OpenSLS: an Open Source Laser-Sintering Research Platform

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Mentors and Sponsors: Jordan Miller, Ultimachine, SeeMeCNC, Coherent

Introduction

Tools and their application to pressing, human-scale problems form the technological foundations for society. Beginning with the simple problem of self-sustenance, humans developed basic tools to secure game, carry foraged food, and eventually carry out small-scale agriculture. As civilizations industrialized, tools became more and more powerful and capable of manipulating the traditionally immutable materials of stone and steel. Society learned to harness steam and electricity to build more and more specialized manufacturing tools. In the modern era, a new type of tool has been undergoing rapid development: the 3D printer.

The fundamental idea at the core of 3D printing is simple: the printer places material only where it is needed. A designer creates a model and the machine creates the object. What is unique about this process is that the complexity of the object is decoupled from the difficulty of its manufacture: a 3D printer can just as easily fabricate a baseball as a scale model of an entire city.

As our capabilities to create tools have refined and advanced, so has our ability to perceive and accept the challenge of a new scale of difficult problems. Today, researchers in bioengineering are studying the formidable challenge of organ synthesis with the goal of replacing those that are damaged by disease. Over the past several years, a series of research projects occurring both inside and outside of academic labs, have yielded a framework and set of tools that show tremendous promise for developing a solution to this pressing problem.

RepRap Community Research

Laser sintering 3D printers provide some of the best examples of the design freedom afforded by 3D printing by avoiding the complications of support material found in many other technologies. In the most widespread form of 3D printing, molten plastic is extruded from a nozzle and woven layer by layer into objects. This process works well provided there is something on which to extrude: either the previous layer or a temporary support structure that is printed with the object. Laser sintering machines differ from extrusion-based printers in that they use a laser to melt sections of the printed object in a layered powder bed. After each melting sequence, a new layer of powder is distributed over the previous and the laser melts the next cross-section of the printed object into the powder. Each section of the object is supported by the layers of powder below it, allowing for unparalleled intricacy.

Laser sintering has traditionally only been applied in industrial-scale systems for rapid prototyping and niche manufacturing tasks. However, several attempts have been made in the RepRap community to implement the technology, each with varying degrees of success.

1. Peter Jansen's SLS Experiments

In 2010, Peter Jansen built a simple SLS testing platform from salvaged DVD players and a small laser module. He translated the laser spot via a stepper-motor-coupled mirrors. Little documentation of either successes or failures exists, though he completed several design iterations.

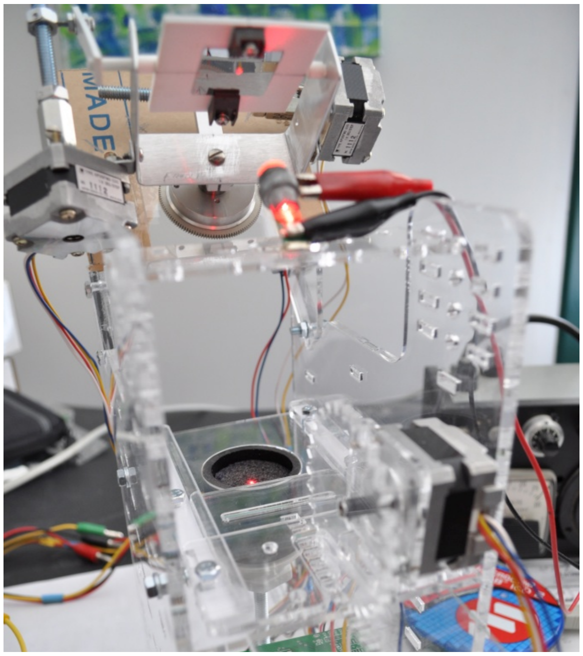

Figure 1. Peter Jansen's later, laser-cut prototype laser sintering system with single, cylindrical piston [1].

2. SLS Wax Printer

In 2011, Andreas Bastian built a prototype laser sintering machine and developed a wax-based powder that sintered with moderate quality.

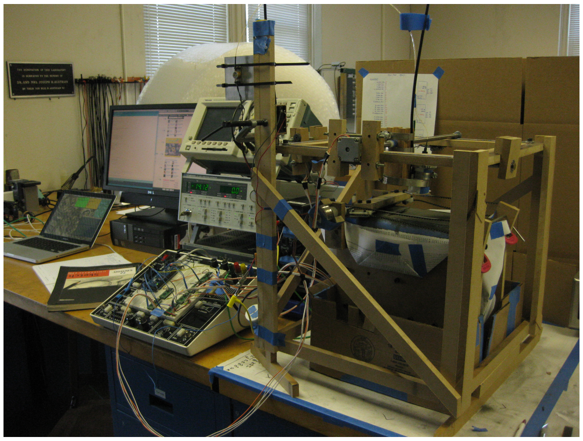

Figure 2. Andreas Bastian's wax-sintering prototype was functional, but not reliable.

