

3D Printing: Digital Documentation of Archive at Center for Puppetry Arts

Preliminary Testing and Reflection of Experience

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Directed Study supervised by Dr. Michael Nitsche

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Summary

The goal of this preliminary testing is for eventual research on archiving historical objects by Dr. Nitsche. In this case, the objects are puppets in storage at the Center for Puppetry Arts. During this time, we tested our available equipment in Digital Media's Digital World and Image Group (DWIG) lab and CPA archival storage. Examining visual detail and looking at the ability of functional use of the duplicated objects was the primary focus of this project.

Outline of Topics

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Current Use and Technology

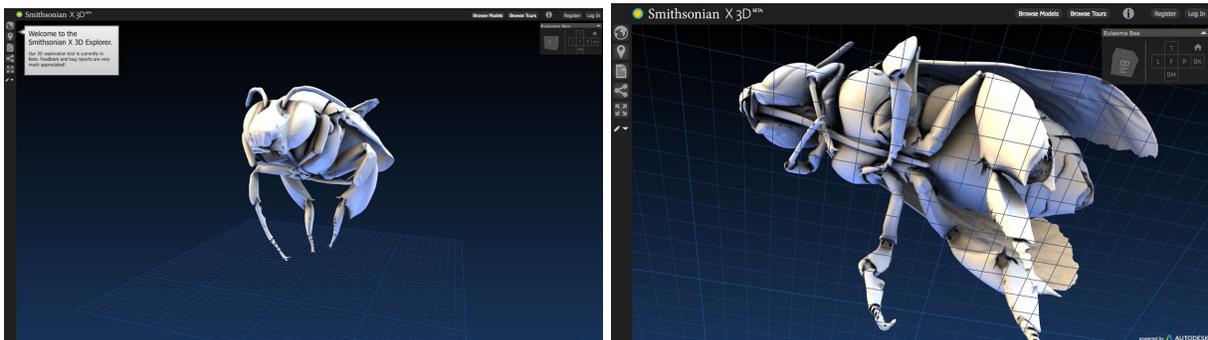
3D Scanning for Archival Purposes

This technology is excellent for duplicating finite, superficial details including texture, volume, and delicate markings such as cracks and dents that makes the original object unique. Also, miniscule changes attributed to factors such as time lapse or climate can be documented faithfully.

Below are examples of 3D Scanning for archival purposes as described by museums and institutions that utilize the technology.

Smithsonian x 3D(software in Beta):

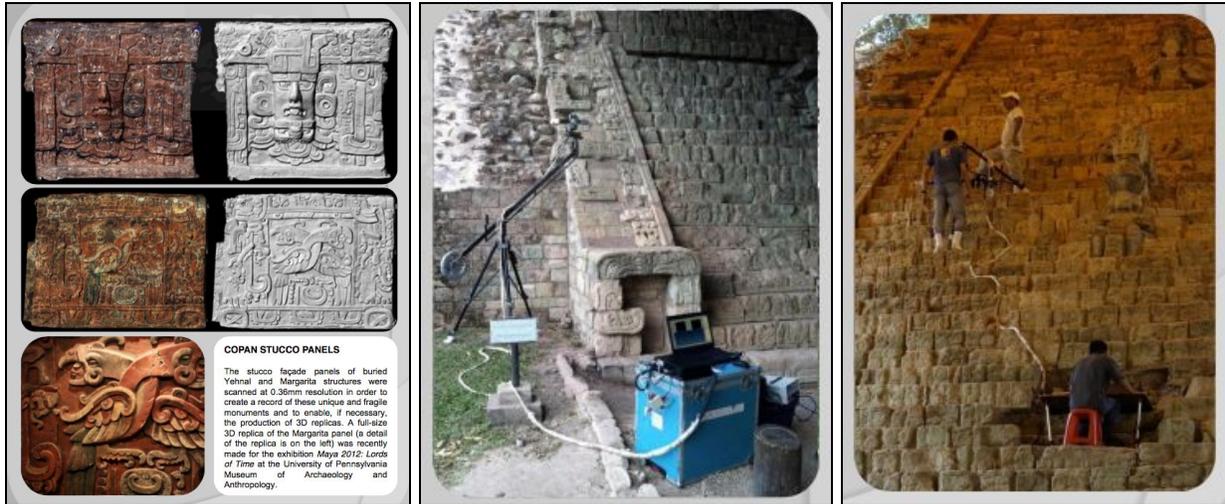
“Smithsonian X 3D launches a set of use cases which apply various 3D capture methods to iconic collection objects, as well as scientific missions. These projects indicate that this new technology has the potential not only to support the Smithsonian mission, but to transform museum core functions. Researchers working in the field may not come back with specimens, but with 3D data documenting a site or a find. Curators and educators can use 3D data as the scaffolding to tell stories or send students on a quest of discovery. Conservators can benchmark today’s condition state of a collection item against a past state – a deviation analysis of 3D data will tell them exactly what changes have occurred... With only 1% of collections on display in Smithsonian museum galleries, digitization affords the opportunity to bring the remaining 99% of the collection into the virtual light. All of these digital assets become the infrastructure which will allow not just the Smithsonian, but the world at large to tell new stories about the familiar, as well as the unfamiliar, treasures in these collections.”¹



Peabody Museum of Archeology and Ethnology at Harvard: *“The Corpus of Maya Hieroglyphic Inscriptions (CMHI) leads the efforts to preserve and study the incredibly rich material heritage of the Maya civilization. The publications of the CMHI set the standard for the entire field of Maya studies. Finding ways to document and publish sculptures and inscriptions has been one of the main challenges in this endeavor. Techniques such as photography and drawing have been limited in their ability to record three-dimensional data. Making paper or latex molds of monuments may damage the surfaces, which are often highly fragile because of erosion. As molds cannot be stored long term, casts have to be made. Such plaster casts are often heavy, bulky, and also fragile, so their storage and use present additional logistical and conservation difficulties... This is why the CMHI has embraced the technology of three-dimensional (3D) digitization. The 3D models produced are an invaluable tool for controlling the lighting and studying minute details that are difficult to see with the naked eye. Furthermore, digital 3D*

¹ Smithsonian x 3D <http://3d.si.edu>

scanning has several advantages over plaster casts: the recording process does not require direct contact with the object, therefore avoiding further damage; it is easier and cheaper to store, move, share, and study digital data; and it is still possible to make full physical replicas from the digital models.”²



