3-D Printers

Abstract

Chapter 5 of Library Technology Reports *(vol. 50, no. 5) "3-D Printers for Libraries" provides detailed descriptions of the most popular printers for libraries. Author Jason Griffey offers general buying advice by comparing features to anticipated library uses.*

In this chapter I'm going to list and discuss the 3-D printers that are available and meet a few criteria. I'm not going to try to be a completist in my listing, because even at this point it would be nearly impossible to find all of the different 3-D printers on the market. By the time this Report actually gets to print, it will be further out of date. So I'm going to talk about the most popular printers in detail, while mentioning and differentiating between a number of others. I will try to give buying advice for libraries, taking into account the possible differences in use case that they may have. I'll also be talking about support, something that could be make-or-break for implementation, especially in small libraries.

In the places I talk about build plate area, all of the numbers will be listed as length (the X axis, or side-to-side in the printer) by width (the Y axis, or back-to-front in the printer) by height (the Z axis, or print height).

MakerBot

As mentioned previously, the 800-pound gorilla in the consumer 3-D printer market is MakerBot Industries. MakerBot was founded in 2009 and began its life as a member of the RepRap community, a 3-D printer community that started in 2005 in an attempt to make a 3-D printer that could replicate itself. MakerBot Industries has had two very different periods in the philosophy and design of its 3-D printers: the open-source period (Cupcake through Replicator) and the closed-source period (Replicator 2 through current models).

The first printer made and sold by MakerBot was the Cupcake CNC, so named because that was roughly the size of the objects it would output. MakerBot quickly iterated on the Cupcake, improving it and releasing the Thing-O-Matic in 2010, which brought with it a better extruder design, heated bed, and larger build volume. Both of these printers were sold as kits, with the expectation that users would put significant time into building the printer themselves. The last of the printers MakerBot made and sold in its open-source period was the Replicator, a radical new design that added significantly to the build volume available as well as being available as a prebuilt unit. As one of the first out-of-the-box 3-D printers, the Replicator was a huge success.

The Cupcake, Thing-O-Matic, and Replicator were all designed around printing with ABS filament, although all were capable of printing with PLA as well. They all use 1.75 mm filament. The Replicator also was one of the first consumer devices to provide dual-extrusion capabilities.

With the release of the Replicator 2 in 2012, MakerBot turned the corner away from open-source designs and started to produce printers with closed aspects. The Replicator 2 schematics and circuit board diagrams were not available, and it was at this point that MakerBot switched from the open standard for G-code to its own proprietary standard of x3g files. The Replicator 2 was designed specifically for printing in PLA, with no heated build platform. For those

Figure 5.1
The MakerBot Replicator (5th Generation), Replicator Mini, and Replicator Z18

Figure 5.2
The Replicator Z18

interested in printing in ABS, MakerBot released a version of the Replicator 2 that it simply called the Replicator 2X. It had a heated print bed and dual extruders that allowed for printing of two different types of filament simultaneously. Both of these were very successful for MakerBot, and while I don't have hard numbers, I would bet that the majority of 3-D printers currently installed in libraries are models of the MakerBot Replicator 2.

In 2014, MakerBot released a brand-new version of its Replicator line, called simply the Replicator (5th Generation), as well as two other completely new printers, the Replicator Mini and the Replicator Z18 (see figure 5.1). There is a great deal of similarity under the hoods of these systems, with the primary difference being the size of the print area. The Replicator Mini has a total print area of 10 cm by 10 cm by 12.5 cm, or roughly 3.9 inches by 3.9 inches by 4.9 inches, almost identical to the print volume of the original Cupcake CNC printer. The Replicator (5th Generation) has a print area of 25.2 cm by 19.9 cm by 15 cm, more than six times the volume of the Mini. But the true behemoth in the MakerBot lineup is the Z18 (see figure 5.2), with a massive build area of 30.5 cm by 30.5 cm by 45.7 cm, or 12 inches by 12 inches by 18 inches. That final height measurement is where the Z18 gets its name, for the maximum print height on the Z axis.