3. PWDR

PWDR is a laser-cut acrylic powder printing system that has been demonstrated with inkjet printing and has speculative applications in SLS, but it has not yet been documented as an SLS platform.

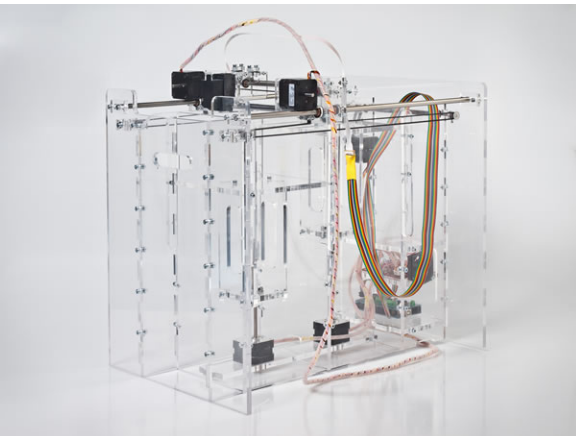

Figure 3. The PWDR printer, developed at the University of Twente, has been used for experimentation with inkjet-binding printing processes, and has the potential for research in SLS technologies [2].

4. Focus SLS

In 2013, Thingiverse citizen Dragonator developed an MDF and printed PLA powder SLS prototype on which he has sintered a wax-based material similar to that developed by Bastian and a Nylon and carbon mixture.

Figure 4. The Focus SLS prototype etching an image into E-PVC powder [3].

Jordan Miller's Research

While much of the exploration of the laser-sintering process was underway in the Maker community, Jordan Miller was developing a powerful new tool for tissue engineering as part of his post-doctoral research at the University of Pennsylvania. Inspired by a plastic cast of a vascular system seen at a museum and by a dessert featuring sculpted sugar, Miller began exploring methods of printing sugars as a way to capture the intricate structure of blood vessels. Frustrated by a lack of openness or cooperation with commercial 3D printer companies, he turned to the Maker community and the open source RepRap 3D printer to find a platform for his research. Several years of collaboration yielded a breakthrough process for fabricating pieces of synthetic tissue interlaced with networks of fine blood vessels. In the process that Miller developed, a 3D printer melted and extruded thin filaments of sugar to assemble simple networks of blood vessels. Once finished, the sugar network was encased in gel containing cells and the sugar was then dissolved out. The resulting channels could then be filled with pumping blood to provide nutrients to the cells in the gel.

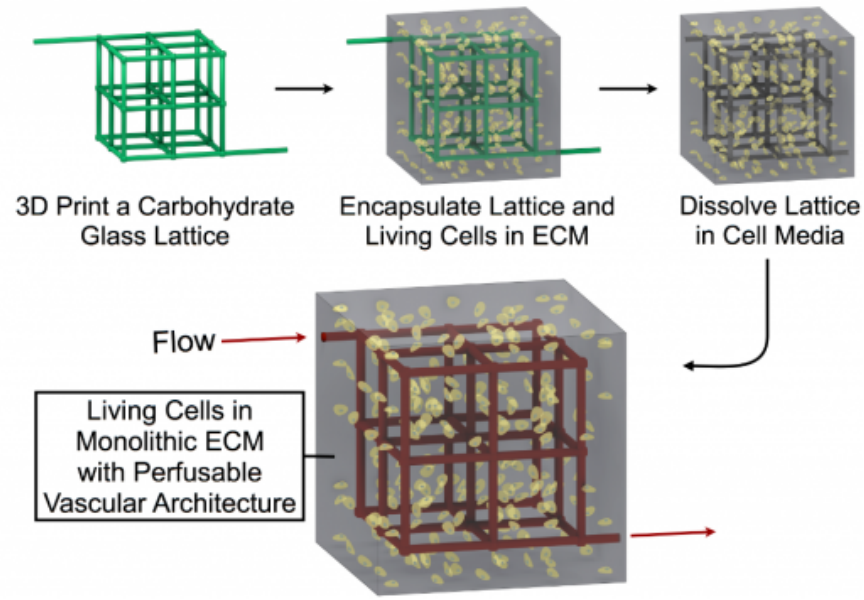

Figure 5. The steps of Miller's tissue casting process.