The Field Museum (Chicago) (From “Mummies and Cheetahs, in 3D!”): “Have you ever wondered whose face is behind the wrappings of a mummy? Well, did you know that scientists at The Field Museum have been using medical CT scanners, which take a series of X-ray images of structures inside a person’s body, to look inside mummies and other objects since 2006? In fact, it was mummies that were used to test full body CT scanning when it was first invented! Contrary to the image of mummies portrayed by the popular Scooby-Doo cartoon, mummies are not monsters, capable of smashing through walls; in fact, most mummies are too fragile even to stand on end. Egyptian mummies are embalmed lying on their back, and so fit easily into a medical CT scanner, which looks a bit like a spaceship with a table for the patient that slides through a hole in the middle of the machine. Peruvian mummies are a different story, though, since they were buried crouching – the larger examples won’t fit through the hole. ‘We have been able to scan 6 ¾ Egyptian mummies,’ said JP Brown, Regenstein Conservator for Pacific Anthropology at The Field Museum. ‘The feet of one of them didn’t fit through the machine,’ he chuckled. Not only can scientists see inside the wrappings of a mummy using this technology, they can also create 3D models for Museum visitors to manipulate. Viewers can strip off layer after layer, head to toe, and down to the bare bone, using an interactive touch screen computer.”³



models for Museum visitors to manipulate. Viewers can strip off layer after layer, head to toe, and down to the bare bone, using an interactive touch screen computer.”³

² Peabody Museum of Archeology and Ethnology at Harvard <https://www.peabody.harvard.edu/3dscan>

³ Field Museum Blog <http://www.fieldmuseum.org/science/blog/mummies-and-cheetahs-3d>

3D Printing for Duplication and Functional Use

3D Printing has also been used to duplicate and use everyday items, from coffee cups to furniture. The technology is even gaining strides in creating functional human organs and body parts that can help with increasing the quality of life.

See examples below that demonstrate use and functionality.

Furniture and Home Decor: Drawn, a French start-up which designs and create custom 3D printed furniture with a large scale printer called Galatea⁴. The furniture is fully recyclable and if used temporarily, they will take it back and reuse the material to make other pieces. *“Our main asset is Galatea, the giant 3D printer made from a robotic arm. She is the star in our team and she always manages to steal the show! Drawn’s founder, Sylvain Charpiot is the father of Galatée. He adapted an industrial robot found in a dismantling automobile factory to create the large scale 3d printer. She was showcased for the first time in June 2014 in Paris on the Maker Faire salon and immediately seduced the visitors and even more (Maker Faire demonstration: <https://youtu.be/v763LjW-Y1g>). Galatea 3D prints objects layer by layer. She extrudes different shades of plastic material, specially the one used to make the Lego bricks, by heating it up to 230 °C and pushing it through its nozzle. The resulting look is instantly recognizable.”*⁵

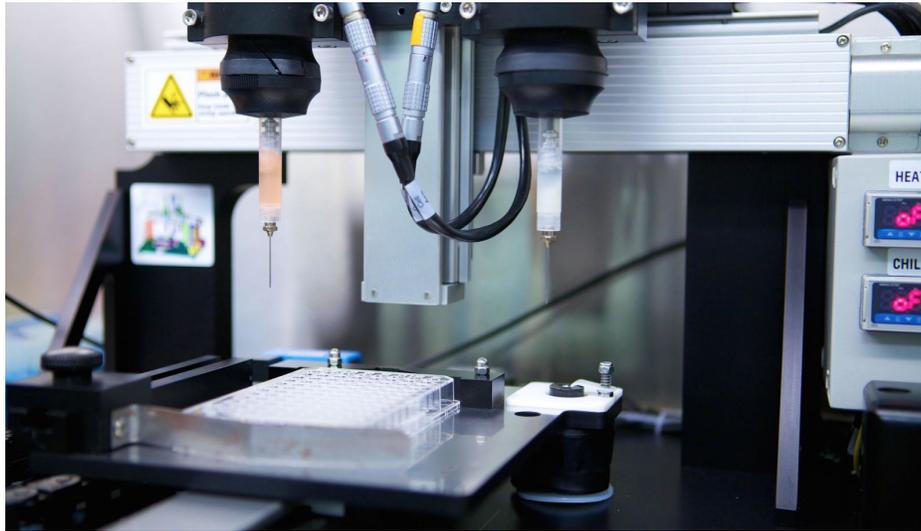


Human Organs (From “Custom Organs, Printed to Order” by Jenny Morber, NOVA Next): *“... Dr. Thomas Boland at Clemson University secured a promising sounding patent: ‘Inkjet Printing of Viable Cells.’ Boland’s patent relies on 3D printers, which can build complex shapes from little more than blueprints and the right type of material, including cells. An ink-jet printer that spits out three-dimensional objects works much like the familiar two-dimensional versions that sit on our desks—in fact, many started their ‘lives’ printing paper. Like the 2D version, a 3D printer precisely deposits material drop by drop. But instead of feeding a sheet of paper past the print heads, a 3D ink-jet printer ratchets its platform down a notch and then deposits another layer atop the last. The ‘ink’ can be virtually anything that can flow through a print-head and later harden—plastic, wood pulp, proteins, human cells. For 3D bioprinting, scientists fill the ink cartridges with cells and proteins instead of plastic. There’s also another promising 3D bioprinting technology, called stereolithography, which uses laser light to harden portions of a soup of polymers into a solid frame or “scaffold.” When the machine is done, the excess*

⁴ Drawn website <http://www.drawn.fr/en>

⁵ Drawn Kickstarter <https://www.kickstarter.com/projects/114240903/drawns-3d-printed-range-of-design-furniture>

liquid drains away to expose detailed supports. Researchers then bathe these scaffolds in cells and nutrients and wait for the cells to grow and remodel the scaffold to their liking.”⁶



⁶ Morber, J., “Custom Organs, Printed to Order,” *NOVA Next*
<http://www.pbs.org/wgbh/nova/next/body/3d-printed-organs/>

Current Technologies Tested for this Project

Skaneect: The Microsoft Kinect can be used with this software to scan objects, people, and rooms for later 3D modeling and printing. The free version was used for testing but there is a premium version sold for retail. *“Unlike existing technologies, Skaneect can acquire dense 3D information about a scene at up to 30 frames per second. Just move around your Structure Sensor, Kinect or Xtion to capture a full set of viewpoints, and you will get a 3D mesh in real time; Skaneect makes it easy to 3D*



scan different kind of scenes by providing a set of predefined scenarios, suitable for most use cases. You can then share your models online in a few clicks - there's no need to be a trained professional to start 3D scanning; Skaneect leverages consumer-grade 3D cameras like the Structure Sensor, Microsoft Kinect and Asus Xtion, limiting the hardware cost to a fraction of previous 3D scanning solutions. For a personal and hobbyist use, you can even download a free version of Skaneect!”⁷



