

Layer by Layer: 3D Printed Art Objects in LACMA's Collections

3D printing has been quite a hot topic¹ in the news of late. Not surprisingly, objects constructed by this process have entered institutional collections. At the Los Angeles County Museum of Art (LACMA), we have identified two works of art as 3D printed. Results of the technical examination of these objects are presented.

3D Printing Technology

What is 3D printing? The technique grew from the manufacturing industry where it is referred to as rapid prototyping.² A manufacturing plant will not make just one of a particular widget because it is not cost effective. However, 3D printing allowed product designers, during their early design phases, to make just one scale model or part at a time as opposed to hundreds or thousands per “run.” All that would be needed is a 3D computer-aided design (CAD) file that could be sent to the software associated with the 3D printer.

3D printing is defined as a process based on stacking many layers on top of one another to generate a physical object. There are many ways 3D printers can deposit these layers (See Table 1). The table illustrates the diversity of the printing methods and printable materials. The most common methods used are fused deposition modelling, stereolithography, and selective laser sintering.

Fused deposition modeling involves a plastic (or metal) filament that passes through a hot extrusion nozzle (Figure 1). At the nozzle, the plastic is heated above the glass transition temperature; upon deposition as a thin layer, it solidifies rapidly.

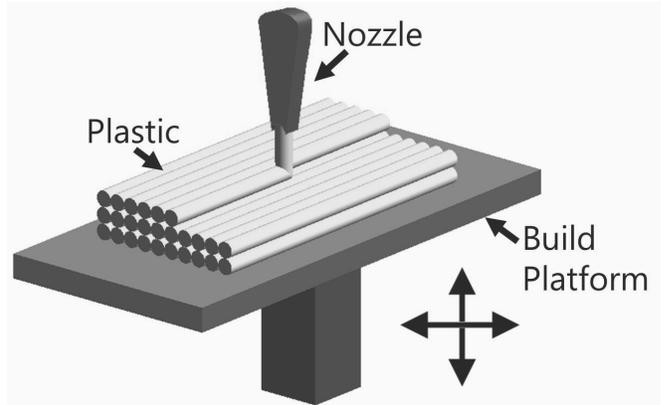


Figure 1: Schematic of Fused Deposition Modeling system [http://upload.wikimedia.org/wikipedia/commons/4/42/FDM_by_Zureks.png accessed August 29, 2014].

Stereolithography (SLA) uses a laser and photosensitive liquid polymer (Figure 2). As the laser is rastered across the liquid surface, a thin solidified layer is formed. The platform on which the layer is deposited is lowered step by step and the deposition repeated until the object is complete. Selective Laser Sintering (SLS) works in a similar manner. However, in the SLS process, the laser is rastered across powder, and the heat from the laser fuses or clumps together the powder particles. Again, the platform lowers, and the next layer is ready to be formed.

An excellent collection of videos of these technologies in action can be found at www.youtube.com/playlist?list=PL6ReneqBS2JDFuygm6Yta1iNBMaUds5fq.

Table 1: Major 3D Technologies

| Technology | Material | How it works |
|--------------------------------|--|--|
| Laminated Object Manufacturing | Paper, metals, thermoplastic | sheets of material are bonded to form an object |
| Stereolithography | UV curable resins, waxes, ceramics | liquid photopolymer in a vat cured by light |
| 3D Inkjet Printing | Composites, polymers, ceramics, metals | liquid bonding agent is selectively deposited |
| Multi-Jet Modeling | UV curable resins, waxes | droplets of material are selectively deposited |
| Fused deposition | Thermoplastics, waxes | material is dispensed through a nozzle or orifice |
| Selective Laser Sintering | Thermoplastics, binder coated metals | thermal energy fuses regions of a powder bed |
| Selective Laser Melting | Metals | focused thermal energy fuses materials by melting as the material is being deposited |
| Direct Metal Laser Sintering | Metals | thermal energy fuses regions of a metal powder bed |