Miller's process was a powerful new tool in tissue engineering, but the process was limited by the capabilities of melt-extrusion printing. As can be seen in figure XX, the networks of printed sugar, while similar in scale to some blood vessels, were not similar in structure to *in vivo* vasculature.

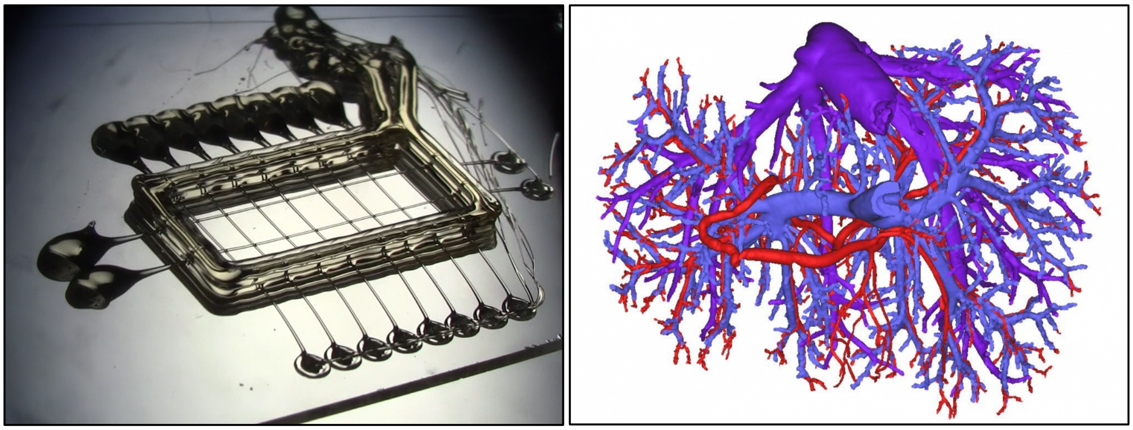

Figure 6. Native vasculature [4] has a structure that is far more complex and intricate than vascular forms that have been attempted via melt-extrusion processes [5].

The Project

This project aims to apply the powerful laser sintering process to the Miller's inspiring and proven work. The laser sintering process is regularly applied in art and design to make objects of similar scale and complexity as vasculature, so it is logical to attempt to apply it to the sugar printing process in order to achieve the complex structure of *in vivo* vasculature.

By combining research from both the Reprap project and Miller's work in an academic research lab, this project seeks to create a new process for fabricating vascularized tissue. The project's goals are the following:

- To develop a robust, low-cost, and open platform for laser sintering research.
- To develop a water-soluble print material compatible with Miller's hydrogel casting process.
- To explore and document the fundamental principles that govern the laser sintering process.

By leveraging the powerful hardware and software development infrastructure of the open source 3D printing community and applying the rigor and precision of academic-level scientific research, this project will develop powerful new tools for tissue engineering research.

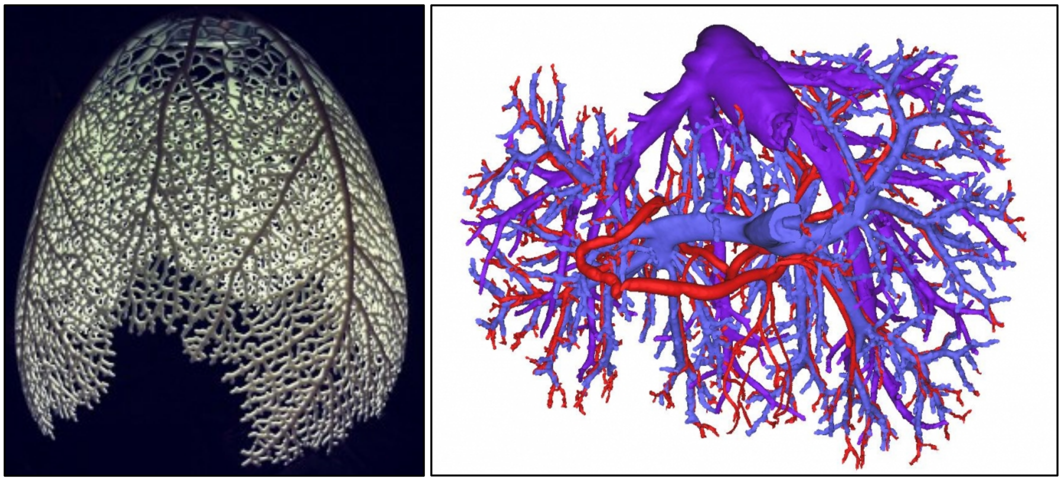

Figure 7. A laser-sintered nylon light fixture [6], left, and the organic structure of liver vasculature [5], right.