NextEngine 3D Laser Scanner: Desktop scanner that can also be mounted on a tripod for versatility and portability. The hardware is used in conjunction with the software ScanStudio which downloads scans. Features include alignment, mesh fusion, and simplification. Also, an account is required to use the scanner and access the software which we had to track down. Descriptions from website⁸:

⁷ Skaneect website <http://skaneect.occipital.com>

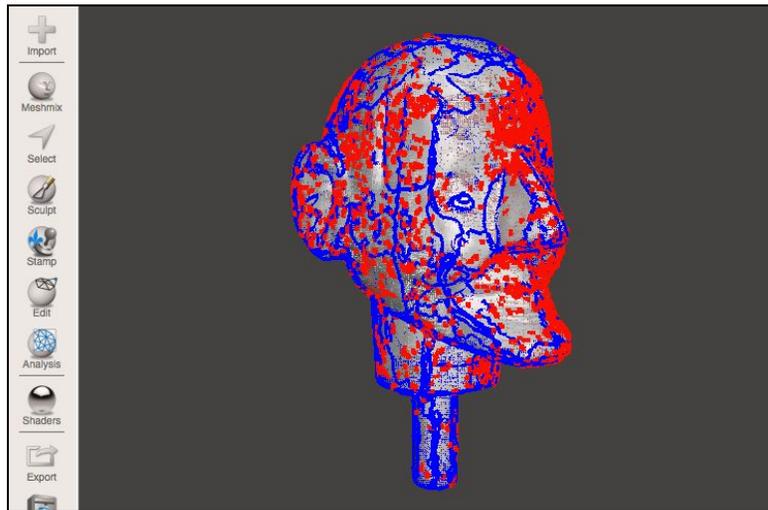
⁸ NextEngine website <http://www.nextengine.com>

- (Overview) *“The NextEngine Scanner measures 50,000 points per second with multi-laser precision providing users unprecedented ease of use to quickly create highly detailed, full color, digital models.”*
- (Arts) *“Capture the essence of natural or man-made shapes for artistic inspiration. Accurately record original pieces for archival or creating scaled reproductions. The NextEngine Scanner captures high resolution 3D geometry together with rich full color texture maps, producing a result that's both mathematically accurate and visually compelling. Artists are using the scanner in ways we never would have imagined, breaking the boundaries of traditional media, and producing amazing work.”*
- (Education) *“The NextEngine scanner quickly captures 3D geometry with rich full color texture, producing a result that's both mathematically accurate and visually compelling. Capture students' imagination by allowing them to bring real objects into 3D software. Scanning greatly reduces the time involved in modeling, allowing students to take on sophisticated projects that capture their imagination and challenge them in new ways.”*

Meshmixer: This application is a free 3D modeling and mesh repair program specifically used to aid 3D printing. We used it to refine models after scanning and aligning the object with Next Engine and ScanStudio. We primarily used

Meshmixer due to ease of use for beginners and the website includes descriptive tutorials and videos.

*“Meshmixer is an experimental 3D modeling tool developed by Ryan Schmidt, who otherwise does computer graphics research at Autodesk Research. Meshmixer is now part of Autodesk, a global leader in innovative design software and services. The goal of meshmixer is to make it easy to compose new 3D models from existing meshes.”*⁹



Stratasys Dimension SST 768 3D Printer (description): *Dimension is designed with ultimate simplicity in mind. The system enables you to build parts quickly, even if you have never used a 3D printer before. Its display panel prompts you to press a few keys to get you modeling quickly. The system models with ABS plastic, so modeled parts are strong and durable. ABS also ensures that you will be able to drill, tap,*

⁹ Meshmixer website <http://meshmixer.com/index.html>

sand, and paint your creations...Dimension is an innovative combination of proprietary hardware, software, and material technology.¹⁰



Links to Other Current Technologies

- Scanify - <https://www.fuel-3d.com/> (“A world of scanning at your fingertips”)
- iSense and Sense from Cubify - <http://cubify.com/products/scanners>
- Makerbot Replicator-
<http://www.wired.com/2012/09/how-makerbots-replicator2-will-launch-era-of-desktop-manufacturing/> - available in GT Invention Studio free of cost
- MAYA - <http://www.instructables.com/id/3D-print-from-Maya/>

¹⁰ Dimension Printer Manual

<http://fab.cba.mit.edu/content/tools/dimension/Dimension%20768%20Elite%20User%20Guide.pdf>

Reflection on Experience

Testing of Scanning Equipment

We began our research of equipment use by first consulting with fellow colleagues, Colin Freeman and Jonathan Shaw, who both have extensive experience with 3D modeling and printing. Colin provided advice regarding immediate use of the NextEngine, including assembly and handling of the material. Jonathan assisted us with demonstrating proper use of the Skanect and editing software, including preliminary scans of our puppet, “Woody”. As we continued testing the quality of the equipment and software independently, there were several factors that we noted:

