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Reframing the Conservation: A case study in using 3D imaging technology to restore carved wooden elements on a painting frame.

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Abstract

This paper will present the story of a collaborative project between the Imaging Department and the Paintings Conservation Department of the Metropolitan Museum of Art to use 3D imaging technology to restore missing and broken elements of an intricately carved giltwood frame from the late 18th century.

Background

In 2018 the Metropolitan Museum of Art in New York began an enormous 5-year long project to replace 30,000 square feet of skylights in the roof over a major portion of the museum. To facilitate this necessary upgrade, the European Paintings wing of the museum, comprising 45 galleries and over 700 works of art dating from 1300-1800, was closed and deinstalled in phases[1]. While the art was not on display, the staff of the museum used this time as an opportunity to perform some needed inspection, cleaning, and conservation work. In September of 2022, Cynthia Moyer and Evan Read from the Paintings Conservation department contacted the Met's Imaging department to inquire about the possibility of scanning and 3D printing some replacement elements for a carved wooden painting frame from the French Revolutionary and Napoleonic period[2]. Marie Guillelmine Benoist's 1802 portrait of Madame Phillipe Panon Debassayns de Richemont and her son Eugene, is mounted in an elaborately carved gilt wooden frame. Created in approximately 1787, the frame features multiple repeating patterns of floral motifs[3]. Over time some of these flower elements broke off and were lost. Traditionally, a molding process would be utilized by the conservator to repair or replace these frame components. The first step would be to use a two-part (base plus activator) silicone-based putty, the same product used by dentists to make dental impressions, to create a mold from an intact component from the frame. The next step would be to create the positive using a moldable epoxy wood filler putty, such as Sculptwood Putty. The last steps would be to add the undercoating of ochre and red ground layers and water gild the molded repairs to blend them in with the rest of the frame. For some areas of the Benoist Frame, this method was in fact used. However, there were intricate three-dimensional flowers that did not lend themselves to the molding approach due to their complex geometry and undercutting. These pieces would have required a wood worker to carve the motifs from scratch. The idea for this project was to see if it would be feasible for the Imaging Department to scan, make clean 3D models of the missing pieces, have the needed parts printed, and then for the Paintings Conservator to gild the 3D prints to match the rest of the original frame. This paper documents the process of trying a new approach to address a common conservation problem.

Approach

To begin the process, a team from Imaging met with the Paintings Conservation department to examine the frame and talk about the goals of the project. The first issue that the frame presented to the Imaging staff was that it is entirely covered in gold leaf. Highly reflective surfaces such as this are almost always challenging to scan. The conservator working on the Benoist frame, Cynthia Moyer, pointed out the two types of elements that were in need of repair and that she thought would be candidates for 3D imaging. The outer edge of the frame features a repeating pattern of three variations of Laurel Berry flower carvings that are set into a

