LOW COST 3D MODELING FOR CULTURAL INSTITUTIONS

by

Dan Hawkins

A Master's paper submitted to the faculty
of the School of Information and Library Science
of the University of North Carolina at Chapel Hill
in partial fulfillment of the requirements
for the degree of Master of Science in
Library Science

Approved by:

____

Ryan Shaw

Daniel Hawkins. Low Cost 3D Modeling for Cultural Institutions. A Master's paper for the M.S. in L.S. degree. May 2017. 19 pages. Advisor: Ryan Shaw

This paper accompanies a project website, www.re3dan.com. The website consists of workflows for using 3D Scanning and Photogrammetry to create and display 3D models of objects from cultural institutions. It includes workflows for the Matter and Form 3D Scanner, the photogrammetry programs Agisoft Photoscan and Visual SFM, the mesh repair programs Meshmixer and Meshlab, and the online display tool Sketchfab. The paper describes the process of choosing these tools, building the website, and the changes made to the site based on feedback from users.

Headings:

Modeling, Computer

Virtual Museums

Digital Technology

Introduction

3D modelling, the process of creating 3D representations of physical objects, offers opportunities to libraries and other cultural institutions in several areas, including virtual exhibits, digital preservation, reconstruction and digital support for research and instruction (Knauth, 2016). From large scale scans using planes, to smaller projects involving the scanning of bones from archaeological sites, 3D modelling has become a regularly used, if not ubiquitous, practice for libraries, museums, and academic departments. There are multiple techniques for creating 3D models of physical objects, the most prominent being 3D scanning and photogrammetry (Johnson, 2016 p 43).

There are two main types of 3D scanning, laser scanning and structured light (or white light) scanning. Laser scanning involves a laser line passing across the surface of an object and a sensor which records the reflected data. Structured light involves projecting patterned light onto the surface of the object. The sensor measures the distortion of the light pattern. In both cases the result is a point cloud “thousands to billions of x, y, z coordinates representing loci on the object” which provide the basic shape of the digital model (Johnson 2016, p. 42). These points are then connected into a series of triangles or polygons in a mesh that forms the surface of the model. Texture (including color) can then be applied (Remondino, 2011 p. 1123).

Photogrammetry, the other main technique for collecting 3d data also creates a point cloud and mesh. This is done by “extracting 3D data from pictures” by matching features that appear in multiple images. Features that appear in multiple pictures are reconstructed to provide depth and shape (Carmo 2013 p. 225). A minimum of three points should match between photographs. This is achieved by taking pictures that overlap. As the points are matched in multiple pictures and multiple angles the matched points take the shape of the object. As with scanned objects, the points are connected to form a mesh.

In the past, the cost of 3D techniques was often prohibitive for smaller libraries and cultural institutions. For instance, Wachawiak (2009, p158) refers to a system that cost $100,000 to $200,000 as a relatively lower cost. Successful 3D modelling programs had been possible for larger entities like the Smithsonian Institute, but entities with shallower pockets were left without the means to implement similar programs. Recent developments are significantly lowering this barrier to entry. The goal of this project is to provide suggested work flows for three of these less expensive techniques for use by cultural institutions, or other interested parties.

I am passionate about the use of these technologies in cultural institutions, particularly in libraries, because I learned to use these technologies in a library. My undergraduate degree is in Recreation Parks and Tourism, and my interests generally run towards history and literature. I have worked at NCSU Libraries for 11 years. Three years ago, my supervisor asked me who should replace the outgoing makerspace manager at the JB Hunt Library. I offered to do it if I could be trained on the job. In the intervening years, I have learned 3D Printing, 3D Scanning and Photogrammetry from colleagues, attending workshops and online tutorials. I have developed workshops on both 3D Scanning and Photogrammetry which I lead at both our main libraries in addition to consulting with patrons about their 3D modelling needs. As libraries continue to move towards providing access to technology as well as information, they provide an ideal context for learning these technologies. The combination of the educational goals of cultural institutions with the benefits that these technologies provide the institutions themselves make these tools a good fit in these contexts. These workflows are offered in that spirit.