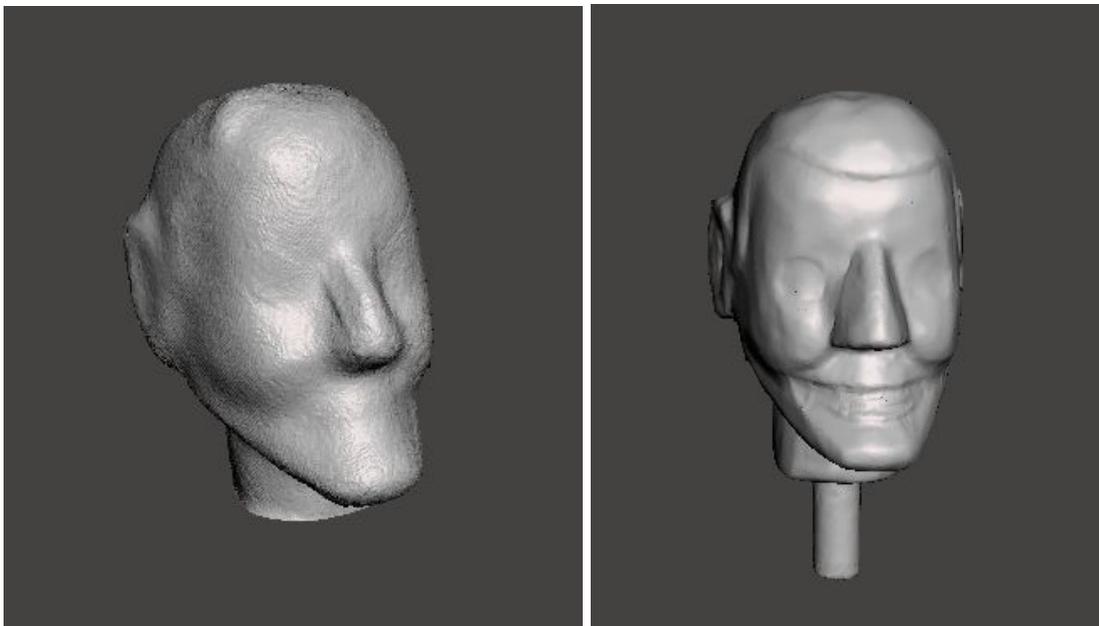
- The Skanect was very unreliable when keeping track of rotation around the object. We also used a rotating surface that we placed the puppet on so the Kinect would be stationary, but the sensor still proved to be very sensitive despite keeping the object stable and the speed of rotation low. This shortcoming made it highly unlikely to complete a full scan of a single object without several attempts. A common error resulting in the method was a “Camera Moved Too Fast” error, which signified that the Kinect needed to be realigned with its previous position.
- Unsurprisingly when scanning with the Next Engine, the size of the object is directly correlated with the amount of scans necessary and therefore more time-consuming. The object also has to be fairly close to capture both detail and depth (up to 17 inches away). Multiple scans for large and small objects alike are required for a high quality model, so this process with the NextEngine can be time consuming. A scan of Woody’s small head for instance still required about 2.5 hours due to some reflectiveness of the surface which impacts the scan’s effectiveness.



The larger puppet (red-haired “man”) we worked with took almost a couple of days cumulatively just for the upper body alone due to both the tall height and larger depth of the puppet that is challenging for the camera in the NextEngine to capture.



- There was a notable difference in surface quality between the Skanect and NextEngine. For this particular project, it is important to record surface detail for archiving. While the Skanect is more compact for portability to CPA storage, the NextEngine is able to record high-resolution detail, which we decided was more valuable to the scope of the project. Below are screen captures of the Woody's head opened in the Meshmixer application.



The left image was scanned with the Skanect and the right with NextEngine.

- Besides reflective surfaces, very soft and textured surfaces are also very difficult to scan such as hair, fur, feathers, etc. which may be a challenge when scanning the CPA archives. It may be best to focus on surface detail rather than the entire object in these instances.

Center for Puppetry Arts Visit

We met with Athena Smith who worked with us in handling the archived puppets during our first visit. The NextEngine was able to capture some detail of the puppets that would be valuable to archiving the craftwork and detail. However, there were limitations that are important to note during the visits:

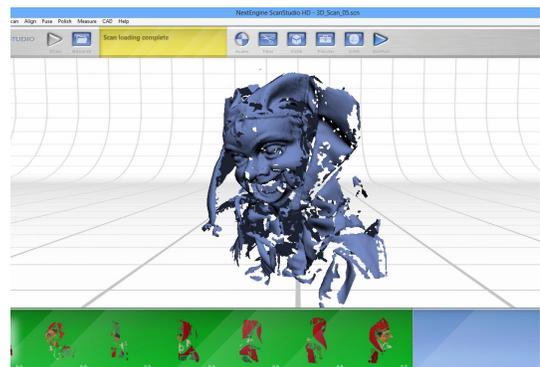
- The amount of space we were provided to scan the puppets was very small (desktop) and the storage space itself is also limited. The NextEngine was the most appropriate at this site since it is stationary and works well when in close proximity. The Center is expanding in the fall, so there will more available space.

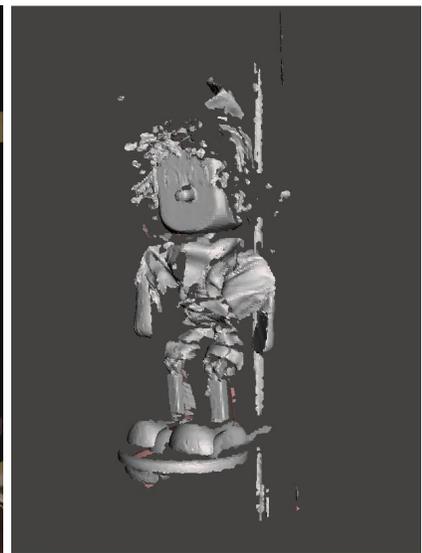
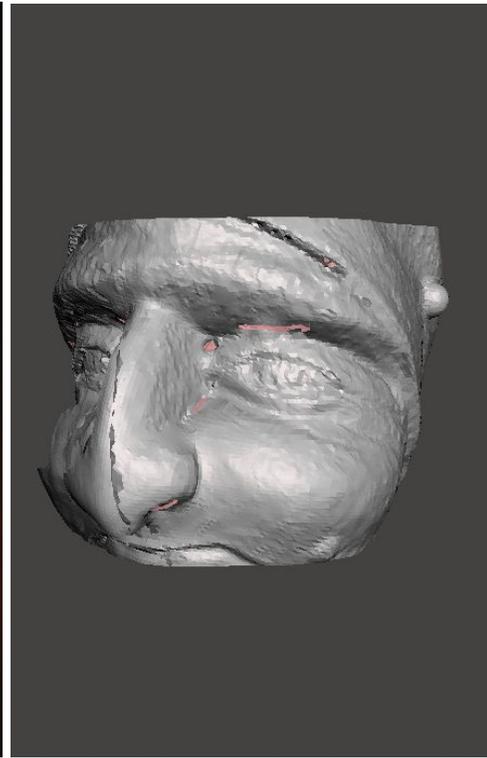


- Athena solely handled the puppets during the first visit but allowed us to handle during the second visit as long as we wore gloves. Since we are not trained on handling archived puppets, we were not able to touch or maneuver the puppet freely when Athena handled them during our first visit. She explained that training would be needed if the archive project continues long-term. This includes proper handling of the puppet with gloves and using acid-free material to store the puppet correctly. Importantly, extra care should be used when handling the heads of puppets to ensure they are properly supported to remain attached the body. Avoiding any unnecessary tension on the strings when handling a marionette style puppet was another directive given when attempting to avoid damage.