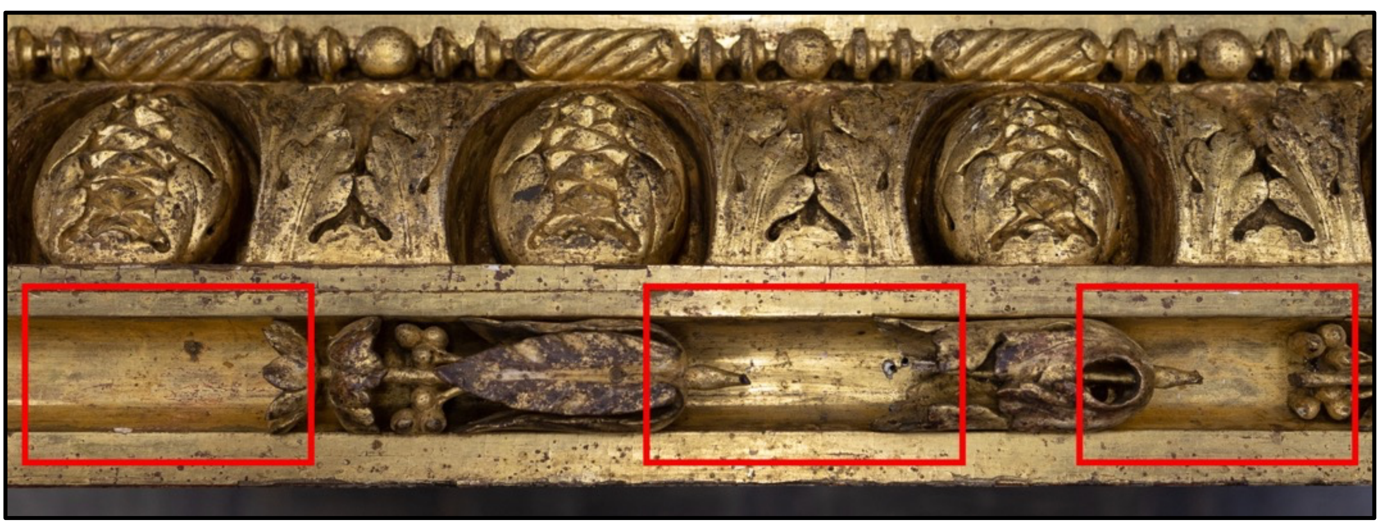


Figure 1. *Detail of Benoist frame showing areas of lost Laurel Berry flower carvings outlined in red.*

semicircular channel, quite a few of which were missing and/or broken. The inner edge is decorated with an alternating pattern of Acanthus and Lotus flower leaves. The Laurel Berry carvings in the outer edge channel are fully three dimensional, while the Acanthus and Lotus leaf elements are flatter and more like relief carvings. Aside from the difficulties with scanning reflective surfaces, it was also clear that the only way to get a proper scan of the Laurel Berry flowers was to remove a few of them from the channel to provide access to all sides. For the Acanthus and Lotus leaf elements, it seemed possible to scan them while still mounted to the frame.

Figure 2. *Details of Benoist frame showing Acanthus and Lotus leaf carvings, losses outlined in red.*

After the initial inspection, we as a group, both Imaging and Paintings Conservation staff, had to decide if it was even reasonable to expect to be able to achieve the goals of reproducing the missing parts to a very high standard using 3D imaging technology and of safely and inconspicuously restoring the frame. The Met Imaging department had been producing high quality 3D models for over 6 years at that point, some had been used to make one to one scale reproductions, some used by contemporary artists in their artwork and some models had been used to make internal supports and mounts for objects, but never at the Met had a 3D printed element been used to repair or replace part of an object. The only other time 3D imaging had been used in a similar fashion was in the restoration of the Cassiobury House Staircase[4]. In this instance a large hand carved wooden finial was scanned and digitally restored by Met Imaging Specialist Jesse Ng. The resulting 3D model was used to CNC mill three replacement finials from blocks of oak. After milling, the oak finial reproductions required hand carving from a woodworker to refine details and add a handmade quality to the surface before they were ready for finishing. Due to the success of the Cassiobury House Staircase project, even though the output process was different, the Imaging department had a blueprint for how to proceed with imaging the Benoist frame components. While we were confident in the Imaging Department's ability to scan and produce high fidelity models of these parts, there were still the unknowns of whether we could find a vendor to print the 3D models to our quality standards and in a material that would be able to accept the finishing treatment required to match the rest of the frame, ideally without needing any hand finishing to the surface. In spite of these uncertainties, it was decided to move forward and start the scanning process.