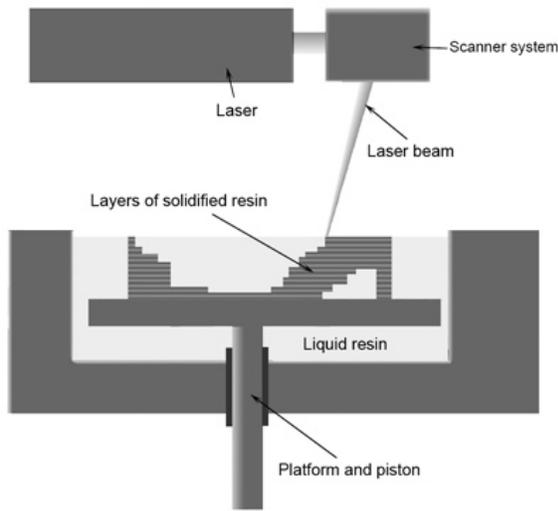


Figure 2: Schematic of a Stereolithography Apparatus [http://upload.wikimedia.org/wikipedia/commons/1/1e/Stereolithography_apparatus.jpg accessed August 29, 2014].

Case Study 1: Flatware Project for Alessi by Greg Lynn

In 2005, Greg Lynn was asked by Alessi, the Italian design factory, to create a prototype of a flatware set (Figure 3).

The prototype was acquired by the Decorative Arts and Design Department of LACMA in 2012. Soon after, there was a loan request for some pieces of the flatware. As the objects conservator Lily Doan was preparing them for the loan, she noticed that the metallic surface of the flatware pieces was atypical; it was very matte and grainy in appearance. The surface color of the different pieces varied considerably, some were more golden while others were grayish in color.

In the museum collection database, the flatware was described as steel and brass alloy, two materials that are already each alloys and are not traditionally mixed. To better understand what the material actually was, selected pieces from the set were examined microscopically³ and analyzed using X-Ray Fluorescence (XRF) spectroscopy.⁴

Under the microscope, the surface of the metal appeared rough and granular. Interestingly, along the edges of the flatware, evidence of a layered structure, or steps, was observed. This is consistent with a 3D printing process (Figure 4). Under very high magnification, separate grey and gold colored areas can be seen, suggesting two types of metal have been intermingled.

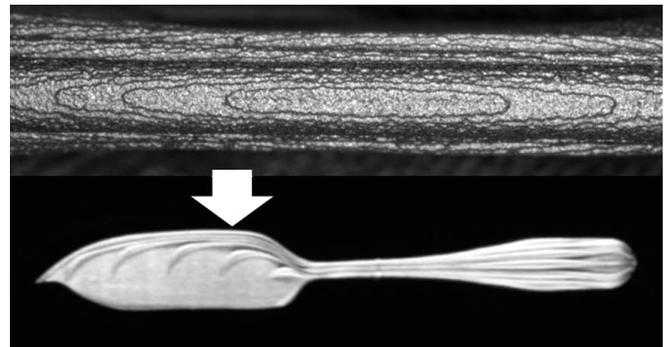


Figure 4: Steps seen on the edge of one of the pieces of flatware.

To identify the metals, we used a portable XRF spectrometer, which provides elemental information. The XRF analysis indicated that the objects were actually made of tool steel, an alloy that contains iron, tungsten, and bronze, which is a copper and tin alloy (not brass as described in the collection database).

Figure 3: Flatware Project for Alessi by Greg Lynn (M.2012.96.1-46) (Credit: Yosi Pozeilov).



Layer by Layer: 3D Printed Art Objects in LACMA's Collections, continued

In addition, the analyses of different pieces indicated that the ratio of the steel and bronze was highly variable (Figure 5). Some pieces had consistent amounts of steel and bronze throughout, while others contained more bronze at one end compared to the other. Still others had very small amounts of bronze.

This variability in the amounts of steel and bronze can be explained by the printing technique that was used to print these objects.