Literature Review

Remondino (2011) provides a survey of various equipment, techniques and workflows for the collection and display of large scale cultural heritage sites and mapping of terrain. These “remote sensing technologies allow the generation of very realistic 3D results” that can be “used for many purposes" including "historical documentation, digital preservation and conservation, cross comparisons, monitoring of shapes and colors, simulation of age and deterioration, virtual reality/ computer graphics, 3D repositories and catalogues, web based geographic systems, computer aided restoration, multimedia museum exhibitions… and so on" (Remodino, 2011 p. 1105).

Despite the benefits that can accrue, these techniques are often adopted slowly because there are still problems with their implementation. He differentiates between Passive and Active sensors. Passive sensors are cameras which create models needing post-processing work to prepare the data for presentation. Active sensors are laser systems that collect the data as the scan is conducted, this would include most 3D scanners, including the Matter and Form scanner for which my website provides a workflow, since the machine is collecting the data directly from the laser scan. Photogrammetry, including structure from motion applications like Agisoft Photoscan and VisualSFM, are passive by this definition in that the photography that provides the data is a   He further differentiates between aerial ("mapping") and terrestrial (3D modelling) applications. Through extensive charts, Remondino lists various sensors and their specifications, acknowledging that they may go out of date as newer systems are introduced to the markets. The bigger issue is the "lack of standards and common terminology" among practitioners (Remondino, 2011, 1126).

The first step for any of these uses is Data Collection, through lasers or digital imaging. After collection, the data is processed to extract features and create a "point cloud (unstructured data)" which roughly corresponds to the shape of the item or tract being scanned. From this data, a "polygonal model" is generated. This means that the points in the cloud are connected to form a mesh, which is the surface of the model, which is then "edited" and "cleaned" to patch holes and smooth rough patches (Remondino, 2011, 1123). Texture, which in 3D refers to color, is then applied to the mesh. Then the model is ready to be displayed, analyzed, or studied.

Wachawiak (2009) describes the process by which the Smithsonian Institute's Museum Conservation Institute (MCI) reviewed the options for 3D digitization and chose a system. In 2004, the Smithsonian purchased a handheld scanner. "The immediate benefits of 3D scanning include virtual examination and research." The Smithsonian created an online exhibit, Smithsonian X3D (http://3d.si.edu/) about which more will be said below. Other benefits Wachawiak found were the digital measuring and ability to compare scans of artifacts, work previously achieved only through careful hand-measurement of the physical objects.

This process can result in the creation of replacement pieces to complete or replace parts of an artifact or even the creation of a mold. The actual fabrication of these parts is usually not a perfect rendering as the processes of 3D printing and Computer Numerical Control (CNC) are often not able to recreate the detail that 3D scanning or photogrammetry achieve. 3D printing, or additive manufacturing is the process by which a digital 3D model is "sliced" into layers and the printer creates the physical model layer by layer. CNC "is the method of controlling a cutting machine, usually a lathe, mill or router" to carve a model out of existing material (Wachawiak, 2009, p. 146). The choice of what process to use depends on the model in question, the needs of the project and the limitations of the machine and materials to be used.

The MCI had several criteria for the selection of a scanning system including accuracy, range, resolution, field of view, speed, the registration/alignment of data, imaging cameras, ease of transport, power supply needs and the software used. Other considerations were the computer power needed to process, light, add texture to and view the models.

Laser scanning and structured light scanning both work on the principle of triangulation. The "limitations" of both systems "lie in what they can see", meaning that both the light source and the sensor (the camera) must have a clear view of an object's surface (Wachawiak, 2009, p 150). Objects that are transparent, shiny or that have multiple overhangs are therefore difficult to scan. Structured light scanners project a pattern of light on an object. The sensor measures the distortion of the pattern and uses that data to create the point cloud. Laser Scanning projects a low intensity laser onto the object. The scanner records each of the laser's reflections as a point in a point cloud (Wachawiak, 2009, p.152).

The process that Wachawiak describes led to the creation of the Smithsonian X3D virtual exhibit. 3D Virtual exhibitions are valuable as tools to develop online exhibits, as advertising for collections and to enhance the onsite experience. Most museums use websites primarily for promotion, but 3D offers the ability to extend these uses beyond this limit. It can extend exhibits beyond the time they are available in the space. It allows guests to examine replicas of objects and spaces that are usually off limits. It can provide additional information to onsite visitors. It can recreate older spaces that no longer exist and provide visitors the experience of entering these spaces.

