Explorations in 3D Printing: Copying a Serpent

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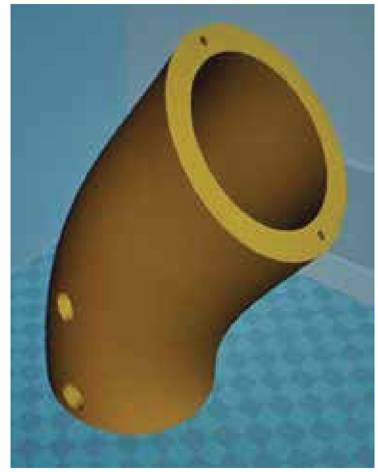
The Bate Collection at the Faculty of Music, University of Oxford, is a leading centre of research into the history and design of musical instruments. A main part of our activities is hosting visits from researchers and scholars. Typically we receive over 50 such research visits during a normal academic year. One returning researcher has been Dr. Mark Witkowski, a scientist at Imperial College, London. Mark's current interest is in 3D printing and looking into the possibilities of developing designs of musical instruments.

Following a number of preliminary experiments with less interesting instruments, Mark finally set his sights on something more ambitious. Following some discussions it was decided to set about making a copy of a serpent from the Collection. The Bate is home to 13 serpents and further assorted bass horns, ophicleides, etc., so the challenge was selecting an instrument of sufficient interest but compatible with the production technology.



Clockwise from top left:
a sliced serpent;
Imperial Advanced Hackspace;
a 3D CAD file of a serpent segment.

The Process of Additive Manufacturing

The process of 3D printing, also known as "Additive Manufacturing" (AM), has been in development since the 1980s when Hideo Kodama of Nagoya Municipal Industrial Research Institute invented two AM fabricating methods of a three-dimensional plastic model with photo-hardening polymer. The process is also known as "stereolithography" in which layers of material are laid down according to the development design of the object desired.

The critical path for the production of an object using 3D printing has now been made sufficiently accessible so as to enable a non-specialist to create objects without background knowledge of the digital and other processes involved. Additionally, the cost of 3D printers has now come down to the level whereby they are sufficiently affordable for people of modest means. The technology used by most hobbyist and consumer-oriented models is known as "fused deposition modeling" (FDM) which is a special application of plastic extrusion. This was the technology used to produce the finished serpent.

Printing a Serpent

The instrument selected as the basic design was an anonymous, French church serpent (Bate Collection 504) most likely constructed in the late 18th century. The original instrument was not in particularly good condition but as a preliminary design it was a useful choice. This gave Mark the opportunity of working with an instrument whereby the materials, method of construction and cardinal dimensions were clearly evident—what we in the museum business describe as an "informative wreck."

The initial process consisted of a complete examination of the dimensions of the instrument. This was the basis of producing a data set, which could then be used to produce the Computer Aided Design file. This is the first step in producing the necessary digital files for ultimate use in the 3D printer.

On January 22, 2016 I visited Imperial College, London to inspect and report on the work Dr. Witkowski has been doing in this area. It should be mentioned that he does not have a background as an instrument maker, having worked in experimental electronics and robotics. However, he has been working at Imperial College Advanced Hackspace with a number of other people who have developed an interest in this area.[1] There is a whole room in Imperial Hackspace devoted to 3D printing. When I visited, a number of projects were in progress, including a chocolate mold, a set of cam ratchets and a miniature representation of Doggerland, the details of which had been derived from a nautical mapping exercise.

Dr. Witkowski explained the process to me: a basic data set can come from a number of sources, including internet downloads, CT scanning of original objects, or the creation of the item from another solid object. This data is then used to create a Computer Aided Design (CAD) file. Mark showed me a file he had created using information from measuring the serpent in the Bate Collection. Nowadays, it is possible to create a CAD file using 3D computer graphics. This avoids the necessity of producing a whole lot of data-input and

1. Hackspaces are settings where individuals can meet, learn, socialize, and collaborate together in order to create and/or assist projects. It should be noted that they tend to focus on digital and computer technology and they are physical spaces rather than internet chatrooms. The more developed ones give themselves exciting but obscure names, such as "Techwizz," HackBurn" and, my local branch, "OxHack."

From top: The completed sections of the printed serpent prior to assembly; the section instrument during assembly; mouthpieces and molds.

number-crunching. Using the dimensions of the Bate instrument, he had created a series of CAD files of various components of the instrument, much as a historical English serpent might be assembled. There were a couple of reasons for this, the most compelling being that the affordable 3D printers have a maximum size of up to 300x175x175 millimeters, which limits the size of the unit to be produced. Larger printers do exist which could produce the instrument in two halves but these are in a much higher price bracket. One of the other advantages to producing a large instrument in discrete parts is that any problems with one component would not impact on any of the others. Mark explained that a number of the components came out of the process in a weirdly-distorted shape and were unusable. It is evident that many things can go wrong in the process, so a conservative approach is advisable.

Once a successful CAD file, or series of files, is produced, it is then converted (using commonly available software) into a STereoLithography (STL) file format. This is the preparation for conversion to the software provided with the printer, also known as the "slicer." This converts the model into a series of thin layers and produces a code file containing instructions for converting to the printer-specific software. All of the preparation can be done on a PC or Mac and the finished files transferred to the printer on an SD memory card of the type used for digital cameras, recorders, etc.

The next part of the process is setting up the printer. As previously mentioned, there are numerous options. The one shown to me at Imperial College consisted of threading a roll of coiled plastic into a feed tube on top of the printer and then heating up the nozzle to 200 degrees. This produces a steady stream of molten plastic that can be used to build up the thickness and density of the object as it rapidly cools. There are now a number of possibilities for setting up the print. One aspect would be the thickness of the layers. The very finest layering could be at 0.1mm. However, a print of this quality and resolution would take considerably longer than a print at 0.2mm (more than twice the time). Dr. Witkowski told me that the average time for printing off a serpent component using 0.2mm resolution was in excess of 10 hours. Some components required a print run of over 20 hours. So, it is clear that there are a number of compromises that need to be considered.

The final process for completion of the serpent was to assemble the sections and seal the surface. Features such as tone holes were integrated into the print design. The real areas requiring finesse included the junction of the joint between the body of the instrument and the mouthpipe. This was resolved by lapping the joint with plumbers tape. The other crucial area was the mouthpiece design. After examining a number of historical serpent mouthpieces and obtaining molds, Mark finally found a successful mouthpiece exterior and interior shape. Having tried the finished product, I can assure ITEA Journal readers that this is a very successful technology for musical instrument making. In fact, Dr. Witkowski has made a variety of other musical instruments using this technology, including crumhorns, cornetti, transverse flutes, and recorders. Since he has completed the serpent, Mark has used it on a number of occasions. I am pleased to report that it has shown evidence of patterns of damage entirely consistent with the original instrument in what could be viewed as a confirmation of authenticity. However, equally pleasingly, repairs have been effected using modeling glue.


When 3D printing goes wrong.

There have been a number of claims in recent years regarding the manufacture of top-end instruments (violins, flutes, etc.) using this kind of production technique. I have to say that I don't think the technology currently has the ability to produce world class instruments; however, one of the outcomes of producing a copy of a historical instrument is that we now have a chance to hear what the original might have sounded like. Did we indeed select an outstanding-playing instrument from the Bate Collection, or does Serpent #504 prove to be merely an adequate instrument that was easy to copy? As methods improve and the cost of the equipment drops, it cannot be long before the production of more complex instruments is attempted—even tubas and euphoniums! 4x24 ■