- Although the puppets we were provided with were smaller in order to reduce time, intricate details still required more time. We focused on capturing the facial and upper body details during our visits but this still proved to be a challenge. Since the puppets are archival, they cannot be pulled apart or overly manipulated. We relied on archival acid-free ribbons to help hold the puppets in place.

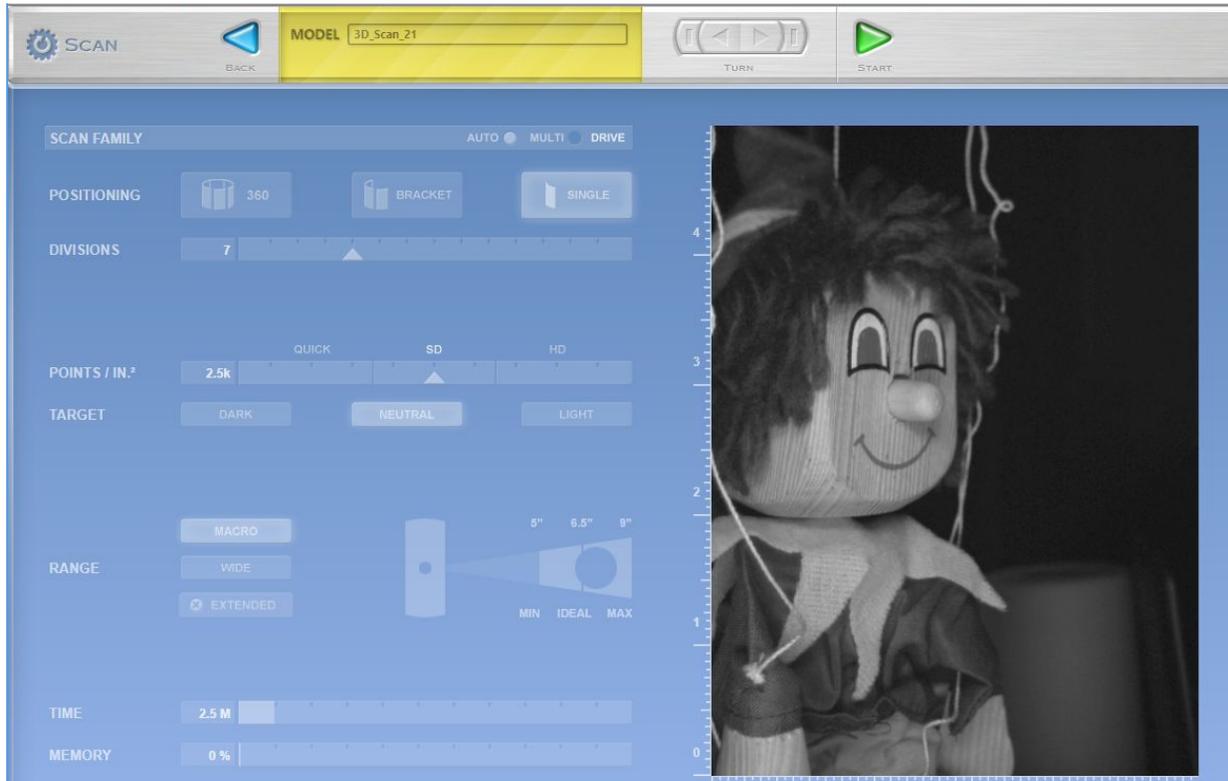




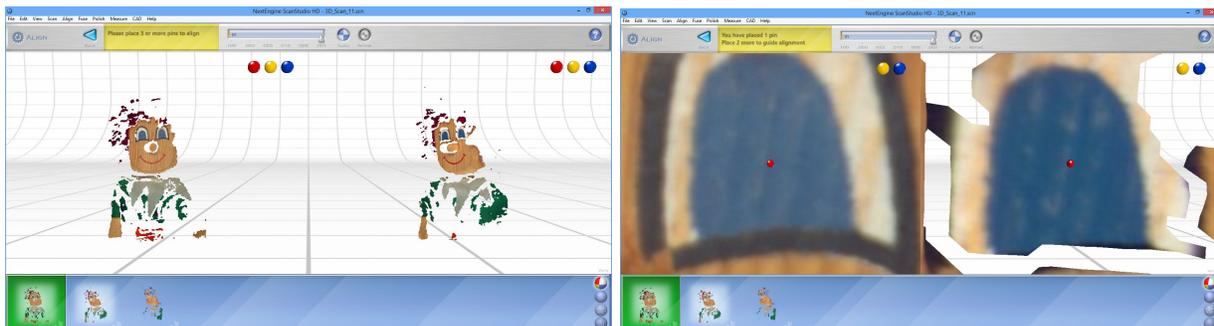
Preparing Scans for Printing in ScanStudio and Meshmixer

After scanning the puppet, we have to prepare for modeling the mesh through NextEngine's ScanStudio software. For a general overview of the software's core feature, please see this link:

<https://www.nextengine.com/products/scanstudio-hd/demo>. Several scans are made in order to document both surface and depth. There can be one scan made at a time ("Single Positioning") or several through the autopositioner base ("Bracket" - 2 scans; "360" - the base automatically spins all the way around).



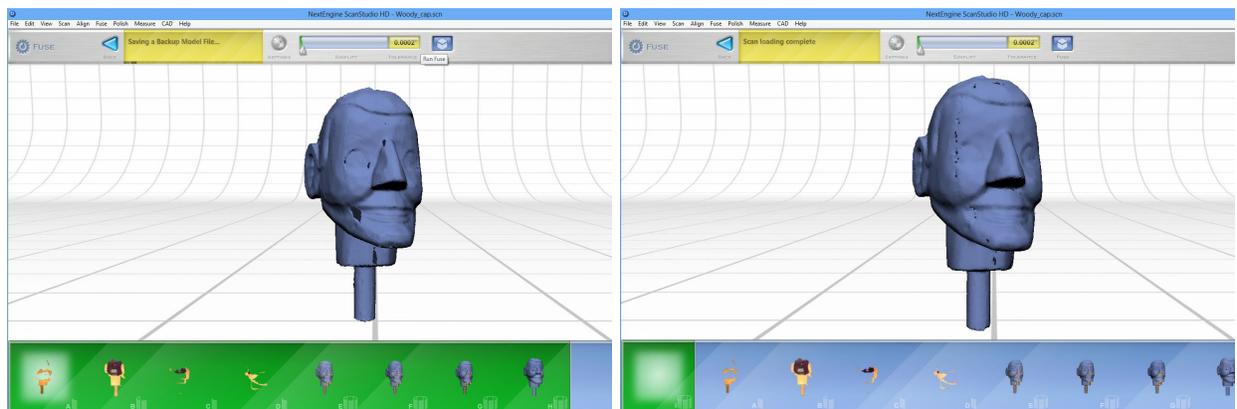
When multiple scans are made, the mesh created must be aligned in order to create the virtual object. The scans were made in color in order to decipher the details that could be matched to each other. "Pins" are used to guide alignment (the red, yellow and blue bubbles near the top of the screen). They should be placed approximately in the same position by color for the alignment to be successful.



