Laser Scanning of organic spruce-root based geometry to create a manifold mesh for Powder Bed Fusion Additive Manufacturing Process

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June-2022

Abstract

This paper highlights the equipment, software, parameters, and workflow required to 3D-Laser scan a complex organic-shaped art piece and physically reproduce it using Powder Bed Fusion (Selective Laser Sintering) technology. The model used for this experimentation was a Coos Clam Basket, which is a museum art piece woven by artist Sara Siestreem (Hanis Coos).

This paper is heavily weighted on the methodology section, as the purpose of this paper is to allow for the re-creation of similar work. The 3D-Laser Scanner used for this project was the Creaform HandyScan Black Elite series, which uses a blue laser to detect and capture surfaces. The majority of the post-processing using raw scanned files was performed using *3D-Systems GeoMagic Wrap* software. 3D-Printing risk failure analysis and digital sectioning were performed using *Materialise* Magics V25. The technology used to recreate the physical model was Powder Bed Fusion (or Selective Laser Sintering) method using *Formlabs Fuse-1* printer. The 3D-Printed piece was printed and at the time of this writing is on scheduled exhibitions at museums and galleries across the Pacific Northwest.

Keywords: Laser Scanning, Powder Bed Fusion, Additive Manufacturing, 3D-Printing.

Introduction

The objective of this experiment was to laser scan and subsequently, Additively Manufacture a museum piece with features and details preserved. Additive Manufacturing is the process of adding material often layer by layer and is commonly known as 3D-Printing (Linke, 2017). A 3D-Laser scanning method was used for the initial data capture process. There are various types of 3D scanners commercially available, and the two major forms of technology either use laser-line or white-light technologies. Laser scanners project one or many laser lines on an object while white-light devices project a light and shade pattern (Pierre-Hugues ALLARD, 2014). Both will analyze the resulting deformed projections to extract the 3D data. For this experimentation, a laser-line scanner *Creaform HandyScan Black Elite* was used.

The *Creaform HandyScan Black Elite* scanner has an accuracy of 0.025mm and is capable of creating a mesh with resolutions of 0.1mm. Although the CAD generated through scanning preserved high details of the original model, the Additive Manufacturing equipment used for this experiment prints with a high success probability of features having wall thicknesses of >0.5mm.

The laser scanner scans and creates point clouds in real-time. These are arbitrary points in a virtual three-dimensional space that mimics the surface of the scanned object. Since point clouds cannot be used directly for 3D-Printing, the point clouds are used as a reference to overlay and stitch vertices of a triangle. This creates a *Standard Tessellation Language.*

A few specialized software were used to create an optimized *Standard Tessellation Language*, analyze print failure areas and mitigate such risks based on the analysis. The workflow and

software used for the process are described in the methodology section.

Fig. 1 – Hanis Coos Clam Basket

Methodology

The experimentation consisted of a ten-step workflow for 3D-Scanning to 3D-Printing.

Process 1.1: Target Setting

Most handheld 3D scanners use stereoscopic vision using two cameras. This enables the scanner to determine its position in relation to specific points, which could be positioning targets, the object's natural features, or textures (Pierre-Hugues ALLARD, 2014)

For this experiment, reflective positioning targets[4] were used. These targets generally come in the shape of a circle with a known diameter with a reflective element in the center. The optics of the laser easily pickups up the reflective targets and registers them as a frame of reference.

Fig. 2 – AMETEK 6mm Positioning Targets

The reflective target stickers could be applied in two methods, the first being an attachment to the

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[4] *Target Stickers Used: Creaform Positioning Targets #6 (+)*

model itself and removing them post-scan. This method was not acceptable for this experimentation since the adhesive could have peeled off fibers from the museum piece post-scan.

The second method, which was the preferred method for this experiment, was to use target stickers on adjacent surfaces next to the scanned object. The targets were sparsely separated with the intent of the laser to pick up at least three targets from each angle.