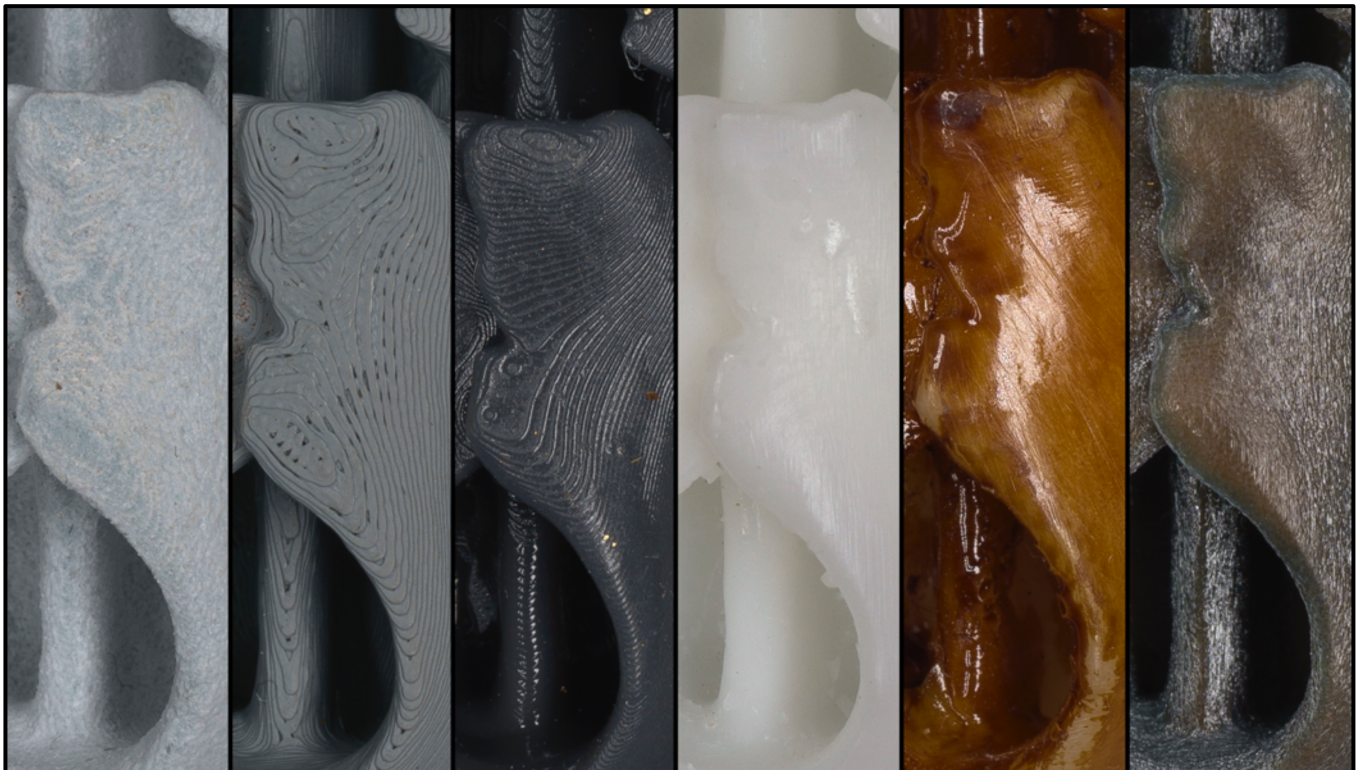
The Met's Imaging Department employs three methods of 3D model creation, Laser Scanning, Structured Light Scanning and Photogrammetry. Laser Scanning produces a highly accurate model but without any surface color information, Photogrammetry and Structured Light Scanning produce both a mesh and full colored texture layer. Due to the small and detailed features of the frame and the fact that we were only concerned with obtaining an accurate mesh, a colored texture was not needed for this project, it was decided that the best technique for scanning would be the Faro laser scanner. The FARO Edge and ScanArm ES have an advertised scan accuracy of +/- .0014 in (.035 mm), a 6 mm Ball Probe attachment and was set to scan at a fine resolution that did not include smoothing or reduction of the points. To address the reflective gold surface of the frame parts and make it much easier to achieve high quality scans, Cynthia Moyer was able to apply a non-reactive and easily removed matte finish to the samples. A mixture of Regalrez, a petroleum-based resin used in varnishes, combined with a mineral spirit solvent (D 38) and a warm grey dried pigment was sufficient in creating a less shiny surface for scanning. After scanning, this matte coating was removed using D 38, the mineral spirit solvent used in the matte coating. Because the gilding and undercoatings are water based, this petroleum-based coating and solvent used to dull the surface for scanning and then to clean the pieces had no negative impact on the original finish of the sample pieces.