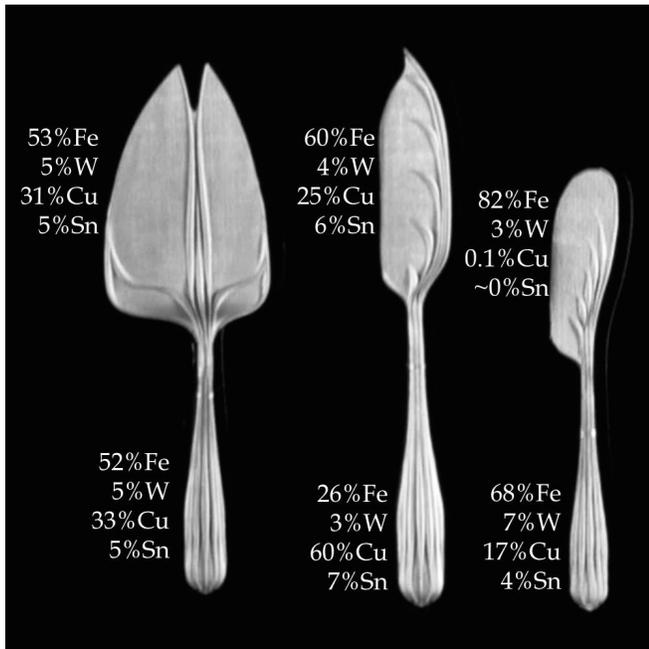


Figure 5: XRF Analysis of selected flatware pieces.

It is likely that indirect selective laser sintering⁵ was used to make the flatware. Tool steel powder coated with a polymer binder is used for the powder bed. As the laser rasters across the powder surface, it melts the polymer binder, fusing the coated metal powder particles together.

At this “green” stage of manufacture, the flatware pieces are very fragile because they are held together only by bits of the binder and contain countless voids. To strengthen the flatware objects, these voids are filled with bronze.

This is achieved by gently placing these porous steel objects in an oven. At high temperature (in excess of 900 °C), the binder coating is burned off and liquid bronze is wicked through the porous steel structure via capillary action.

If the conditions are not optimal during this stage, the bronze infiltration is not complete. This could account for the variability in color and elemental composition of the individual flatware pieces.

Case Study 2: *Fashionista Golden Girl* by Ted Noten

LACMA also has a Ted Noten necklace made of plastic (Figure 6) in the Decorative Arts and Design Collection.

Ted Noten is a Dutch jewelry designer and artist. As part of his “Haunted by 36 Women” project, he created a number of *Fashionista* necklaces.⁶ LACMA acquired the purple *Fashionista Golden Girl* necklace in 2013.



Figure 6: *Fashionista Golden Girl* by Ted Noten (M.2013.221.24) (Credit: Los Angeles County Museum of Art).

To verify the description in the museum database (i.e. glass-filled nylon, gold), it was submitted for technical examination.

At first glance, it did not appear that the object was 3D printed, but upon closer observation of the areas of high curvature, we were able to find concentric ellipses, again indicating the object was made layer by layer using a 3D printing process (Figure 7). These circles are the remains of the steps that were polished down during the post processing stage.

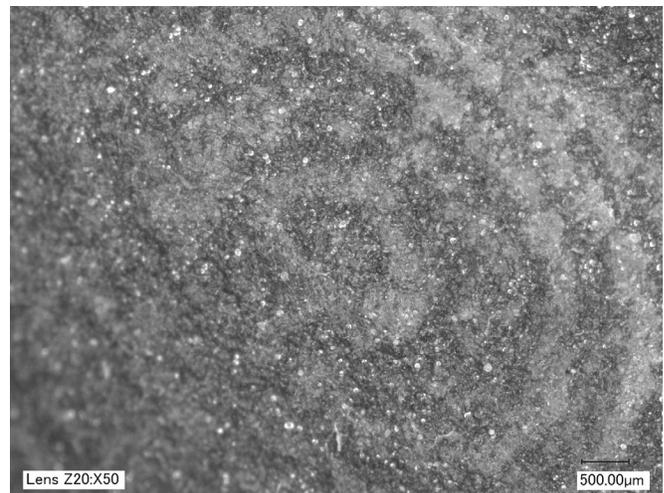


Figure 7: Detail of one of the shoes in *Fashionista Golden Girl*.

Layer by Layer: 3D Printed Art Objects in LACMA's Collections, continued

At really high magnification, we were even able to see plastic grains as well as shiny clear beads agglomerated together (Figure 8).