For enhanced registration of the target stickers from multiple angles, the 3D-Print lab designed and printed pyramids with a diameter recessed for adhesion of the stickers. These pyramids were placed around the scan object and allowed for greater scanning flexibility.
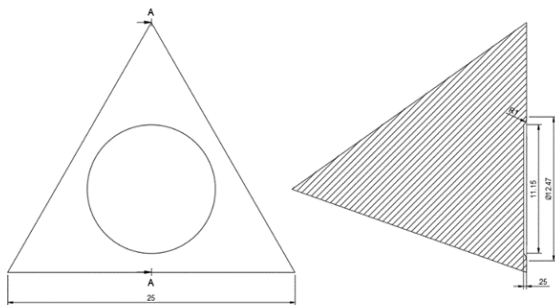

Fig. 3 – Drawing of Pyramids for Target Sticker Attachments

Process 1.2 Laser Scanning

The Creaform HandyScan Laser Scanner is a handheld 3D-Scanner, capable of picking up 1.3 million scans per second with a measurement resolution and accuracy of 0.025 mm. It uses a blue laser to achieve a higher level of accuracy and resolution as compared to traditional photogrammetry-based 3D-Scanners.

Software Parameters

The laser parameters were modulated using the *Creaform VX Elements* software. Key parameters used for scanning were as follows:

Software: Creaform VX Elements

Resolution: 0.3mm

Shutter: 0.10 m/s

Laser Pass: Hatching/Crosses

Fig. 4 – Screenshot of Raw Scan with Artificial Color Added

Process 1.3 Points-to-mesh creation

The laser scanner picks up scans from surfaces and synthesizes them in arbitrary space. Each raw scan consists of multiple points in a digital cloud. To give it form, all the points are stitched to translate to a file format called *Standard Tessellation Language* (STL) or commonly known as *meshes* and is used as the programming language for most 3D-Printers. This process was done using the laser's native data capture software – *Creaform VX Elements*. Point clouds converted to meshes through the stitching process tend to have non-manifold triangles with various voids, bad edges, overlaps, and contours as seen in a diagnostics analysis in Fig.8. A manifold mesh contains triangles whose vertices are bound and form a watertight volume – that is without any voids or overlaps (David A. Bonneau, 2019). The construction of manifold meshes is critical for reducing the chances of 3D-print failures.
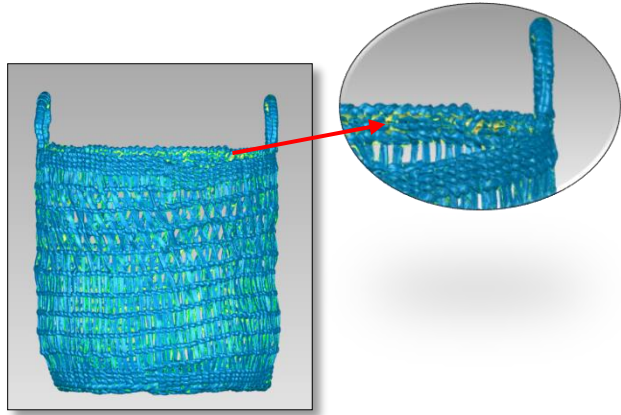
Fig. 5 – Raw Scan with Non-Manifold Mesh with voids

Process 2.1 Post-Scan Mesh Refinement

This process is the most time-consuming segment of the 3D-Scanning process. Since the laser detects surfaces and features within its line of sight, any undercuts or areas the laser is unable to scan are depicted as void spaces (missing geometries) on the initial mesh. Subsequently, any unwanted surfaces such as features of the workspace, pyramid triangles or other noises will also be merged in the mesh.

The workflow consists of importing the initial mesh to *GeoMagic Wrap* – a scanned mesh post-processing software. Although the initial prompt allows for automatic fixing, which would be great for parametric shapes of scans, the lab opted for manual fixing of the mesh file. Automatic fixing caused the creation of geometries and features that did not resemble the actual art piece.

The first step taken was to select and eliminate any "noise shells" – features that are irrelevant to the final scan. Performing this step in the beginning stages allows for a lower graphic and processing load on the working computer for future steps.