Other than those print volume differences, the specifications for the swath of 5th Generation printers from MakerBot are surprisingly similar. They share the same newly-redesigned extruder, they are all designed for PLA filament, they all have a camera, and each uses the MakerBot Desktop software to print.

The choice between the three printers really depends on the question "How large a part do you want to print?" (or possibly how many smaller objects you want to print simultaneously). Either way, it's about the size of the build plate, and each step up the levels of printer with MakerBot carries a fairly substantial price increase. The Mini retails for $1,375, the Replicator (5th Generation) for $2,899, and the Z18 for an unbelievable $6,499. Those prices don't include MakerBot's enhanced support service or warranty that they call MakerCare, which brings the prices up by $150, $350, and $750, respectively.

For the time being, MakerBot is still selling the Replicator 2 and the Replicator 2X, for $2,199 and $2,799 respectively. It is unclear how long these older models will remain for sale, but both are still very capable printers. The technology differences between these and the 5th Generation models have less to do with the quality of the prints possible and more to do with the management possibilities and the future of the 5th Generation platform.

For the majority of libraries looking at which 3-D printer to buy, MakerBot is the right answer. MakerBot's printers have the largest install base, they provide an option for enhanced support (which libraries without someone fairly technical on staff will need), and the printers themselves are solid and reliable. They are not, however, open and interchangeable with other types of 3-D printers. If you are dedicated to using open-source software or prefer interchangeability in your hardware, MakerBot printers may be less of a good thing.

MakerBot
http://makerbot.com

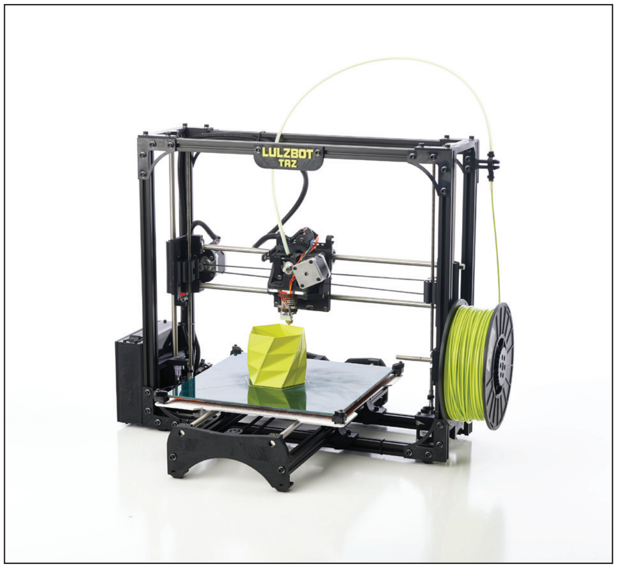

Figure 5.3
The LulzBot TAZ

Pretty much every other printer on this list uses open-source software as its print engine, and the majority of them are open hardware as well. Sticking with open source for your 3-D printer ensures that you will be able to update your printer later without huge changes to your workflow and that if you need replacement parts you can often purchase them from a variety of sources. While MakerBot is probably the right answer for the majority of libraries right now, that will not be the case for every library, and it will not be the case forever.

LulzBot

LulzBot is a 3-D printer company based in Loveland, Colorado, that is dedicated to producing printers that are completely open. Its flagship printer, the TAZ 3 (see figure 5.3), is an open-hardware and open-software printer, with everything from the firmware to the corner brackets open and shareable. This is, obviously, very different in business model from the MakerBot family of printers.

