3D Printing for Architects with MakerBot

Matthew B. Stokes

Chapter No. 1
"A Primer on 3D Printing"
In this package, you will find:

A Biography of the author of the book

A preview chapter from the book, Chapter NO.1 "A Primer on 3D Printing"

A synopsis of the book’s content

Information on where to buy this book

About the Author

Matthew B. Stokes graduated with a combined Mechanical Engineering and Computer Science Dual Degree and Technological Entrepreneurship Certificate from the University of Western Ontario. He is interested and has been actively involved in consumer 3D printing since 2009, and has completed an Engineering Co-op at KnowRoaming—a Canada-based technology company, where he worked to design and test 3D-printed cellphone cases for embedding hardware. He has owned and operated a MakerBot Replicator since spring 2012, and has competed in several 3D printing design contests.

Currently, Matthew is back at the University of Western Ontario completing a Master's degree in Biomedical Engineering in a collaboration model involving Muscular Skeletal Health Research (CMHR) and Computer Aided Medical Intervention (CAMI) under Dr. Louis Ferreira. His expected date of graduation is 2015.

Matthew has a wide range of interests outside 3D printing, including Raspberry Pi, Android applications, hackathons, Tough Mudder events, and design challenges.

I'd like to thank my parents for being so supportive, my good friend Sean Watson for continually fueling my interest in 3D printing, and my girlfriend Meghan Piccinin for helping push me to complete this book.

For More Information:

Welcome to 3D Printing for Architects with MakerBot! This book will take you through the process of building 3D prototypes for simple to cutting-edge architectural design projects using MakerBot Replicator (1, 2, or 2X) and other allied software packages.

What This Book Covers

Chapter 1, A Primer on 3D Printing, introduces you to different methodologies, technologies, materials, and history of 3D printing with a focus on the MakerBot Replicator 2X.

Chapter 2, 3D Modeling Software, introduces you to modeling practices useful in 3D printing with common free and paid 3D modeling software.

Chapter 3, 3D Printing Software, covers the topic of transforming a 3D model into a 3D print.

Chapter 4, Multicolor Design, explains the utilization of the multiple heads on the MakerBot Replicator 2 in the design process for a model composed of two distinctly different colors.

Chapter 5, Multipart Design, introduces you to creating more advanced assemblies. A special focus is on component tolerance.

Chapter 6, The Community – Thingiverse and GrabCAD, helps you in finding and modifying online CAD resources into an existing design. It also shows how valuable and powerful the community around MakerBot is.

Chapter 7, Iterative Design, explains a culminating example of several iterations of an apartment building’s floor plan.

For More Information:
A Primer on 3D Printing

With the growing demand and increasing applications of 3D printing, it is important that we take a look at the history and some basic concepts before jumping on to the actual working of MakerBots. We will begin by covering a brief history on 3D printing, including a description of some of the main methods and technologies currently in use. Next, we will familiarize ourselves with the MakerBot, covering a select few of its specifications and the impact these have on printed parts. Lastly, we will touch on printing limitations using the MakerBot and the different material options available for use.

A brief history of 3D printing

Over the last several years, we have seen a tremendous increase in media attention surrounding 3D printing, as new technical advancements have led the number of applications to grow exponentially and encompass a broad range of disciplines. Today, 3D printing is being used across a plethora of industries, in applications that are pushing the limits of modern technology and innovation. While the new printing technology is revolutionary, 3D printing itself has been around for almost 30 years, beginning in 1984 with Charles Hull, who later went on to co-found 3D Systems in 1986. By modifying technology used in traditional two-dimensional inkjet printers, Hull created the first 3D printer, patenting the method of stereolithography (SLA) and introduced the industry to additive manufacturing.

For More Information:  
Understanding stereolithography

In SLA printing, an ultraviolet laser traces the cross-section of a part onto the surface of a vat containing an ultraviolet curable photopolymer resin. The resin exposed to the light will cure and solidify, sticking to the layer below it before the platform descends by a set distance and more liquid resin is added to the vat. This process will repeat for each subsequent cross-sectional layer until the three-dimensional part has been created. The following image illustrates this process:

![SLA printing](http://en.wikipedia.org/wiki/File:Stereolithography_apparatus.jpg#filelinks)


**Downloading the example code**

You can download the example code files for all Packt books you have purchased from your account at [http://www.packtpub.com](http://www.packtpub.com). If you purchased this book elsewhere, you can visit [http://www.packtpub.com/support](http://www.packtpub.com/support) and register to have the files e-mailed directly to you.
SLA printing began the additive manufacturing revolution and remained the main 3D printing process until mid-1980 when Dr. Carl Deckand and Dr. Joseph Beaman, with sponsorship from DARPA, developed and patented Selective Laser Sintering (SLS).