Carmo (2013) describes how virtual exhibits can be “built from scratch” with Computer Aided Design (CAD) programs or created from photogrammetry or 3D scanning. Scanning large objects can result in multiple point clouds that need to be combined before a model can be developed. There are multiple ways to create 3d data using photographs, the most accessible being photogrammetry. “Virtual recreations … are used both for museum exhibitions and for cultural sites (Carmo, 2013 p.226).” These sites can be shown as they evolve or decay over time. Lighting can be staged in such a way that it mimics the best sense of what life might have been like in a site during a time-period. There are opportunities for both virtual reality and augmented reality (Carmo, 2013, p. 224). Augmented reality can be used both in museum settings and in outdoor settings.

Johnson (2016) studies user reactions to five online virtual exhibits. She examined the Museum of Fine Arts, Boston (http://www.mfa.org/collections), The Digital Fish Library (http://www.digitalfishlibrary.org/), The Eton Meyers Collection (http://www.vista.bham.ac.uk/3D%20LS/Eton_Myers.htm), Epigraphia 3D Project (http://eadh.org/projects/epigraphia-3d) and the aforementioned Smithsonian X3D project (http://3d.si.edu/). Her broad methodology was to divide questions into user-centered questions and system-centered questions. She used four evaluative criteria: Functionality, Usability, Presentation, Content. None of these projects scored highly in all aspects. For instance, the Smithsonian X3D received high marks for presentation and functionality, as its interface allows for lighting changes, a digital tour, and notes about each model. It received middling reviews on content and usability, because there are relatively few items in the collection and the interface is not searchable. The Eton Myers collection was rated low in all categories, the most glaring reason being the fact that a separate program viewing the files requires the user to download a separate program.

Johnson (2016) notes that the method of digitization should match the needs of the collection. The most important considerations are a full comprehension of the digitization tools to be used, and ensuring the compatibility of the models with the method with which the users will access the models.

Baleri et al (2014) document a case of choosing the right form of scanning for a given task. The Richard-Ginori porcelain factory in Sesto Fiorentino, Italy has a large collection of porcelain models and molds that were used when the factory was active (beginning in 1737), and additional molds that were collected by the factory's owners. The problem was that there was no way to ascertain whether the models matched the molds in most cases short of casting new models, which was costly, time-consuming, and potentially damaging to the molds. Using a NextEngine laser scanner developed a method to scan the molds and recreate models. They tested this with one of a series of models called Gigante. With this process, they confirmed that the model was a part of a series. The project will ultimately digitize the entire collection and store them in a database for use in preservation. The NextEngine scanner is 3D scanner which uses the laser scanning method and features prominently in a couple of Library services in the literature.

Given that the price of 3D tools has been reduced over time, and the demonstrated utility of these tools to the educational, preservation and display goals of cultural institutions, it is no surprise that makerspaces have become increasingly commonplace in academic library settings. A makerspace is "a space that has been designed to allow users to create, build and learn new projects and technologies (Bagley, 2014, p. 1)". They often include 3D printing, 3D Scanning, Microcontrollers (EG Arduino or Raspberry Pi), sewing machines and various tools. The perceived benefit of locating makerspace in a library setting is the democratization of these technologies. One primary mission of libraries is to provide access. In most cases one thinks of access to information, but increasingly access to technology is equally important. On a college campus, students in certain departments (e.g., Engineering or Design) may well have access to tools like 3D printers, 3D scanners or microcontrollers. This was the case at Dalhousie University, where the Libraries tried to “bridge the digital divide that has traditionally existed around these technologies” by introducing a 3D printing and scanning service to students in disciplines that did not usually have access, like “Biology, Chemistry, Physics, Mathematics, History and Theater” (Groenendyk 2013, p. 35).

Groendyk et al (2013) described the process by which they created their 3D printing and scanning services from the selection of which machines to include (they chose a Makerbot Replicator (3D printer) and a NextEngine scanner), and considerations including safety and library space. This process was familiar to me as I have overseen a similar service at NCSU Libraries. At Hunt Library we provide a 3D printing service. Students can bring 3D model files and we print them. We also have a NextEngine scanner as well as a Matter and Form scanner. I teach workshops and give individual consultations on the use of these technologies. While Groendyk et al underestimate time spent in 3D printer maintenance and the ease and speed with which patrons can learn to get quality scans from the NextEngine, they do report good success in the implementation of their program in providing opportunities for “students and professors from different departments” to collaborate making possible “more innovative, inter-Faculty research collaborations” (Groenendyk 2013, p. 40).