We started by scanning three Laurel Berry components that could be removed from the frame and transported to the Imaging Studio. These Laurel berry and Acanthus leaf pieces ranged from 6.3 cm (about 2.48 in) to 9.8 cm (about 3.86 in). While some pieces could be detached from the frame easily, there were two flat components fixed to the surface of the frame. The Acanthus flower measured 5.1 cm (about 2.01 in) and the Lotus flower measured 4.2 cm (about 1.65 in) across. It was necessary to transport the laser scanner to the frame to capture those two flowers. Scanning was done in passes. As the scanner passed over the piece(s), points along that surface were collected to provide a scan pass of that area. If the component needed to be turned to capture more information, that entailed starting a new scan pass. To create a complete model, these multiple passes would need to be aligned first to form a proper mesh. For the Laurel Berry flowers, five to six scan passes for each piece were required to capture all of the data points that the scanner could collect. Because of the complex geometry and small size of these parts, even after aligning the multiple scans into a single mesh, all of the models were full of holes where the scanner just could not get a measurement. Digital editing was a necessary step to fill in any information that was not captured during the scanning process. This was done using Geomagic Wrap and Blender. Most of the holes or missing scan data were in the deep recesses of the carvings. Filling in these incomplete areas of the mesh was achieved using Geomagic

Wrap. Once the meshes were made whole and watertight, sculpting of those filled parts was done in Blender to bring back the surface detail that may have been lost in the process, and to correct the geometry of some of the fills. Throughout this digital repair process the original frame parts were kept on hand to be referenced when filling and sculpting. This was done to ensure that the missing information was filled in as closely to the original piece as possible.

With the 3D files nearing readiness to print, a group of Met staff from both the Imaging and Paintings Conservation departments went on a tour of the LaGuardia Studio 3D Scanning and 3D Printing facility at NYU. The wide range of materials and printing devices available as well as the staff expertise and their willingness to collaborate, made for a good fit on this project. Multiple rounds of test prints would be made before the right material and print process and settings were found.

The Imaging Department finalized the preparation of the 3D models, making partial variants of some elements to match the variously sized losses in the frame and the files were sent to LaGuardia Studio for printing. The staff at the NYU 3D printing facility were responsible for operating the multiple printers utilized in this endeavor. They also had the difficult task of removing print



Material: Nylon 12	ASA	Acrylic Resin	White Acrylic Resin	White Acrylic Resin Shellac Coated	Grey Tinted Acrylic Resin
Printer: HP Fusion Jet 580	Stratasys Fortus 450	Formlabs 3B	Formlabs 3B	Formlabs 3B	Stratasys Polyjet J850 Pro 3D
Approval: NO	NO	NO	NO	NO	YES
Reasons: Color too light. Surface too textured.	Visible banding of 3D printing layers.	Visible banding of 3D printing layers.	Good print quality but color too light.	Shellac surface not good for gilding process.	Excellent print quality. Surface works with gilding process.

Table 1. *Chart showing details of different print output samples, print material, printing device, and an evaluation of the printing.*

supports structures without fracturing these thin prints. One of the Laurel Berry flower models was selected to be used for test printing. The first print was produced in a light grey nylon material on an HP Fusion Jet 580, a multi jet fusion (MJF) 3D printer. MJF is a powder-based process known for producing high resolution 3D prints due to the very thin printing layer height and for quick turnaround time. This print was rejected due to the color being too light and because of the surface quality. If the base color of the printed parts was too light, the layers on top of that would not match the original frame. Additionally, there was an extraneous bumpy texture that did not exist in the actual piece. The printed parts would eventually need to be gilded, covered with a very thin layer of gold leaf, any surface texture would show through and actually be exaggerated by the shiny gold coating, so it was vital for the printed surface texture to be as close to the original pieces as possible.