The TAZ 3 has the best price-to-print build plate area of any printer anywhere. The TAZ has a build plate area of 298 mm by 275 mm by 250 mm, or 11.7 inches by 10.8 inches by 9.8 inches, slightly smaller than the MakerBot Z18, but the TAZ retails for $2,149, less than a third of the cost of the Z18. It will also print in a much wider variety of filaments, since it has a heated build plate. As a matter of fact, LulzBot specifically advertises the TAZ as capable of printing nearly any filament you throw at it. In the description for the TAZ, LulzBot specifically calls attention to the fact that it can print in PLA, ABS, PVA, polystyrene, nylon,

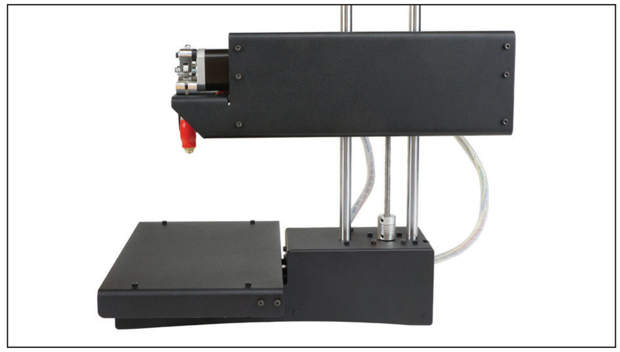

Figure 5.4
The Printrbot Simple

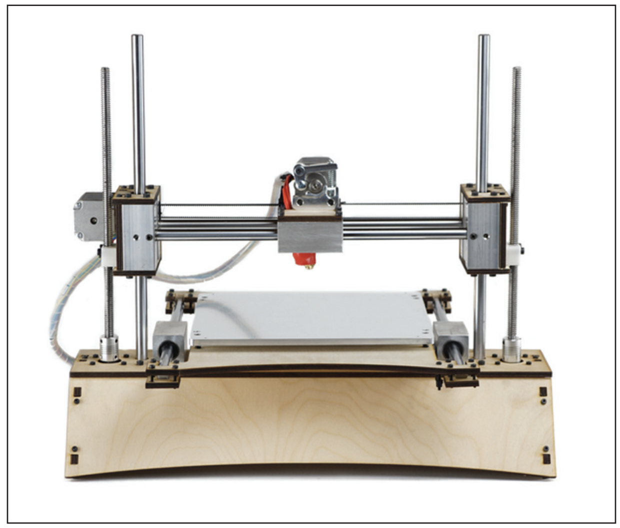

Figure 5.5
The Printrbot Plus

and more.

The downside of the design of the TAZ is that it's totally an exposed build-plate design, which makes temperature control very difficult in the area around the build plate. This isn't limited to the TAZ; most 3-D printers don't ship with an enclosed print area by default, but it is a downside that can affect the reliability of printing, especially with ABS or other temperature-sensitive plastics.

I would say that the LulzBot TAZ 3 would be a great 3-D printer for a library that has been working with an older Replicator or other printer and has the in-house knowledge to take advantage of the open nature of it. But if you don't think your staff will be doing significant upgrades or maintenance to the printer, it may not be the right printer for you.

LulzBot
www.lulzbot.com

Figure 5.6
Solidoodle's 4th Generation 3-D printer

Figure 5.7
SeeMeCNC's Rostock Max

Printrbot

Printrbot makes two different models of 3-D printers, the Printrbot Simple and the Printrbot Plus (see figures 5.4 and 5.5). The main difference in the two is, again, size of build plate. The Printrbot Simple is designed as an entry-level 3-D printer, with a print area of 150 mm by 150 mm by 150 mm, or 6 inches by 6 inches by 6 inches. The Simple prints only in PLA but is available, assembled and ready to print, for only $599. The Printrbot Plus is a larger printer, with a 10-inch-by-10-inch-by-10-inch print area, also only for PLA. The Printrbot Plus retails for $1,299, a fantastic deal for the print volume, although limited in print material options.