Once the noise shells were deleted, the next step was to digitally stitch any gaps and voids. A feature in *GeoMagic Wrap* called c*urvature filling* identifies edge surfaces next to the void spaces and automatically fills in the void using the approach angle for the surfaces. Similar to

automatic fixing this process is not accurate for complex shapes and tends to create non-relevant geometries.
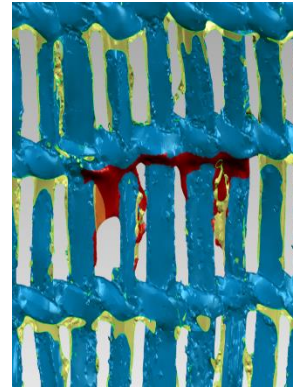

Fig. 6 – Curvature Fill Creating Non-Relevant Geometries

To avoid this issue, *bridges* were used to manually patch void spaces using a *Flat Fill* feature. This reduces the open areas the software needs to interpolate and generally tends to allow for well-preserved surface mergers. Once the bridging method is completed, a *curvature fill* feature was used to fill the gaps between the bridging. This process was repeated over all missing geometries and void spaces to refine the mesh as a watertight manifold.
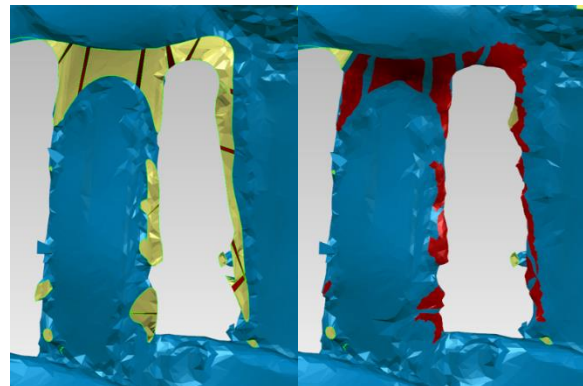

Fig. 7 – A Bridging Sequence (left) followed by Curvature Filling Sequence (right)

Process 2.2 Optimizing mesh for 3D-Printing

Software Used: Materialise Magics

The optimization step included the following

1. Aligning the scanned file to XYZ planes.

2. Enhancing and further fixing any odd triangles of the mesh output from *GeoMagic Wrap*.
3. Performing print failure features analysis.

Alignment

When a scan file is directly imported to *Materialise Magics V25*, it may not be bound to a parametric orientation corresponding to the XYZ planes of the software. An alignment operation was performed in Magics using the alignment tool. The mesh model was digitally rotated with the bottom of the object in view. Using the *alignment feature*, a 3-point plane was selected using three points that ought to be on the same bottom plane. The 3-point plane was then constrained to the software-defined XY plane.
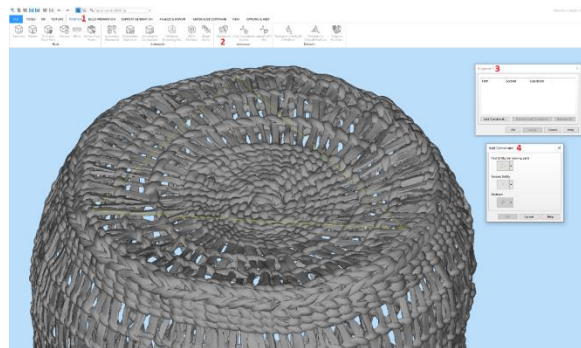

Fig. 8 – A 3-point Alignment with XY Plane as Constraint

Enhancement

Albeit *GeoMagic Wrap* is the primary post-processing software for raw scanned mesh, the software used in Process 2.2 – *Materialise Magics V25* is equipped with a toolkit for further enhancement of the post-processed scan files. The first step of the enhancement process using this software was to select the part and perform a *shell-to-part* operation. This dissected the CAD file and output multiple shells, assorted on the command tab in order of largest shell to lowest shell in terms of model volume (cubic dimensions). The first few shells are the primary shells that preserve most of the mesh and the remainder are points are noise shells. The next operation is to delete all the unwanted

point/noise shells, ensuring that critical features are not eliminated from the model.

The next step was to select the remaining shells and perform a *merge* operation. The STL model after this analysis will be lower in file size since noise shells were deleted. After merging, the file went through *Materialise Magics V25's automatic fixing* operation. This was performed in case of any overlapping triangles were potentially created while merging the shells. All these operations ensure a watertight manifold STL model is created from the scanned file, which greatly reduces the chances of potential print failures.

Fig. 9 – Diagnostics of the raw scanned non-manifold mesh file

Fig. 10 – Diagnostics of the fixed manifold watertight mesh file

Print Failure Points

The *Creaform HandyScan Elite* laser scanner is capable of scanning at resolutions 0.025mm, however, the Selective Laser Sintering using Formlabs Fuse-1 3D-Printer constraints feature sizes to be 0.3 mm at minimum. The challenge with printing 0.3mm features is the post-processing since such features tend to break off during post-processing. For accurate printability and for post-processing, the features need to be at least 0.5mm.