The second print was produced on a Stratasys Fortus 450, a Fused Deposition Modeling (FDM) printer, using light grey ASA (acrylonitrile styrene acrylate) material. FDM printers work by depositing melted filament material in successive layers to build up the model. The print from the Fortus 450 was not approved due to the surface quality which contained visible banding caused by the excessive, in this case, thickness of the printing layers. The final three prints were all made using acrylic resins. The first of these, a grey resin print was made on the Formlabs 3B printer, a Stereolithography (SLA) printer that is primarily used in dentistry. The SLA printing process uses a laser to cure (harden) liquid resin in successive layers to build up the model. SLA printers can often print in very thin layers leading to high printing resolution and smoother more organic output. The first Formlabs 3B print was not approved because the printing supports created a rough surface at the points where they were removed and there was visible banding all over the print surface and the color was too dark. After this iteration, it was determined that the file would need to be printed at a higher resolution and rotated 90° to properly show the details without banding. The next print was made with white resin and also completed on the Formlabs 3B, incorporating these changes. Although the increase in printing resolution and rotated orientation of the 3D model on the printing axes produced a part that was satisfactory as far as detail and surface qualities, the color was too bright to be used even when coated with dye and shellac. There was no option to try other colors on the Formlabs printer without incurring a significant extra cost, so it was decided to try another printer. The final approval came when the prints were done on a Stratasys Polyjet J850 Pro 3D. The Polyjet printer is capable of layering, combining and then curing multiple different types and colors of resins at a high resolution. The Polyjet J850 was set to combine a white resin at the core with a gray resin on the outside. At last, we had a product that met all of our requirements, the color was good, the surface quality matched the originals very closely, the detail was good and when the conservator tested the sample the surface of this print reacted well to the undercoating treatment.

Now that Cynthia Moyer, Associate Conservator in Paintings Conservation, had given approval to the printing process and material, the lab at LaGuardia studios was able to start printing all of the variant model files that Imaging had rendered out. After receiving all of the 3D prints, Cynthia was able to create a gilded finish atop the 3D prints and secure them to the frame. The gilding process began with primer layers of bole (clay) and rabbit skin glue. Bole provided a base color and smooth surface that the gilding would look better on. The first layer of bole was a sienna/ ochre color that was painted thoroughly onto the surface of the 3D print. The second layer of bole was red ground only painted on the front-facing areas, not deep crevasses. The rabbit skin glue helped make the print surface adhesive and ready to accept the gold leaf. The gold leaf was water-gilded on top of the coating. The gilded prints were finally secured onto the frame using PVA (polyvinyl acetate). Some other adhesives that did not work were fish glue and hot melt. The original frame ornaments were secured to the frame with hide glue and small nails. The long-term archival quality of the resin acrylic material used for these frame ornaments is not known. Therefore, the frame will need to be monitored over the long term and checked that the new components remain fixed to the frame and for signs of instability in or negative impacts from the 3D printed materials.

Results

The Benoist Frame components were scanned, resin printed, and successfully used to repair the frame. Multiples of five separate parts were printed and utilized for the final repair. The parts were coated and finished to match the original frame and then fastened in place. After the completion of the skylight renovation project, the painting and its restored frame went back on display, in Gallery 634, for the reopening of the European Paintings Gallery on November 20, 2023. Following a year of conservation work, the seamless repairs go unnoticed by visitors who gaze up at the beautiful painting and its ornate golden frame.