Printrbot
http://printrbot.com

Solidoodle

Solidoodle, which has been around for a few years now, was one of the first companies to build and ship a fully assembled, non-kit 3-D printer. Its current model, the Solidoodle 4th Generation (see figure 5.6), is a PLA- and ABS-capable printer, with an 8-inch-by-8-inch-by-8-inch build platform. It comes ready to print for $999, and Solidoodle's older model (the 3rd Generation), with the same build plate size but a slightly less aesthetically pleasing case design, sells for only $799.

Solidoodle
www.solidoodle.com

SeeMeCNC Rostock Max and Orion

The printers sold by SeeMeCNC are a very different breed of fused deposition printer. They are the only delta-style printers on the list, as opposed to the Cartesian style of the rest of the pack. The Rostock Max (see figure 5.7) has an 11-inch-diameter print bed (delta printer beds are measured in diameter, as they are circular rather than rectangular), with a vertical height of 14.5 inches, one of the largest overall volumes available on an FDM printer. But I wouldn't recommend the kit to anyone who didn't have some experience with complicated electronic builds. The positive thing about buying the kit is the price, which at $999, gives you a huge amount of value for the money, but you will have to put a few dozen hours into building it.

The Orion, however, is a fully assembled delta-style printer (see figure 5.8). Smaller than the Max, with only a 6-inch diameter and 9-inch height print area, it comes pre-assembled and ready to print. The

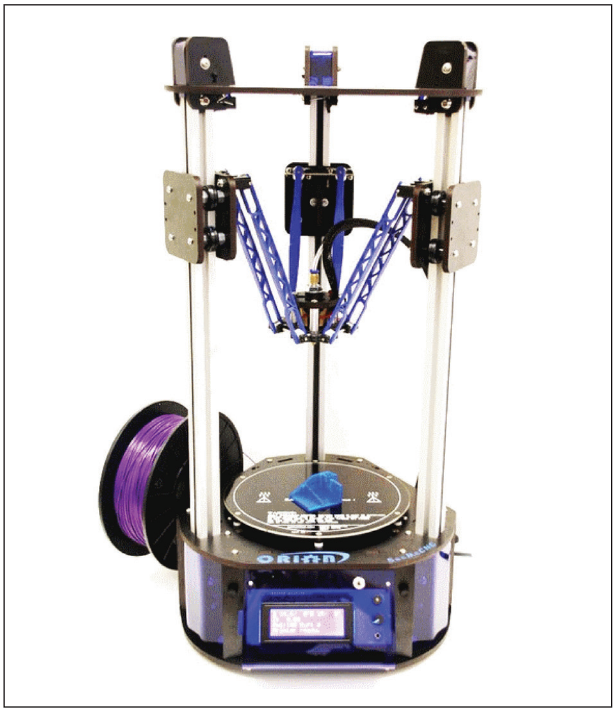

Figure 5.8
SeeMeCNC's Orion

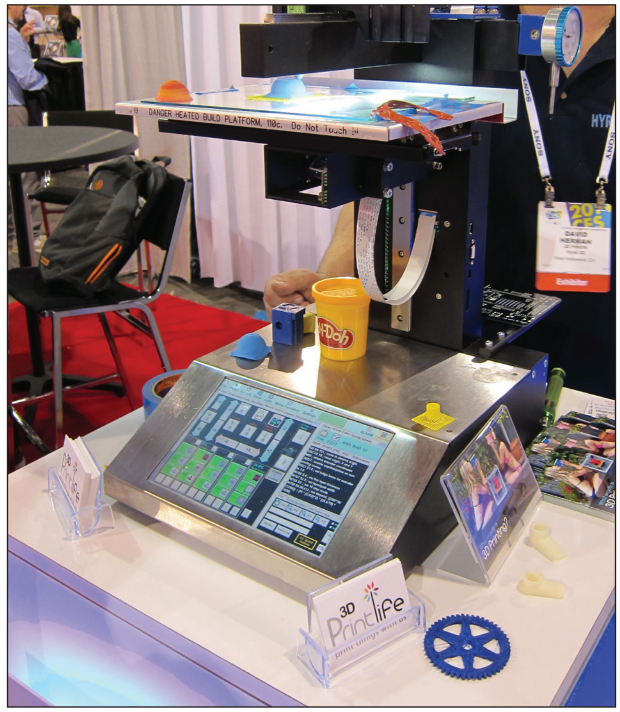

Figure 5.9
The Hyrel System 30 printing in Play-Doh

quality of a delta 3-D printer is nearly identical to that of a Cartesian style, but they are amazingly cool to watch. Check out the YouTube video of a Rostock Max printing if you want an idea of how they look in action.