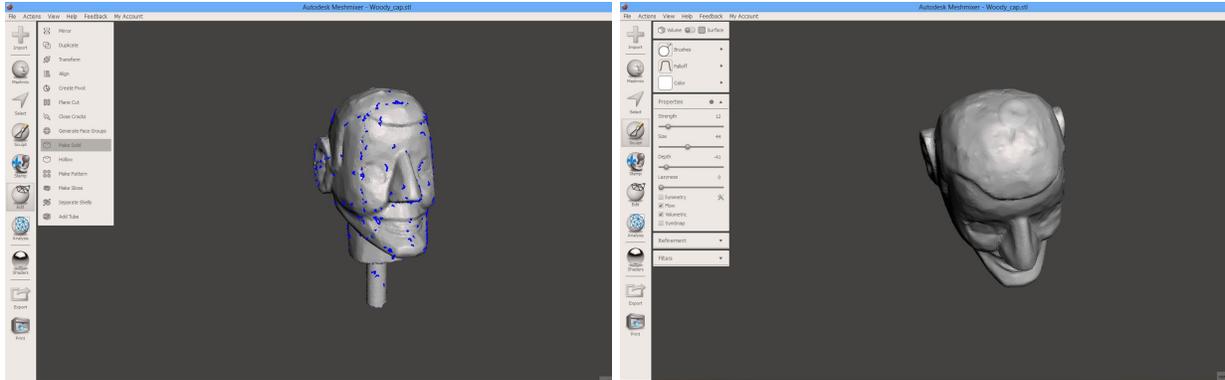
More pins can be used to increase accuracy, but at least 3 need to be used in order to proceed with alignment.



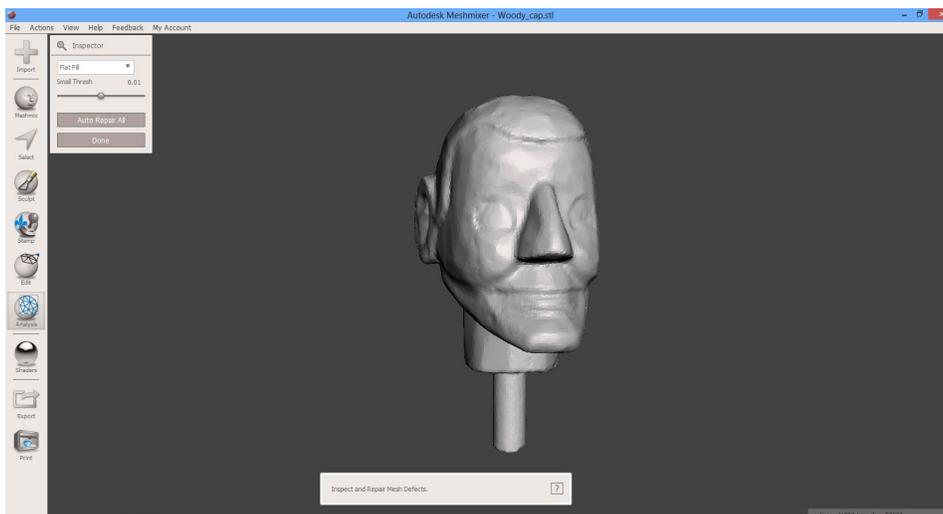
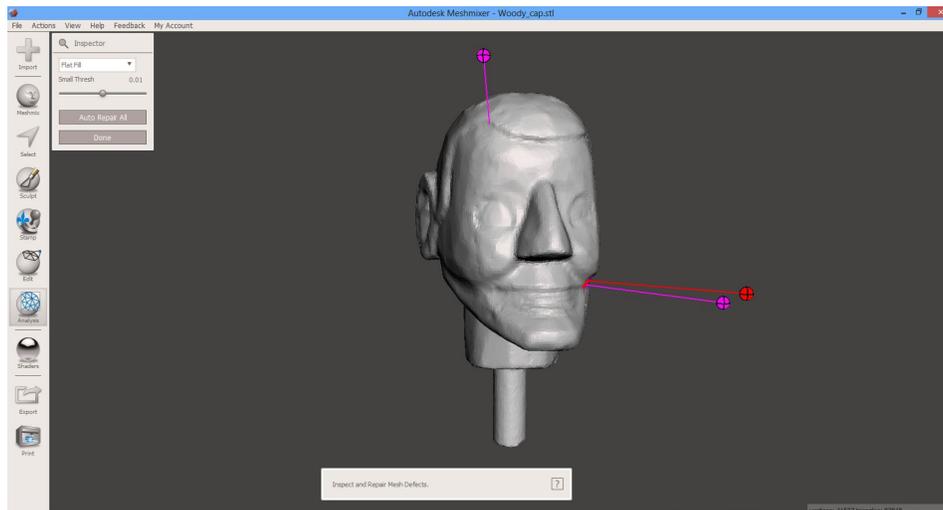
After scans are aligned, they should be fused together to create a single mesh. Sometimes, holes may appear in one area of mesh that can be compensated for from another scan. Once the fuse is ran, the model may appear more solidified. Also, it is suggested that for less detailed objects, to select the option of “Remesh (fill holes),” which can be found below the menu heading “Polish.” Then, select the “flat” variation to give the scan an initial pass at making it “watertight.” Being “watertight” or having manifolded edges is the term identifying a scan as having the surface of the object connected in its entirety. After this however, there may be more work to do that is beyond the scope ScanStudio.



At this point, the mesh can be imported into Meshmixer (“IMPORT”) for further editing. If blue lines appear on the model, those represent the cracks. We want the lines to disappear in order to make the model “watertight” so the scan will successfully print. When handling 3D scanning and ultimately printing, it is important to note that all prints need to consist of objects with no holes in them or else the printer will not output a print that is structurally preserved. Several tools can be used to refine the model including “sculpt”, “edit”, “analyze”, etc.