Reuscher (2014) imagines a 3D scanning service as a useful tool, but highlights its “potential to become time-consuming and cumbersome” in its implementation, staffing, scheduling and maintenance (p. 65). He discusses the selection and implementation of the same NextEngine 3D Scanner used in the Richard-Ginori Porcelain factory in a program at Pennsylvania State University’s Library. The experience there has been largely positive.

Similar experiences have been documented in recent SILS master’s paper research. Knauth (2016) conducted guided interviews with seven professionals who used, or had used, 3D in their work. Like the Pennsylvania and Dalhousie staff report, those who used 3D scanning largely used the NextEngine. The primary program used for photogrammetry was Agisoft Photoscan. Providing digital access to 3D models of cultural heritage was a “natural extension” of previous digitization work for one of the participants. 3D modelling provides access to objects that the participants “were never going to be able to display” at UNC (Knauth, 2016, p. 33). Like their counterparts at the porcelain factory, preservation is a concern of the participants in the study. 3D models of items that degrade over time, or need to be returned to their original locations can be made available in a better form than allowed by photography, a boon for research and scholarship. In addition to preservation, the participants saw reconstruction of lost sites as another benefit. They cited the destruction of the Mosul Lion statue by ISIL (sic) and efforts to recreate a digital model of it from photographs as a vital example.

As Johnson (2016) indicates, the needs of the user should be considered as well as the professionals who do the digitizing. Groendyk (2013), too, highlights the need for some type of workshop or instruction session for users to acclimate to the usage of these technologies. Pope (2016) performed hour-long interviews with participants in workshops at UNC’s Kenan Science Library Makerspace and analyzed previously gathered information about the workshops to gauge user perceptions of the workshops, including one on 3D scanning. While Pope did concede that the Makerspace needed to work on its marketing, the interviewed participants all viewed the sessions favorably, and would come back for further sessions.

The price of 3D modelling has come down considerably since Wachawiak referred to $200,000 as an affordable option. The literature shows the benefits that can accrue to cultural institutions in the areas of preservation and sorting of artifacts, as in the case of the Richard-Ginori porcelain factory, and in digital display, as in the Smithsonian X3D project and other similar projects. Now that the cost is less of a barrier, these technologies are available to institutions with less funding. In the library makerspace movement and similar spaces in other institutions a context into which 3D scanning and photogrammetry can easily fit has developed. I see this project fitting well into that context.

Project

Given the demonstrated value for 3D in cultural heritage settings, I planned to develop a set of workflows for using several low-cost 3D tools to help further “bridge the digital divide” for institutions who cannot afford more expensive 3D modelling options (Groenendyk 2013, p. 35). Toward this end I established several goals. I wanted the tools to be affordable to most institutions. I wanted to represent both 3D scanning and photogrammetry. I wanted a way to create printable 3D models. I wanted a way in which the resulting models could be displayed digitally. Finally, I wanted a tool that would have utility beyond the scope of this project, something I could continue to use and build on in my career past graduate school.

First I needed to define affordable. When the old standard of affordable was over $100,000, this seemed easy at first. However, the more I thought about it, even the NextEngine Scanner mentioned in several articles, priced at approximately $4,000, could exceed the available budget of many libraries, academic departments, museums, or makerspaces. Ultimately, I decided that to qualify as inexpensive, the tool should cost less than $1,000. This eliminated the NextEngine, a tool I had originally intended to include in the project. I also considered the Structure scanner from Occipital (which costs @ $400) as an additional scanner and 123D Catch from Autodesk as an additional photogrammetry program. I rejected the Structure scanner because it creates models with much less detail than the Matter and Form. While 123D Catch allows the convenience of a mobile app, it limits the number of pictures that can be used for a model. The processing takes place on their servers so the user has less control over the process than other options.

After considering and rejecting these other options, I decided on one 3D scanner, the Matter and Form, and two photogrammetry programs, Agisoft Photoscan and VisualSFM. The Matter and Form scanner costs $499.00 and is relatively easy to use. Models from objects scanned using it compare favorably to the same models scanned on the NextEngine. The comparative drawback is that the user is constrained to smaller objects; the maximum size for an object is 8 inches in diameter and 9 inches tall. Some post scan work is usually required to make the model print ready. An open sourced program, Meshmixer, can handle this part of the process well. Agisoft Photoscan comes in two versions, Standard and Professional. The primary difference between the two versions is that the professional version allows the user to enter georeferencing data (latitude and longitude) and allows scaling of the model within the program.