Both of these are well-designed and solid choices for printing in a library, but the fact that delta printers are far more unusual and that one of them is kit-only means that I don't expect these to take the world by storm. They are extraordinarily cool, though.

SeeMeCNC
http://seemecnc.com

YouTube: Rostock Max printing
https://www.youtube.com/watch?v=k--r3C8Hu7A

Hyrel 3D

One of my favorite 3-D printers that I've had a chance to see over the last year is the Hyrel System 30. Hyrel 3D manufactures a variety of printers, but the System 30 is the one that really is worth exploring. At first glance, it appears to be just a high-end FDM printer, with the typical enhancements for a high-end FDM, such as an enclosed build area, a heated build plate, a 225-mm-by-200-mm-by-200-mm build area, and a printhead that is capable of printing PLA, ABS, nylon, and other plastics. In addition, the System 30 includes a full Linux computer embedded in the printer, complete with a touchscreen LCD. This means that you can not only control the printer, but the printer itself will do the slicing and plating, obviating the need for a secondary computer at all. You can load an STL file directly into the system, and it will take it from there.

But the real secret sauce for the System 30 is in the swappable printheads. The printer really is a printing system, as it supports up to four FDM printheads being mounted simultaneously. Yes, it can simultaneously print in four different filaments. The thing that really makes the System 30 stand out, though, is the EMO-25 optional extruder. The EMO-25 is a sort of industrial syringe that is computer-controlled and can be loaded with any putty-like material as a printing substrate. With the System 30 and the EMO-25, you can make 3-D prints literally in Silly Putty. Or in clay. Or, my personal favorite, in Sugru, an air-curable rubber. When I was able to play with a System 30 at CES 2014, they were making little 3-D printed houses out of Play-Doh (see figure 5.9). And that printing ability is just interchangeable with a traditional FDM printhead, so you don't lose capabilities.

All of this is available at a base price of $3,995, with additional FDM extruders costing $250 and the EMO-25 syringe-style printhead at $225 for a basic and $300 for a professional kit. The professional kit includes an extra barrel for the syringe cylinder so that you can reload the material for printing while a print is happening, then swap when it runs out, thus allowing for larger prints of unusual materials. So it is far more expensive than most of the rest of the printers I've highlighted, but it is also a more robust and flexible machine. I'd love to see what sorts of things a good children's librarian could do with the ability to arbitrarily create 3-D objects from Play-Doh.

Hyrel 3D
www.hyrel3d.com

Cubify

Cubify makes a series of printers, but it is best known for its attempt to simplify the process for home users. Its goal appears to be to create Apple-like products, heavy on the design aspects, to make the printer itself an attractive gadget for the home. It features an auto-leveling print bed, cartridge-style filament reloading (which also means it isn't capable of using arbitrary filament purchased elsewhere), and Wi-Fi connectivity for remote printing. The Cube (see figure 5.10) has a 140-mm-by-140-mm-by-140-mm print area and is capable of printing in both PLA and ABS.

The Cube retails for $1,299, and while it may be the most attractive of the 3-D printers that I've listed, it's also the least flexible. My main concern for libraries would be the cartridge-style filament loading, as it locks you into being able to purchase only directly from Cubify, so that you won't be able to take advantage of the variety of filaments available on the open market. And, of course, if Cubify goes out of business, it may leave you with the inability to purchase new filament altogether.