Learning about Selective Laser Sintering

SLS fuses small particles of material (plastic, metal, ceramic, or glass) using a high-powered laser. The technique is similar to SLA printing in such a way that the laser traces the cross-sectional shape before a platform descends. Perhaps the biggest advantage of SLS printing is that the granular material supports the top layer of material, giving rise to part geometry not previously possible using SLA printing without some sort of supporting structure created underneath the model.

An example of this is illustrated in the following image in the printing of one side of an inverted two-dimensional triangle. If the internal angle of the pyramid is low, there is enough material in the bottom layer for the current layer to sit on top (B). However, by increasing the angle, we eventually reach a point where none of our current layer is sitting on top of the bottom layer, but rather is floating in space as seen in A in the following image:

In SLS printing, the top layer will sit on unsintered powder, whereas with SLA printing, the layer will fall to the platform, ruining the print.

It took a number of years before an SLS printer came to the market, in which time S. Scott Crump invented, patented, and brought to the market Fused Deposition Modeling (FDM) and later went on to co-found Stratasys.

For More Information:
Basics of Fused Deposition Modeling

In FDM, the material is fed from a spool through an extrusion nozzle where either the nozzle or the platform is moving, so as to again trace the cross-section of the desired part at the given layer onto the platform. The nozzle has control to turn the flow on/off and in general applications, the nozzle is heated to melt a thermoplastic material, which immediately hardens, solidifying to the layer below it. This process can be seen in the following image:

![FDM printing diagram](http://reprap.org/wiki/File:FFF.png)

The source of this image can be found at [http://reprap.org/wiki/File:FFF.png](http://reprap.org/wiki/File:FFF.png).

Similar to SLA printing, FDM requires a supporting structure to account for layers floating in space. FDM printing is the technique used by the vast majority of the open-source and consumer ($300-$5,000) 3D printers. The major advantage of this technique is the cost of material as FDM printing most commonly uses ABS thermoplastic, which costs fractions of pennies per gram. MakerBot is one such example of an FDM-based printer.

For More Information:

The origin of MakerBot

The RepRap project was founded in 2005 by Dr. Adrian Bowyer, who can be credited for being the first to target the hobbyist/DIY/early adopter community. The intended purpose of the RepRap project was to be an open source, affordable, self-replicating 3D printer (self-replicating meaning capable of producing all its own parts with the exception of electrical components). All of RepRap's printer specifications are released to the open source community who contribute to its evolution. MakerBot would later be birthed in 2009 from progress made by RepRap printers.

MakerBot's first printer was the CupCake CNC in early 2009, which was a repstrap (3D printer cobbled together from whatever parts you can find, which will eventually allow you to print the parts for a RepRap machine, or to simply use as a standalone machine). After the CupCake came the Thing-O-Matic in late 2010, followed by the Replicator in early 2012, and ending with the Replicator 2 and 2X (eXtreme), released late 2012. Between each release, monumental changes were made, as the technology was evolving in leaps and bounds. The CupCake and Thing-O-Matic printers were DIY kits by default, whereas the Replicators, by default, came preassembled. Probably, the biggest source of controversy in MakerBot's history was the announcement that the Replicator 2 would be a closed source project. While this shocked the loyal MakerBot community, MakerBot did not slow down and on June 19, 2013, they were acquired by Stratasys for $403 million USD.

FDM is a trademarked term by Stratasys. Members of the open source community coined an equivalent term Fused Filament Fabrication in order to use a term that is unconstrained.

Applications of 3D printing

From examination of SLA, SLS, and FDM, we can generalize the concept of 3D printing to be an additive manufacturing process that takes a digital model, slices the model into layers, attaches material onto a platform following the cross-section of the model, and lastly, drops the platform, repeating the process of laying material until the 3D model has been recreated.