It was clear from the very beginning that for this project the laser scanner was the tool to use to model the parts for the Benoist frame. From a mesh generation standpoint, the laser scanner produces a more accurate and finely detailed model than either photogrammetry or the structured light scanner. One of the drawbacks of laser scanning is that it renders form only, with no color texture information. In this use case, an accurate mesh was all that was needed, so not having a texture layer was of no concern.

The 3D resin prints were determined to be the ideal material through an iterative process. Multiple combinations of different materials and printing processes were tested before arriving at this conclusion. Earlier test samples proved unsatisfactory mostly due to issues such as printing artifacts that would have required many hours of handwork to smooth out, loss of fine detail and the difficulty of working with the materials. The resin printing process produced very detailed, clean and smooth prints that were nearly ready for surface finishing right from the printer.

Conclusions

To conclude, the Benoist Frame Repair was a highly collaborative process that involved not only two departments within the Met, but also the LaGuardia Studio lab at NYU for 3D printing. What helped us succeed in this larger scale project was to communicate openly to one another about the expectations of what we wanted to achieve, adjusting our working methods to match the needs of the conservator and vice versa. Since this was new territory for all involved, it was vital to the success of the project to be flexible in our approaches.

As a pilot project, the Benoist frame restoration has been considered very successful by all involved at the Met. The positive outcome of this experiment and the awareness of it by other conservators throughout the museum mean that the techniques of 3D modeling and printing replacement elements for frames and other objects will be considered as an option more and more. As with all restoration methods there are certainly pros and cons associated with its use, but having more viable and practical tools at the disposal of our cultural heritage caretakers can only be seen as a benefit. Resin prints from 3D models will not always be the best method of replacing losses but the relatively low cost compared to the high quality of result make it an option well worth consideration for future restorations.

Beyond the conservation of the frame, we intend to share the work done on this project through educational outreach. The collaboration between Imaging and Paintings Conservation is a unique story that many people will be interested in learning about. We will share this story, through programs with the Met's Education department, by using silhouettes of the frame ornaments we designed to be a puzzle. The students can handle the laser cuts of each frame component and place them into an acrylic board cut to match that shape. In addition, video renders can help the viewer see what work was done by viewing the models prior to editing compared to the final, print ready files. The Met places importance on educational outreach using projects such as this one, because it fosters interest in our collective cultural heritage and in the skills and technologies employed by the staff to preserve and present the artworks.

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Author Biography

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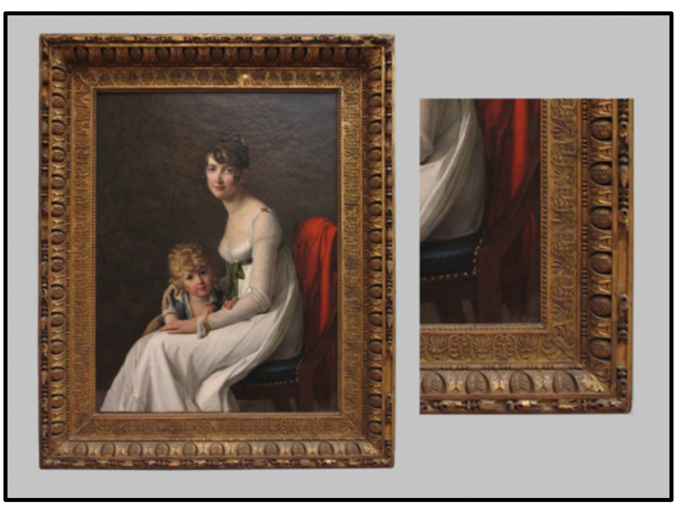

Figure 3. *Pre-frame repair (2013), Madame Phillippe Panon Desbassayns de Richemont and Her Son, Eugène [c.1802, Marie Guillelmine Benoist]*