Cubify is trying to create an ecosystem for its printers, in the same sort of way that MakerBot has. It has a cloud service that stores STL files for printing, as well as a store from which you can purchase printable files for output to your Cube. Cubify clearly wants a closed ecosystem, again in the Apple vein, where it owns the entire stack of the ecosystem of 3-D printing. It hasn't been successful at that just yet, but its solution might be reasonable for some libraries.

Cubify
http://cubify.com

Formlabs

The Formlabs Form 1 (see figure 5.11) is the first consumer-level stereolithography printer. This makes it both amazing, because it can print at nearly ludicrous resolutions (see figure 5.12), and terrible, because the consumable resin is considerably more expensive than the plastic filament that FDM printers use. The build area is smaller than that of most FDM printers, at only 125 mm by 125 mm by 165 mm, but the minimum layer thickness is only 25 microns, a quarter the height of the best FDM printers.

Formlabs sells three colors of resin that work with the Form 1, clear, grey, and white. The resin sells for $149 per liter, which is roughly three times the cost for the same amount of PLA filament for an FDM printer. Because Formlabs is the first out of the starting gate with SLA printing for the consumer, other companies are beginning to sell resin that they list as "compatible with the Form 1." This resin is almost always much cheaper than that offered directly from Formlabs; a

Figure 5.10
The Cubify Cube

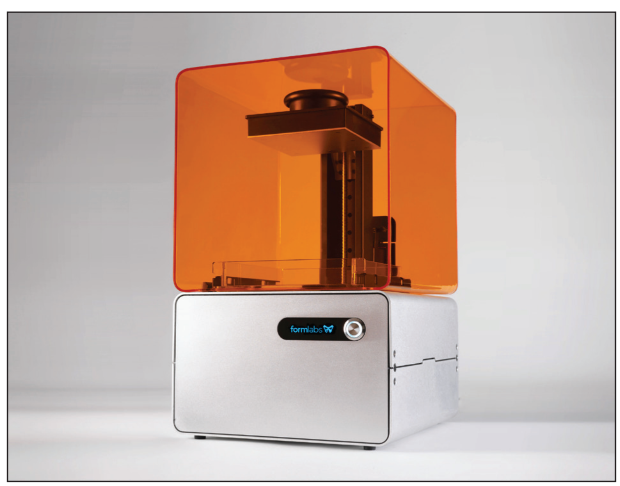

Figure 5.11
The Formlabs Form 1

Figure 5.12
A tiny, intricate figure printed with the Form 1

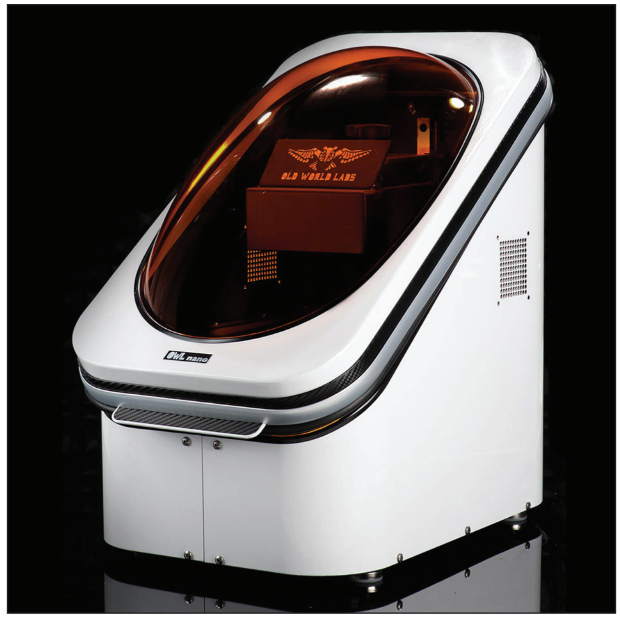

Figure 5.13
The OWL Nano

quick look around shows that said resin is about two-thirds the price of the Formlabs resin, and it's available in many more colors.