With an educational discount, the Standard version costs $59 and the professional version costs $549. Photoscan is capable of capturing data for good models of both large objects/scenes and smaller objects. With an adequate number of pictures, it can create models that work well when displayed digitally, and create printable 3D objects. VisualSFM is an open source program, and is therefore free. It gets better results from smaller objects than with a larger scene. It also has the drawback of only getting the user through the first half of the process. The model must be finished in another open source program, Meshlab. It is more difficult to get a printable model from VisualSFM. I would generally recommend Photoscan over VisualSFM, but I wanted to include a completely free option in these tutorials.

To guide users through the process of creating models using these tools, I needed workflows for the Matter and Form software, post-scan processing in Meshmixer, Photoscan, VisualSFM and Meshlab. Additionally, I wanted to show the user how to display their work digitally, and for that process I chose Sketchfab, which allows the user to create an account (there are free and paid levels of accounts) and upload models. Once the model is uploaded, the user can then embed the model into a website or enhanced/virtual reality application. I needed a workflow that would show the user how to do this.

I had a basic grasp of how to use the Matter and Form scanner from using it in the makerspace at Hunt Library where I work. I learned how to use Meshmixer for post scan processing from two separate online tutorials I initially learned Agisoft Photoscan from two workshops at UNC, “3D Imaging Resources for Archaeology and Cultural Heritage” taught by Rachel Opitz in February 2015 and “Structure from Motion parts 1 and 2” taught by Steve Davis and JJ Bauer in November 2016. Before I was ready to create the workflow, though, I had to learn two extra steps. I had learned to use VisualSFM through a web tutorial in 2015. However, the meshing portion of the work flow had changed, due to an update in Meshlab. I go into more detail about my learning process and cite the sources from which I learned these tools in Appendix A.

Once I had determined which workflows I needed to create and learned the portions of the process I did not already know, I chose SquareSpace as the web platform on which to build them. I used it to build a site for a previous class, and it is easy to use. I briefly considered using the UNC servers to house the site, but since I want to continue to use the tool, it made more sense to use a platform that would not expire upon my graduation.

I designed the workflows as a series of screenshot images from the different software with text explaining each step of the process, as this is a format that helps me learn. I tried to break each step into a separate page. A user can follow the steps linearly if they want. It immediately became clear that while this path should exist, the site needed an index so that one did not have to navigate through all the steps to get to needed information, so I have provided a site index and an index for each subsection on the tool's introduction page. For each tool, I embedded a 3d model created using that tool.

Feedback

Once I created the site, I needed to get feedback from several different perspectives to see if it would be useful in different contexts. I got feedback from four different people. One is an Associate Professor in a School of Design and teaches the History of Design. One is a Digital Archivist oversees the creation and management of digital archive for an Academic Library. One is an Emerging Technologies Librarian who created and oversees a makerspace program consisting of two makerspaces in an Academic Library. One was a college freshman who attended a photogrammetry workshop I taught at NCSU Libraries who wanted to learn how to use Photogrammetry for cosplay and personal art projects.

All four agreed that the workflows on the website would be useful in their use contexts. The Digital Archivist mentioned that he had overseen a digitization project with a summer intern a few years ago that could have benefited from these workflows. The Design Professor mentioned a desire to build up a collection of digital artifacts based on design "classics," like a series of models of old phone handsets that he wants preserved. The Emerging Technologies Librarian said that it would be useable in the Makerspace context and could be a good platform to expand upon in the future. While the Workshop attendee thought that that the tools may not help with cosplay as much as he had hoped, he thought that it would be useful for some personal art projects.

Most of the suggestions for improvement centered around the way the website was structured. The first hint of this came when I turned in the first couple of workflows and was advised that I should have some way of navigating the site that was not merely linear. The way it was initially set up, the user had to go through each step in the process to get to the link for the next one. While think the linear path should exist, I did immediately agree that some way of skipping to pertinent steps was necessary. My first attempt at fixing this issue was to create an index page with links to each step of each workflow. This, too, is useful, but not enough. The Workshop Participant gave me feedback before the other three got back to me, and I saw immediately that the site index needed to be supplemented by an index for each section on the introduction page for each tool. I implemented this before the other three responded.