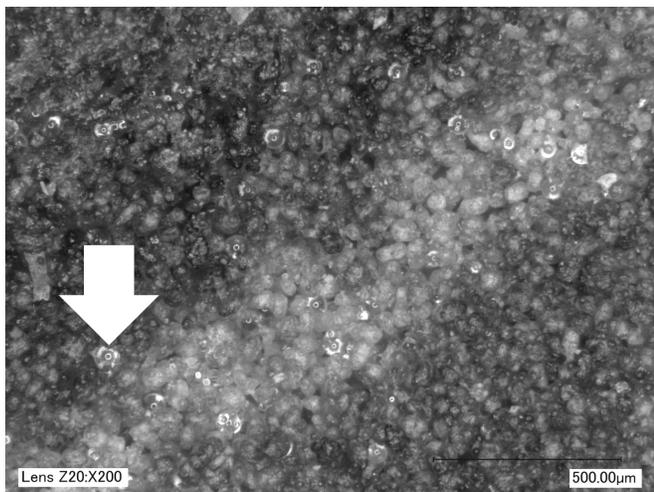


Figure 8: Micrograph showing glass beads (arrow) and granulated nylon.

Fourier Transform Infrared (FTIR)⁷ and XRF analysis indicate that the plastic is nylon while the shiny beads were made of glass. The grainy surface indicates that the necklace was made using selective laser sintering, which was confirmed by the artist.⁸

Storage and Display Recommendations

Bronze infiltrated steel objects printed using the SLS method pose a long term stability problem if they are stored improperly. The facts that the steel and bronze are so intimately associated and especially that voids are present, make these objects susceptible to galvanic corrosion, a process in which one metal is protected preferentially at the expense of the other, which corrodes away.

In the case of steel and bronze, the steel will be the alloy that corrodes. Therefore, we recommended that for storage and display, these pieces should be kept in a low humidity environment, preferably below 35%RH. And as an extra precaution, scavengers that remove acids and other air pollutants should also be present.

Over time, 3D printed plastics like all plastics, will develop deterioration problems such as yellowing, crazing, embrittlement, delamination, and distortion. In addition, it should be noted that if the plastic is colored – as in the Ted Noten necklace – the colorants used may also fade or shift in hue over time. To slow down the inevitable deterioration, these objects must be appropriately stored and displayed.

For storage, lowering the temperature would decrease the rate of the chemical reactions leading to deterioration. Some of the chemical processes require oxygen and or water,

so containers could be made with impermeable materials and contain oxygen scavengers and water absorbers. Light induced damage, particularly for objects made of the photopolymer resins used in stereolithography, could be mitigated by storage in the dark and display at low light levels with UV-blocking filters.

Conclusions

To determine whether an object was made by 3D printing, its surface should be examined for steps indicative of the process. However after objects are printed, they could be polished to create a final surface without noticeable steps. Therefore, communication with the artist is important, particularly if the object had been post- processed such that identifying attributes are not so clear.

Because 3D printed objects are made using techniques that grew out of the prototyping field, longevity was never a concern. Thus, for long term preservation, environmental conditions should be carefully controlled to slow down deterioration of these objects. As the 3D printing industry matures, it is hoped that there will be a stronger emphasis on use of more stable materials and combinations.

Acknowledgements

Sincere thanks to Lily Doan, objects conservator and Bobbye Tigerman, associate curator of LACMA's Decorative Arts and Design for their contributions to the investigations of these objects. I would also like to acknowledge Frank D. Preusser, LACMA's senior research scientist for his suggestions and support. Helpful comments and corrections of this article were provided by Terry Schaeffer, LACMA's scientist emeritus.

- 1 There are over 6000 hits in Google News if “3D printing art” is searched [https://www.google.com/?gws_rd=ssl#q=3D+printing+art&tbm=nws last accessed August 29, 2014]
- 2 Rapid Prototyping / History / Prototyping Technologies [<http://www.mechanicalengineeringblog.com/tag/history-of-rapid-prototyping/> last accessed August 28, 2014]
- 3 Micrographs were captured using a VHX-2000 microscope with a 20-200x lens [Keyence Corporation of America, Itasca, IL]
- 4 XRF analysis was performed using a handheld Delta XRF Analyzer [Olympus NDT, Waltham MA]
- 5 <http://repositories.lib.utexas.edu/bitstream/handle/2152/ETD-UT-2011-05-3301/VALLABHAJOSYULA-DISSERTATION.pdf>
- 6 http://en.wikipedia.org/wiki/Ted_Noten
- 7 FTIR analysis was performed using an IlluminatIR FTIR microscope [now Smiths Detection, Inc, Edgewood MD]
- 8 www.tednoten.com/work/portfolio/haunted-by-36-women