Using this constraint, a wall thickness analysis was performed using *Materialize Magics V25*. The parameters for the analysis had the lowest point set to 0.5 mm and the highest point over 1mm. The analysis outputs a heat map of features/regions within the mesh that is between

the boundary conditions of the user-prescribed parameters. The regions which are less than 0.5 mm were digitally extracted and thickened.

2.3 Digital Sectioning

The software used for digital sectioning of the regions below the minimum printing tolerance was *Materialise Magics V25*. The mesh is selected and under *Tools>Sectioning>Straight* line section is selected. Each section is meticulously sectioned and saved as a new mesh STL. Each of those sectioned pieces is highlighted using a *shell highlight* feature and thickened using the *extrude* feature in Magics. Each piece was extruded, such that they were >0.5mm in thickness. The intended goal was to print the thickened pieces separately and bond (glue) them together post-print.

Once the thin walls are sectioned, the next step of the operation was to section the whole model into four separate pieces. This was done due to the limitations of the effective build volume of the 3D-Printer. The *Formlabs Fuse-1* printer has a build volume bearing 165mm x 165mm x 300mm. The scanned mesh has overall bounding dimensions of roughly 217mm x 216mm x 235mm. Therefore, the minimum sections required were four.

Traditionally when sectioning is done for 3D-Printing, various forms of sectioning are performed, such as lap-joint, pins/holes, notched sections, etc. Such operations require a relatively thicker cross-section between walls. Since the 3D-Printed model had weaving patterns with wall thicknesses as low as 0.5mm, traditional sectioning methods were not used. Rather, a *straight-line* cut was performed using *Materialize Magics V25* to section the part.

2.4 Slicer Setup

The slicer used for Powder Bed Fusion 3D-Printing is *Formlabs PreForm*. Each piece of this project was oriented with the longest dimensions aligned in the z-direction. The sectioned pieces were printed bearing parameters as below:

Equipment/Printer: Formlabs Fuse-1

Slice Height/Layer Thickness: 0.110mm

Material: Polyamide-12 (Nylon-12)

3.1 SLS Printing

There are four major types of Additive Manufacturing processes – Material Extrusion, VAT Photopolymerization, Sheet Lamination and Powder Bed Fusion. Except for certain Powder Bed Fusion technologies, the majority of these technologies require support structures that serve as anchors and pillars that hold the 3D-Printed part(s) to a fixed base while printing. Despite its benefit, a major challenge in 3D-Printing is the removal of the support structures post-print. The challenge is further amplified when the 3D-Printed object has complex interweaving structures, latticing, or cavities.

Since the intended 3D-Printed object would have complex interwoven patterns with thin wall thicknesses, the experiment was done using a *Powder Bed Fusion* technology using the *Selective Laser Sintering* method.
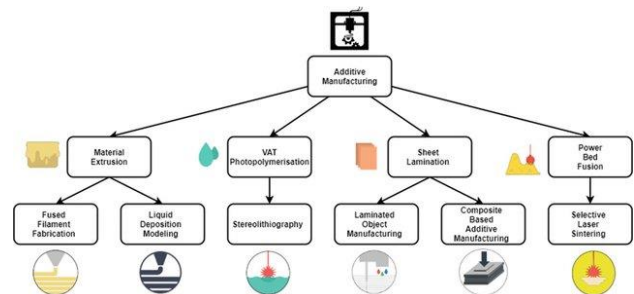

Fig. 11 – Types of Additive Manufacturing (Borra N Dhanunjaya Rao, 2020)

The material choice available for the Selective Laser Sintering method was Polyamide-12 (or Nylon-12).

The printing method involves dispersion of Polyamide-12 powder in layers of 110 microns each time. The printer's build chamber, or the printing component, have quartz tube heating elements that provide heat energy to the chamber to increase the temperature of the dispersed material to a temperature of a few

degrees below the material's sintering point. This is followed by a laser being activated that scans the cross-sections of the 3D model at each layer, which adds enough heat energy to sinter the material. This process is continued for each cross-section to 3D-Print a part.