At that point, each page had the embedded 3D Model at the top of the introduction page, followed by the section index, followed by the text introduction. While the Associate Professor seemed satisfied with this, both the Emerging Technologies Librarian and the Digital Archivist recommended changes. The Digital Archivist suggested that I make clear that the index was the workflow. I renamed it such. The Emerging Technologies Librarian suggested that each section's introductory text belonged at the top of the page, and that the workflow index and embedded 3D model should go further down the page. I implemented both changes, as I think they do improve the site's navigability and look. The Emerging Technologies Librarian suggested that I might not need the full site index after implementing. I think it can be useful if someone is making a quick visit back to the site, though, so I left it in.

Both the Digital Archivist and the Emerging Technologies Librarian suggested that if the Welcome page had more detail that the whole website might be more understandable. The initial introduction made it sound as if the website only contained three workflows, for the Matter and Form Scanner and the two photogrammetry programs. However, since VisualSFM has additional steps that need to be taken in Meshlab, and I created workflows for getting models print ready and for uploading them to the web, I needed to make that explicit on the first page. The updated introduction page is much clearer, I think. At the urging of both the Archivist and the Librarian, I also added information about how I captured each of the embedded models (IE approximate number of pictures used, etc).

The Digital Archivist asked for a comparison/recommendation section. I considered a chart or table that compared the tools. While I may eventually go with a chart or table, I chose to add a page recommending that Agisoft Photoscan be the tool of choice. While both programs can produce usable models, they are not equally useful. VisualSFM is free, but Agisoft Photoscan gets better results with less effort. To illustrate this I embedded three models all captured from pictures of the same model, two from VisualSFM and one from Photoscan. Again, I was tempted to use just the Photoscan workflows for the project and jettison the VisualSFM section, but I wanted an open sourced option for people who did not want to pay for a program and ultimately left it in.

The Emerging Technologies Librarian suggested that I add more information about myself on the About Me page, that I should try harder to convince the users to trust me. I added more about my role overseeing the Hunt Library Makerspace and teaching 3D Scanning and Photogrammetry workshops for NCSU Libraries. He also suggested that I might include a list of other useful 3D Modelling resources in the sources site. I think that that might be a later addition to the site, but for the purposes of this project, I'm limiting the page to the sources from which I learned the program. Finally, he mentioned that the website's title was awkward for use on phones. I tried to adjust this in SquareSpace, but with this template, I could not. I could shorten the title, but I think that would convey less information than I want.

Conclusion

The suggested changes seemed to make for genuine improvements to the workflows, and the respondents seem to agree that the workflows are useful, which was the primary goal of the project. One of my secondary goals was to create a tool that I could continue to amplify and use beyond the scope of this project. While I think that this is a tool that is useful in its current form, particularly after the feedback and modifications, I can build upon it later as more related technologies are brought to my attention. I already foresee some changes coming. I think I will add zoomed in views of some of the screenshots, as they can be hard to read on smaller screens. A glossary of 3D modelling terms would be helpful as well. As I teach myself CAD (specifically Autodesk Fusion 360) and coding languages (I would like to learn R and Python) I could see a place for them on the site. I think that adding the section indexes (IE all the links to each step of each tool) to all the pages to further increase navigability. Finally, I have considered adding a blog to chart my progress in learning these and other tools as well as exhibiting newly created models. I have already begun to use the tool in my makerspace work with people interested in 3D modelling. Since I completed the draft I have given out the url several times a week. In its current form, I think that the project is useful, and its adaptability promises to only increase its utility.

.

Appendix A: Sources Used to Learn the Tools:

I learned to use the Matter and Form scanner in the course of my work at NCSU Libraries' Makerspace. We have one for in library use at each of our main libraries, and one that patrons can check out for a week. I learned to use the scanner from the user manual. This is the only of the tools I was able to learn with the official documentation. I learned to do post scan processing in Meshmixer from two different tutorials, one on Lynda.com and the other on Honeypoint3d.com.