Figure 4. *Scanning with FARO Laser Scanner*

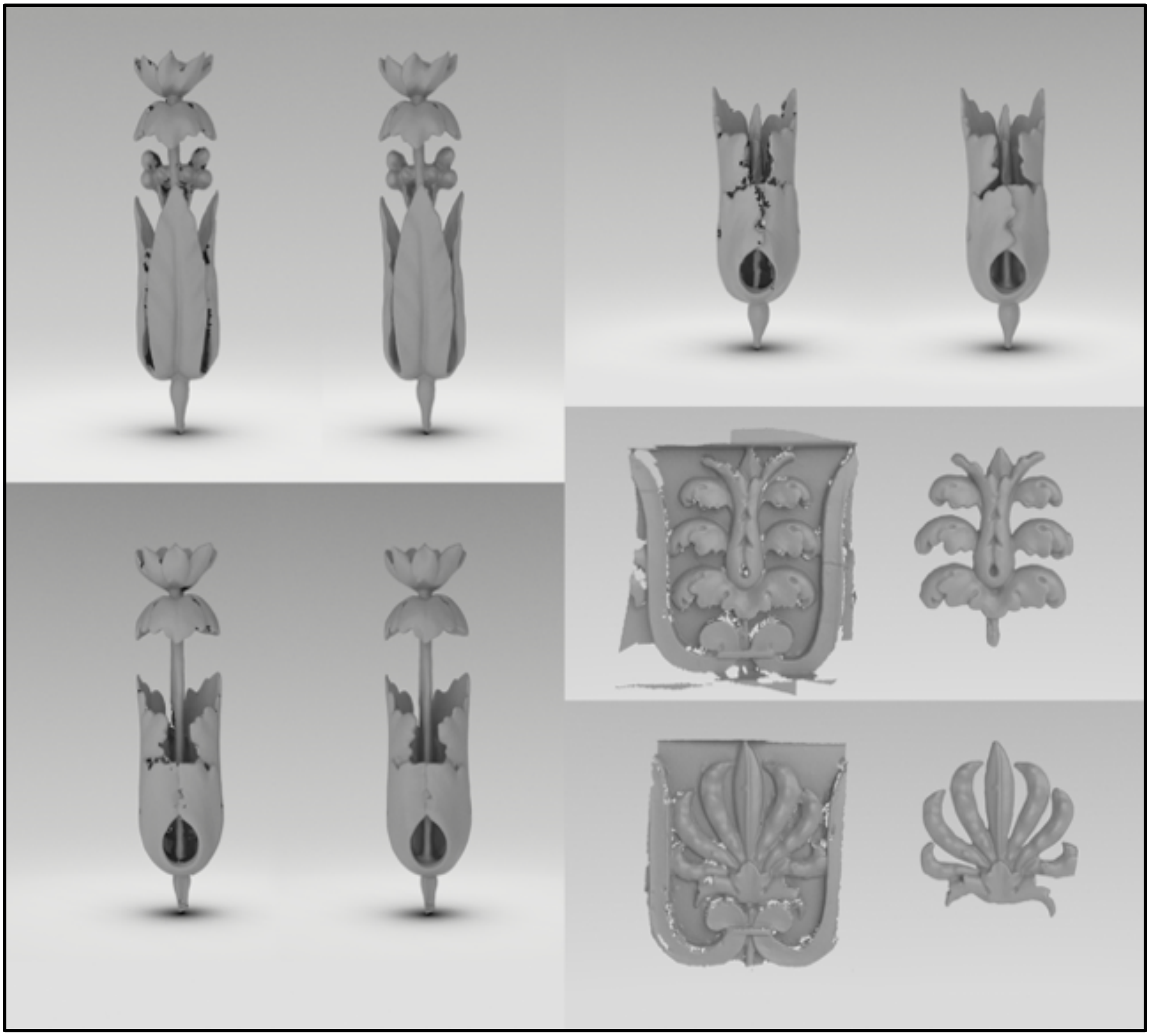

Figure 5. *Laser Scans of Laurel Berry, Acanthus and Lotus Flower Motifs, Raw scans on left showing missing data, filled and sculpted models on right*