3.2 Post Processing

Upon the completion of 3D-Printing using Powder Bed Fusion technology, the 3D-Printed models are encapsulated in a block of unsintered powder. Mechanical tools such as brushes and dental picks were used to extract the printed models from the unsintered powder. These tools were also used to ensure all loose powder attached to the surface of the models was carefully removed. This operation is performed in a station where unused powder particles could be recaptured and reused.

Extracting and cleaning the models free from loose powder followed a gluing/bonding procedure. A cyanoacrylate-based glue is generally used to bond 3D-Printed pieces. This glue is preferred over an epoxy-based material as it does not leave behind cured traces that can be seen when epoxy-based glue is used. The lab experimented with using cyanoacrylate glue, however, due to the porous nature of the sintered material, the glue was discovered to be absorbed into the printed material. The lab experimented with various brands of bonding agents and found the JB Weld Two-Part epoxy to be effective at bonding the pieces together.

To reduce the visibility of the epoxy on the bonded sections, a thin film of base material – Nylon-12 powder was sprinkled to trace along the bonded section lines. The epoxy adhered to the powder and any excess deposition was removed using compressed air and sanded using a 120-grit sandpaper to level.

Results

The final piece preserved most of the geometries and features as the actual Coos Clam basket. Due to the thin features, the printed model had to be handled with care. As being the first of its kind, the 3D-printed model at the time of this writing was scheduled to be at exhibitions at various museums and art galleries in the Pacific Northwest.

Theoretical Improvements

Powder Bed Technology: MJF vs SLS

The surface integrity and overall cosmetics of the 3D-Printed pieces could be enhanced if the 3D-Printed model could have been printed as one piece instead of four-pieces. It will be viable to utilize the benefit of non-supported 3D-Printing technique of a *Powder Bed Fusion* technology, therefore, the suggested 3D printer for larger build volume is HP Jet Fusion 4200 series. This printer also prints in a layer thickness of 80 microns (HP, 2022), as compared to 110 microns used for this experiment, thus preserving even finer features of the model. Furthermore, the mechanical properties, particularly the overall strength of the thin features would be theoretically enhanced using a Multi Jet Fusion (MJF) technology. Since a laser-based Powder Bed Fusion system follows a gaussian temperature distribution for the laser beam, sectioned pieces positioned at the edges of the print area have lower heat penetration as compared to areas in the center of the build area. This causes features printed at the edges to be mechanically weaker and increases the risk of breakage. Furthermore, due to the overlap of the heat received by the Nylon material, the 3D-printed model had unintended material adhered to certain regions. This occurs due to the overlap of the heat between the laser beams. Homogenous heat distribution across the build area and reduced probability of unintended material adhesion are theorized to be reduced using a Multi Jet Fusion technology since it does not use lasers and uses infrared heating lamps instead (Stefano Rosso, 2020)
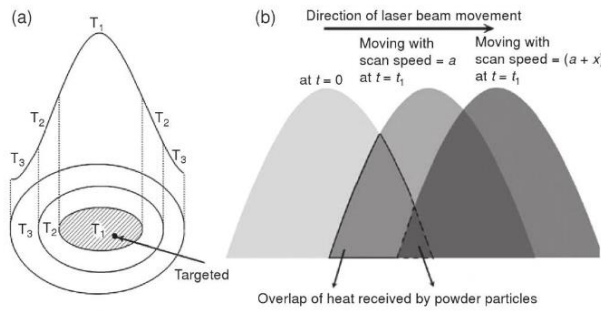
Fig. 12 – a) Gaussian distribution of temperature through laser beam b) Sintering model of a moving laser beam (Brandt, 2016)

Adjusting energy density parameters

The 3D-Printed final model was handled with care to ensure thin pieces of the model do not break off. To enhance the safe handling of the 3D-Printed model, the tensile strength of the model could be improved by increasing the energy density of sintered material during the 3D-Printing process. This could be done by either increasing the laser power or by decreasing the scan speed or scan spacing (Brandt, 2016) as per Andrew's number from the equation below.

$$E_a = \frac{P_l}{V_s * H * d_{layer}}$$

where E_A is the area-related energy density, P_L is the laser power, V_s is the scan speed, and H is the hatch distance and d_{layer} is the layer thickness.

Increasing the area-related energy density also increases the mass density of the 3D-Printed part. This could theoretically improve the porosity of the 3D-Printed part whereby a Cyanoacralate-based glue could be used instead of an Epoxy, giving the final piece a more cosmetically appealing surface finish.

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