I learned the basic workflow of Agisoft Photoscan by attending two workshops held at UNC Libraries in 2015 and 2016. This gave me the basis for developing the workflows I created for the website. I learned tips for getting a better model by doing cleanup between two of the steps from an online tutorial. I learned to merge two chunks, or sets, of photographs from a post on the Agisoft forum and some subsequent guesswork.

I learned to use VisualSFM from an online tutorial shortly after attending the first of the photogrammetry workshops. However, in 2016 Meshmixer updated the way the meshing process worked, and I had to relearn that portion of the process from Mr. P's Meshlab Tutorials. This is a series of Youtube tutorials from the people who created Meshlab.

Matter and Form:

M. (n.d.). Matter and Form- Manuals and Guides. Retrieved March 4, 2017, from https://matterandform.net/manuals

Agisoft Photoscan:

“3D Imaging Resources— for Archaeology and Cultural Heritage” Workshop taught at UNC Libraries on February 2-4 2015 by Rachel Opitz (then of University of Arkansas).

"Structure from Motion 1 and 2" Workshop taught at UNC by Steve Davis and JJ Bauer on November 1st and 3rd, 2016.

Agisoft. (n.d.). Agisoft Photoscan Manual. Retrieved March 4, 2017, from http://www.agisoft.com/downloads/user-manuals/

James. (2016, March 9). Agisoft Forum Post. Retrieved March 4, 2017, from http://www.agisoft.com/forum/index.php?topic=5068.0

Mallison, H. (2015, October 11). Photogrammetry tutorial 11: How to handle a project in Agisoft Photoscan. Retrieved March 4, 2017, from https://dinosaurpalaeo.wordpress.com/2015/10/11/photogrammetry-tutorial-11-how-to-handle-a-project-in-agisoft-photoscan/

VisualSFM/ Meshlab:

Jesse. (2013, July 12). Open Source Photogrammetry: Ditching 123D Catch. Retrieved March 4, 2017, from http://wedidstuff.heavyimage.com/

Mr P's Meshlab Tutorials. (n.d.). Retrieved March 4, 2017, from https://www.youtube.com/user/MrPMeshLabTutorials

Meshmixer:

K. H. (2014, December 2). Lynda.com Tutorial: 3D Scanning a Person. Retrieved March 4, 2017, from https://www.lynda.com/Meshmixer-tutorials/3D-Scanning-Person/185327-2.html

Kloski, N. (n.d.). Meshmixer for 3D Printing and 3D Design. Retrieved March 4, 2017, from http://education.honeypoint3d.com/p/3d-printing-and-3d-design-using-autodesk-meshmixer

Works Cited:

Bagley, C. A. (2014). Makerspaces : Top Trailblazing Projects:A LITA Guide. Chicago, US: *ALA TechSource*.

Balleri, R., Di Tondo, S., Adembri, G., & Gherardelli, M. (2014). 3d laser scanning of historic molds for documenting the richard-ginori factory collection. *Journal of the American Institute for Conservation*, 53(3), 145-158.

Carmo, M. B., & Clá, A. P. (2013). 3D virtual exhibitions. *DESIDOC Journal of Library & Information Technology*, *33*(3).

Groenendyk, M., & Gallant, R. (2013). 3D printing and scanning at the Dalhousie University Libraries: a pilot project. *Library Hi Tech*, 31(1), 34-41.

Johnson, T. M. (2016). Let's get virtual: Examination of best practices to provide public access to digital versions of three-dimensional objects. *Information Technology and Libraries* (Online), 35(2), 39. doi:10.6017/ital.v35i2.9343

Knauth, W. (2016). *Practical approaches to 3d digital imaging at cultural heritage institutions.* Retrieved from http://search.lib.unc.edu.libproxy.lib.unc.edu?R=UNCb8534204

Pope, H. (2016*). Make-ing the difference: Makerspace instruction and the student perspective.* Retrieved from http://search.lib.unc.edu.libproxy.lib.unc.edu?R=UNCb8534229

Remondino, F. (2011). Heritage recording and 3D with photogrammetry and 3D scanning. *Remote Sensing*, 3(6), 1104-1138.

Reuscher, J. A. (2014). Three-dimensional (3-D) scanning within academic libraries: exploring and considering a new public service. *Pennsylvania Libraries*, *2*(1), 64.

Wachowiak, M., & Karas, B. (2009). 3D Scannin and replication for museum and cultural heritage applications. *Journal of the American Institute for Conservation*, 48(2), 141-158.