Results and Discussion

Preliminary results demonstrate linear, one-dimensional sintering of crystalline isomalt and nylon-12 (PA 650), as well as basic, two- and three-dimensional sintering of iron powder. Glassy, amorphous isomalt and isomalt-dextran blends were also fabricated, powdered, and sintered, though the hygroscopic nature of the glass-phase material made the material un-useable after several minutes of exposure to ambient conditions.

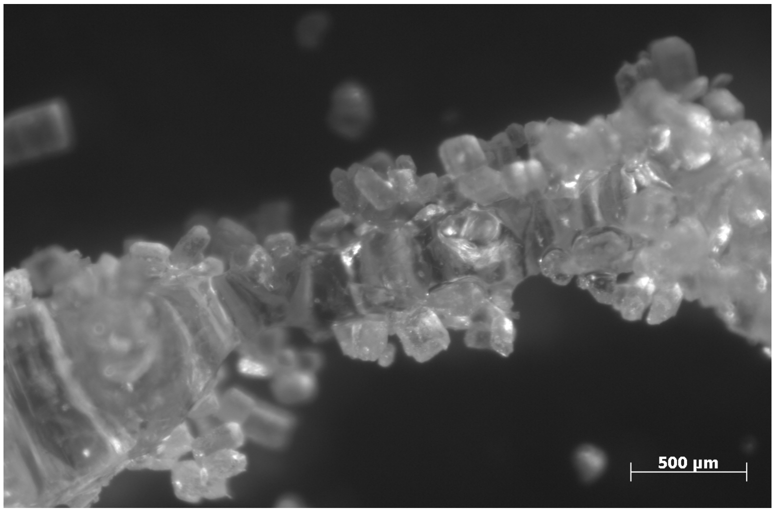

Figure 8. Laser sintered sucrose demonstrating the melting and forming of particles into continuous structure.

Integration and control of the laser cutter was achieved with a RAMBo 3D printer control board and Arduino Uno. Combined with common RepRap host software and slicing engines, this provides a robust platform for exploring sintering parameters.

Figure 9. The prototype hardware during assembly.

Powder production methods were also explored and relevant parameters and trends have been identified. Increased grinding media size results in finer substrate particles, as does an increase in the ratio of grinding media to substrate.

Implications and Future Directions

This prototype system builds on work conducted both inside and outside of traditional academic research labs and aims to contribute to both the academic and RepRap communities. The hardware development and electronics control and integration work may prove useful to members of the RepRap community and this new method of fabrication of vascular structures could enable new types of research in tissue engineering.

Much remains to be done to develop and optimize appropriate materials and to refine the process itself. Once printing vascular structures While these first steps are basic, when strategically applied, this technology has the potential for widespread impact across a variety of fields. Beyond organ printing, this technology could be used to create tissue samples for drug screening and toxicity trials, for cancer research, and allow researchers to create identical pieces of tissue in labs across the planet. It has the potential make huge changes in basic research in tissue engineering.

References:

[1] Peter Jensen, 2010, "Selective laser sintering printer: part 4 (putting it all together)," http://builders.reprap.org/2010/03/

[2] Univversity of Twente, 2012, "Pwdr- Open source powder-based rapid prototyping machine," http://pwdr.github.io/

[3] Dragonator, 2013, "Focus' Progress," Blog, http://focussls.blogspot.nl/

[4] Segers, Verdonck, Verhegghe, 2013, "Modeling the blood flow through the human liver and kidney to optimize machine perfusion of donor organs," Webpage, http://www.biommeda.ugent.be/img/upload/show/Charlotte3.JPG

[5] Jordan Miller, 2012, "How to: Innovate in Science with Open Source Technology," Blog, http://www.hive76.org/wp-content/uploads/2012/07/MillerJS_3DPrintedSugar.png

[6] Lightopia, 2012, "Awaken Your Nervous System with the Hyphae Collection," Blog, http://www.lightpublic.com/lighting-products/awaken-your-nervous-system-with-the-hyphae-collection/