cemetery, North Carolina - Archaeological Institute of America*. https://www.archaeological.org/project/oberlin-cemetery-north-carolina/

Blender Foundation. (n.d.). *About — Blender.org*. blender.org. https://www.blender.org/about/

Cerasoni, J. N., F. D. N. Rodrigues, Y. Tang, & E. Y. Hallett. (2022). Do-It-Yourself Digital Archaeology: Introduction and Practical Applications of Photography and Photogrammetry for the 2D and 3D Representation of Small Objects and Artefacts. *PloS One* 17 (4): e0267168. https://doi.org/10.1371/journal.pone.0267168.

Davis, D. S., & M. C. Sanger. (2021). Ethical challenges in the practice of remote sensing and geophysical archaeology. *Archaeological Prospection*, *28*(3), 271–278. https://doi.org/10.1002/arp.1837

Dunnavant, J., D. Justinvil, & C. Colwell. (2021). Craft an African American Graves Protection and Repatriation Act. *Nature*, *593*(7859), 337–340. https://doi.org/10.1038/d41586-021-01320-4

Friends of Oberlin Village. (n.d.) *Friends of Oberlin Village - Historic Oberlin Village*. https://friendsofoberlinvillage.org/

Flewellen, A. O., J. P. Dunnavant, A. Odewale, A. Jones, T. Wolde-Michael, Z. Crossland, & M. Franklin. (2021). "The future of Archaeology is antiracist": Archaeology in the time of Black Lives Matter. *American Antiquity*, *86*(2), 224–243. https://doi.org/10.1017/aaq.2021.18

Haukaas, C., & L. M. Hodgetts. (2016). The Untapped Potential of Low-Cost Photogrammetry in Community-Based Archaeology: A Case Study from Banks Island, Arctic Canada. *Journal of Community Archaeology & Heritage*, *3*(1), 40–56. https://doi.org/10.1080/20518196.2015.1123884

Landes, T., M. Waton, E. Alby, S. Gourvez, & B. Lopes. (2013). 3D Modeling of Headstones of the 2nd and 3rd Century by Low Cost Photogrammetric Techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-5/W2 (July): 397–402. https://doi.org/10.5194/isprsarchives-xl-5-w2-397-2013.

Lexar-Dev. (2024). How to choose the right SD card sizes for your tech needs. *Lexar*. https://americas.lexar.com/sd-card-sizes/

Little, M. R. (2020). Rooted in Freedom: Raleigh, North Carolina's Freedman's Village of Oberlin, an Antebellum Free Black Enclave. *The North Carolina Historical Review* XCVII (October): 425–50.

Magnani, M., M. Douglass, & S. T. Porter. (2016). Closing the seams: resolving frequently encountered issues in photogrammetric modelling. *Antiquity*, *90*(354), 1654–1669. https://doi.org/10.15184/aqy.2016.211

Marín-Buzón, C., A. Pérez-Romero, J. L. López-Castro, I. B. Jerbania, & F. Manzano-Agugliaro. (2021). Photogrammetry as a new scientific tool in archaeology: Worldwide research trends. *Sustainability*, *13*(9), 5319. https://doi.org/10.3390/su13095319

McGill, D., J. K. Millhauser, A. McGill, V. Melomo, D. Bohnenstiehl, & J. Wall. (2020). Wealth in People and the Value of Historic Oberlin Cemetery, Raleigh, North Carolina. *Economic Anthropology* 7 (2): 176–89. https://doi.org/10.1002/sea2.12173.

Rainville, L. (2009). Protecting our shared heritage in African-American cemeteries. *Journal of Field Archaeology*, *34*(2), 196–206. https://doi.org/10.1179/009346909791071005

Render Baking - Blender 4.4 Manual. (n.d.). https://docs.blender.org/manual/en/latest/render/cycles/baking.html

Wall, J. (2018). *Analysis and characterization of closed topographic depressions* [PhD dissertation]. North Carolina State University.

Wall, J., D. R. Bohnenstiehl, N. S. Levine, J. K. Millhauser, D. E. McGill, K. W. Wegmann, & V. Melomo. (2023). A Geospatial and Archaeological Investigation of an African–American Cemetery in Raleigh, North Carolina, USA. *Archaeological Prospection*. https://doi.org/10.1002/arp.1921

Westmont, V. C., & E. Clay. (2021). Introduction: Current directions in community Archaeology of the African Diaspora. *International Journal of Historical Archaeology*, *26*(1), 195–210. https://doi.org/10.1007/s10761-021-00631-6

Use D/2 — D/2. (n.d.). D/2. https://www.d2bio.com/use-d2