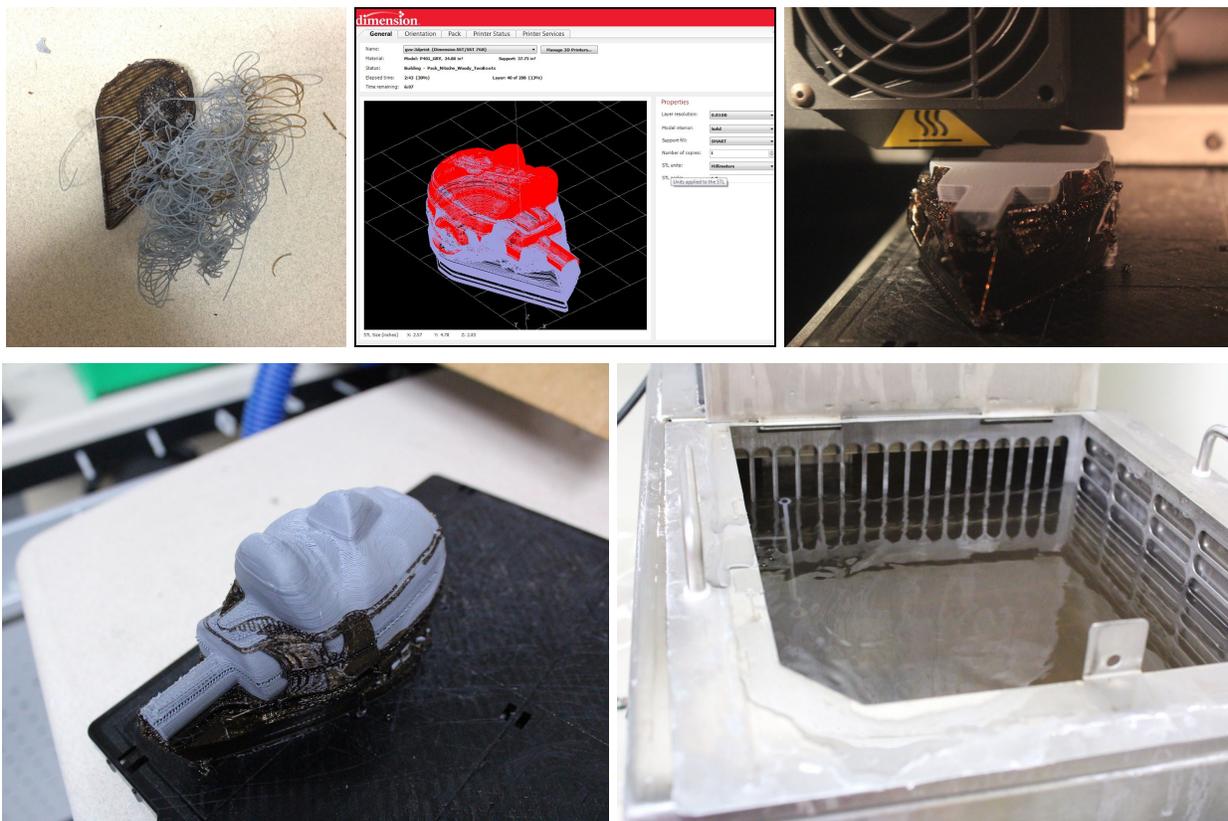
After the refinement is finished, the inspector under the “ANALYZE” menu should be ran to find remaining holes or cracks. If there are bubbles that appear, they can be clicked on to fill. It should be ran a few times to make sure holes or cracks are being filled. Once the bubbles disappear, the model is ready to print and must be saved as an **.stl** file to print in the Dimension printer in the GVV Prototyping Lab.



3D Printing in GVU Prototyping Lab

After being confident that we had a ready model, we moved on to printing with the Dimension printer. 3D printing is available to students working on projects sponsored by GVU professors. Another option was using the Invention Lab, free to all Georgia Tech students and faculty, but the hours are more limited while the Prototyping Lab provides 24-hour access to any student or faculty with an activated Buzzcard.

The very first print was scaled down when working in inches in the Catalyst software which uploads the file to the printer. However, the print did not stay intact; we felt that maybe the print was too small and hollow. When we attempted the next print, the settings were changed to work in millimeters which we noticed may print to scale. The interior changed to “solid” from “sparse” which did seem to give us a better result.

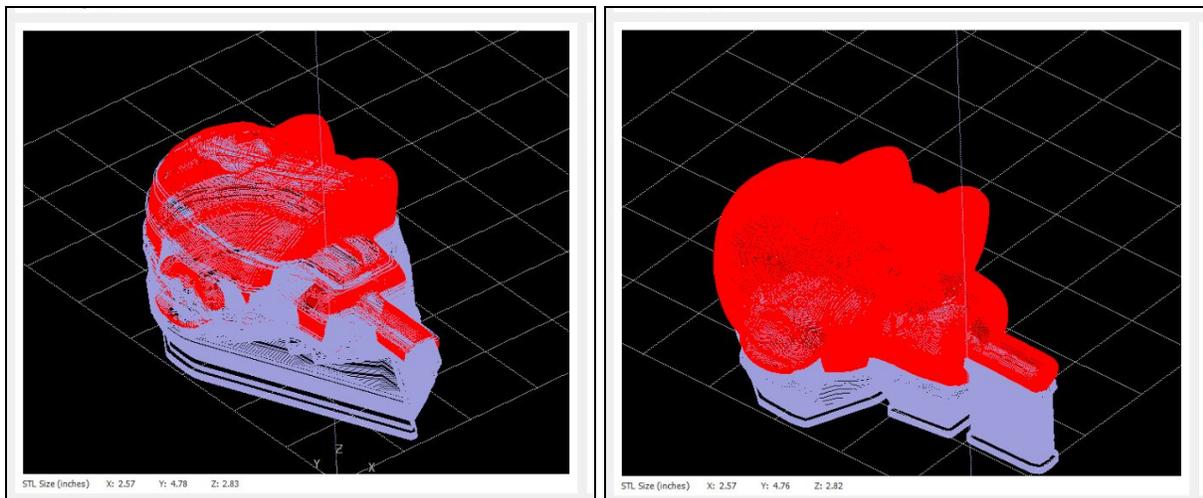


This print took about 10 hours to complete. Very thin layers are built in order to maintain small, intricate details in the final print and contributes to the long time frame necessary for a successful result.

The final print is made of melted ABS plastic, but there is soluble brown material also printed that encases the object for support. When finished, this material can be snapped off but if it becomes stuck in harder to reach crevices, the print needs to go into a heated lye bath. At 70 degrees Celsius, the support material will melt from the object and leave the print intact. During handling, arm length heavy duty gloves must be used to prevent direct contact with the lye. After this step is completed, the print can be washed with water and dried.