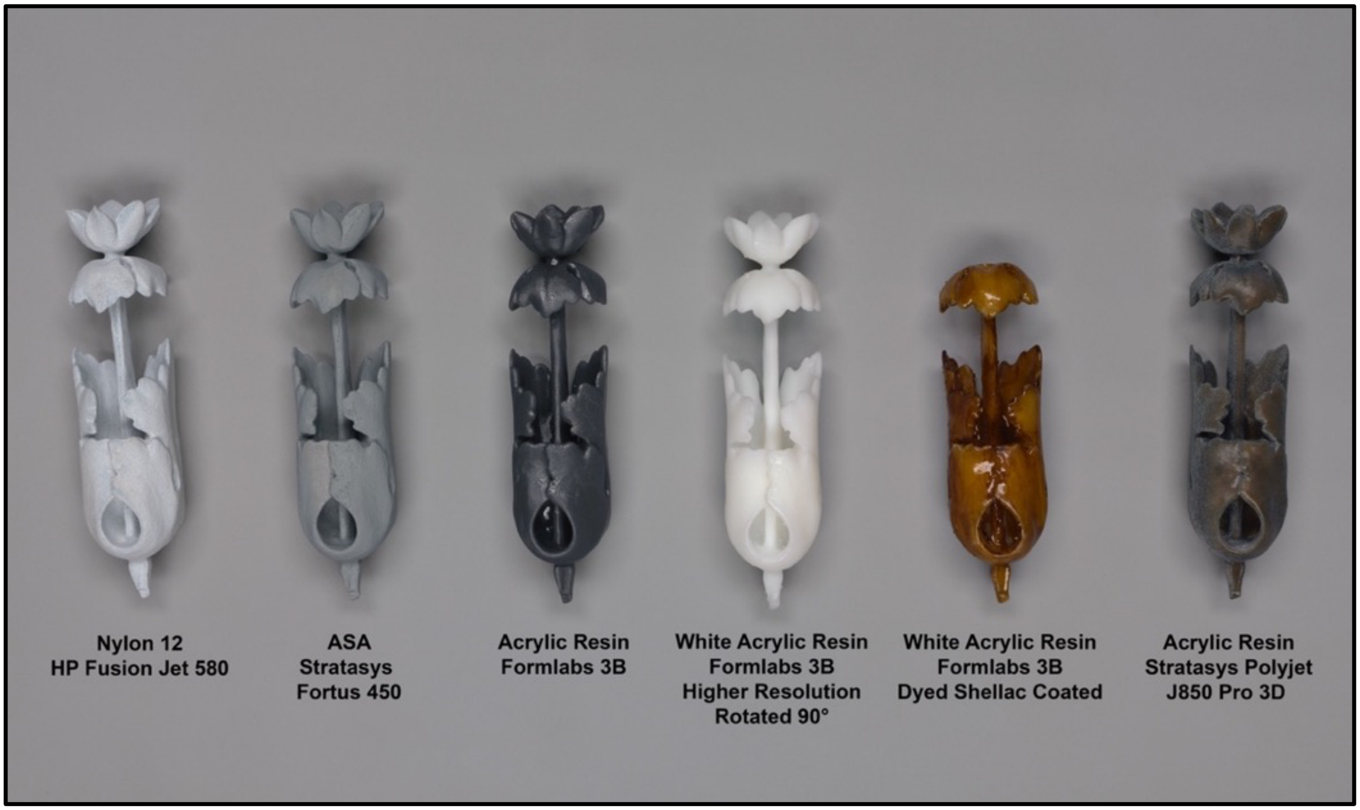

Figure 6. *Lineup showing the progression of sample 3D prints produced in the process of identifying a satisfactory output solution.*

Figure 7. *Examples of final 3D printed parts, before surface treatment and gilding.*

Figure 8. *Post-frame repair (2023), Madame Phillippe Panon Desbassayns de Richemont and Her Son, Eugène [c.1802, Marie Guillelmine Benoist]*