I think that SLA printers may become far more common in libraries over the next few years, especially as competition heats up and more companies begin selling their own versions of this technology. Because they can print geometries that are difficult for FDM printers, and the parts they produce are far more finished in look and feel (see figure 5.12), it's a natural progression. The Form 1 retails for $3,299, well within the budgets of many libraries that might want to play with the next generation of 3-D printers.

Formlabs
http://formlabs.com

Old World Laboratories

A very recent entry into the stereolithography game, Old World Laboratories, showed off its printer, the OWL Nano (see figure 5.13), at CES 2014. The OWL Nano has a slightly larger build area than the Form 1, at 150 mm by 150 mm by 200 mm, and it uses a slightly different technique for aiming the laser that gives it a claimed .1 micron layer detail height. The OWL Nano is more expensive than the Form 1, at $4,900, and I'm guessing that most of that is due to the scale of the company, given that many of the underlying systems are likely the same.

In addition to the incredible layer detail, the OWL Nano uses a generic photopolymer, which should mean that the consumables for printing are less expensive over time. Given a drop in price for the photopolymer, the printer itself actually has fewer moving parts than an FDM printer and might be a better long-term-use machine than something like the MakerBot models. It just isn't quite there in terms of price yet.

Old World Laboratories
http://oldworldlabs.com

Mcor

The last specific 3-D printer that I want to talk about is the Mcor Technologies IRIS, the only example of laminated object manufacturing that I've had a chance to examine. The IRIS is a LOM printer that uses plain copy paper as its printing substrate, with a full-color ink-jet printer as a part of the process that enables full color 3-D printing at very inexpensive costs per print. It produces prints that have a layer height the same as the thickness of a sheet of paper because the layers are literally sheets of paper.

The results of the printer are remarkably sturdy and solid. Unlike FDM-printed models, the objects that come off of the IRIS are solid and quite hefty. The glue used is just a basic wood glue, like the Elmer's Glue you remember from your childhood, except a little thinner. As a result, the layers are very solidly

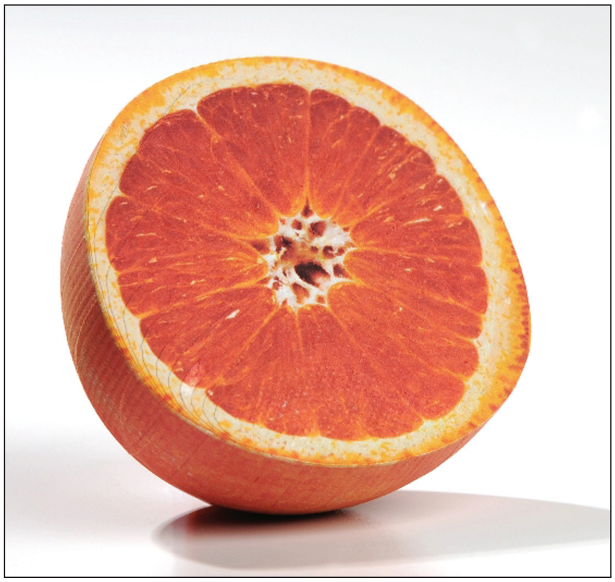

Figure 5.14
An object printed on the Mcor Technologies IRIS

put together, and the objects really do feel like a solid piece of wood (see figure 5.14).

If LOM prints are solid, high quality, and full color, then what's the downside? The downside is the fact that it's still a commercial and not consumer technology, which means that the price is still very high for the printer itself. Mcor Technologies doesn't list a price on the website (always a sign that it is more than you want to pay), but in discussion at CES 2014, I was told that its printers started around $35,000. Yes, you read that right. So it's clearly not something that every library could even think of affording, especially as an experiment. But again, as the price drops and the technology becomes more common, this might be an interesting type of printer to keep an eye on.

Mcor Technologies IRIS
www.mcortechnologies.com/3-D-printers/iris