After dipping into the lye bath, it was noticed that half of the model was still missing. Also, it seemed that some layers were visible and thin in some spots of the print. This made us question the integrity of the model itself, which led us back to look at it again in Meshmixer. Also, we found a [wiki document](#) from the Prototyping Lab which also helped with troubleshooting. There were still cracks read in the rendering, so the model was “solidified” which filled the interior. We also had to refine the surface again to maintain detail. When we uploaded the file again to Catalyst before printing, there was a significant difference in quality and detail. The areas in red represent the print and the purple areas are the support material.



After we figured out why the first two prints were not completely successful, we still kept the size in millimeters true to scale but changed the interior back to sparse since we were more confident that the print would stay intact. This printing took 8 hours, since less material was used to build the interior.

After being dipped in the lye bath and washed, it took longer to dry since the interior was more hollow than the solid print.



We also needed to print the boots and hands which were all printed together to save time. This printing took 8 hours. When done, we were able to just snap off the support material by hand.



Rebuilding Woody

To show possibilities for education and functionality, we decided to focus on “rebuilding” Woody. Since the prints are true to scale, we figured it would be simple to put together a mock 3D print version of Woody to show how curators and educators could expand the archive remotely and develop active learning activities through puppet “re-building” with printed archival 3D scans.



We began with our prints and recycled Woody’s clothing that we pulled apart for the testing for the build. Also, we reused the wooden block that made Woody’s torso, but it is a possibility to scan and print this section as well.



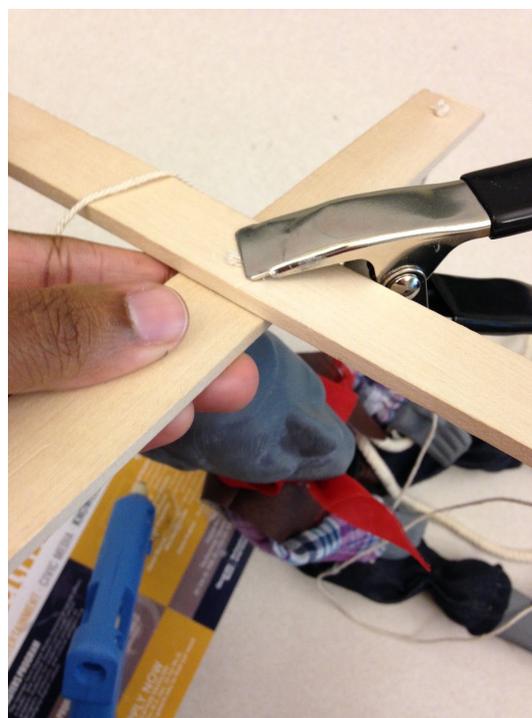


The original yellow shirt was no longer reusable for the model, so we took an old shirt and created a new one. Then, we fitted the hands inside of the sleeves as well as create hems on the jeans to fit around the boots. A hot glue was also used to secure the fabric to the prints.



A hole had to be create at the neck of the new shirt to fit the print into the peg of the block. Then, the jeans was secured onto the torso with hot glue and anchor threads to keep it secure. For the strings, holes

were drilled approximately into the same locations that strings were placed in the original version of Woody. The strings were added for preparation to attach to the crossbeam. The ABS plastic can also be sanded down for smoothness and painted.





Conclusion

What is the current best option available to us now?

For scanning, the NextEngine seems the best at capturing detail of the puppets that is necessary for archiving the collection. The challenges of using the device would be the amount of time needed with each object to fully capture accurate detail that represents the original craftsmanship, in particular larger and highly-decorated puppets. When working with complicated puppets at CPA such as marionettes, expect to work with the puppet for several hours with the NextEngine.

The 3D printing and finishing options on campus are excellent for creating final products. However, it must be kept in mind that the process is extremely time consuming using the Dimensions 3D printer. Even printing small objects with material saving options took about 8-10 hours at a time.

The modeling and mesh editing software used will depend on the skill level of the person working on this project. For us, we worked best with Meshmixer due to its user friendly features such as “select and fill”, “solidify”, and “sculpt” which were simple to use without much prior knowledge of 3D modeling. It should also be noted that after filling most holes, Microsoft 3D Printing Repair service can assist in removing errors from scans for lower detailed objects. The online service is free and works best/fastest with scanned objects that has most cracks and holes filled in¹¹. For someone who has advanced experience in 3D modeling, software such as Blender (free) or the more sophisticated MAYA would also work for preparing a 3D print.

What are the possibilities to make this project successful long-term?

More experimentation with other hardware and software such as MAYA and more stable portable scanners such as Scanify will provide more viable options for a long term archival project. MAYA does require more knowledge and expertise, so we would still recommend a modeling software that is accessible to any skill level like Meshmixer which allows for easy sculpting and refining for beginners like us.

Free Software vs. Possibilities with Premium Software (better scans and detail): There were some limitations with the equipment and software available to us and premium versions of these applications contain advanced features that do not exist on free versions.

- NextEngine comes with a standard version of ScanStudio, but there is a HD version which allows the camera to capture a larger object with less scanning; this version costs an additional \$995.
- Skanect also includes a premium version which also increases possibilities for better scanning and editing, in particular smaller objects with more detail. Skanect in general seems to be better suited to capture large surfaces such as rooms or people. The Xbox Kinect camera lenses simply are not designed in their intended use (full-body motioned sensor based gaming) to capture detailed, smaller objects effectively. Also, if using the free version, larger scaled scans will capture fairly clearly, but upon exporting the file’s resolution will significantly decrease making it virtually unusable.

¹¹ Microsoft 3D Printing Repair <https://modelrepair.azurewebsites.net/>

Due to the amount of space currently available at CPA (until expansion is complete), the complicated detail of some puppets, and the inability to “dissect” archived puppets, it may be valuable to invest in high quality portable equipment like Scanify that will accurately scan for both volume and detail without the need for much elaborate setup. Since the goal is to scan the collection at CPA, a piece of equipment that is both portable AND high quality that will save time. The process as it exist currently would take hours, even days, to complete just one puppet. At least cutting down the gathering time would allow for more production when modeling the 3D scans to develop a digital database for the Center.

Additional References and Links

Metallo, A. and Rossi, V. (January 2011). “The Future of Three-Dimensional Imaging and Museum Applications” *Curator*. 54, 63-69.

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