The first commercial 3D printers were intended for use in rapid prototyping. By incorporating 3D printing into the design life cycle, engineers could reduce both time and cost between product revisions. SLA, SLS, and FDM can be considered the base models for more highly specialized printers that have developed since the 1990s, including Direct Metal Deposition (DMD), Direct Metal Laser Sintering (DMLS), Electron Beam Melting (EBM) Laser Consolidation (LC), and Multi-Jet Modeling (MJM).

For More Information:
Product design
By providing a rapid and inexpensive solution, 3D printing is perhaps most useful in any application that requires iterative development. A company may go through several stages of iterative development before finally arriving at a final product with each stage being a slight modification of the last. These customized modifications are something that can now be offered to the consumer. You are capable of not only downloading a model for say a lamp, but you are also able to personalize your lamp (for example, adjust the height and curvature) before purchase or download to print on your own printer.

Healthcare
Around the late 1990s, we began to see 3D printing being explored for the first time in medical applications and in the early 2000s, researchers at the Wake Forest Institute for Regenerative Medicine successfully printed a miniature functional kidney able to filter blood and produce urine in animal testing. This would be the first major successful application of 3D printing in medicine, but in the coming years, we would see advancements in 3D printed patient-specific prosthetics, surgical implants, cells, blood vessels, organs, casts, biomaterials, and many other medical uses. Perhaps the most fascinating aspect of 3D bioprinting is its patient-specific application. That, by using CT scans or other means doctors can tailor a completely customized solution specific to a patient's exact needs.

Food
One of the most recent largely mediatized applications for 3D printing is food. On June 14, 2013, NASA awarded a $125,000 contract to build a 3D printer that can make pizzas. In the past, there have been other food projects, including chocolate, pasta, cookies, sugar structures, and 3D printed meats (however, with a price tag of over $300,000 USD, 3D printed meats are far from a viable food source...yet).

Fashion
While companies such as Nike have traditionally used 3D printing in their engineering design iterations, today 3D printing in fashion has exploded. Companies are emerging that are 3D-printing custom fit shoes, high heels, jewelry, sun glasses, accessories, and even clothing. With the immergence of new 3D printing material mediums, the fashion industry can design for style, function, and comfort.
Additional applications
The applications for 3D printing are ever-expanding as new companies push the boundaries of current technology. We are 3D-printing structures impossible to ever duplicate using modern manufacturing, as we push the envelope of efficiency. 3D-printed clothing, shoes, accessories, and jewelry allow us to truly express our individuality, while 3D-printed guns call into question current laws and regulations. 3D-printed musical instruments allow us to create new musical dynamics, and 3D printing on the nanoscale is opening doors to new stronger, lighter materials.

MakerBot Replicator 2X specifications
The following image shows the MakerBot Replicator 2 printing specifications. These specifications are identical to the Replicator 2X except for build volume, which in 2X has decreased to 9.7 L x 6.0 W x 6.1 H due to a second print head being added.

<table>
<thead>
<tr>
<th>PRINTERING</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Print Technology:</td>
<td>Fused Filament Fabrication</td>
<td></td>
</tr>
<tr>
<td>Build Volume:</td>
<td>11.2 L x 6.0 W x 6.1 H in (28.5 x 15.3 x 15.5 cm)</td>
<td></td>
</tr>
<tr>
<td>Layer Resolution Settings:</td>
<td>High 100 microns [0.0039 in]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Standard 200 microns [0.0078 in]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Low 300 microns [0.0118 in]</td>
<td></td>
</tr>
<tr>
<td>Positioning Precision:</td>
<td>X: 11 microns [0.0004 in]; Z: 2.5 microns [0.0001 in]</td>
<td></td>
</tr>
<tr>
<td>Filament Diameter:</td>
<td>1.75 mm [0.069 in]</td>
<td></td>
</tr>
<tr>
<td>Nozzle Diameter:</td>
<td>0.4 mm [0.015 in]</td>
<td></td>
</tr>
</tbody>
</table>

MakerBot Replicator 2 print specifications

Printing with MakerBot
Build volume is self-explanatory, but what's important to note are the maximum dimensions in each of the axes, as these will limit the part size and constrain orientation.

Before printing, we will have the opportunity to specify the intended part resolution—the higher the resolution, the longer the print duration.

It is recommended to only use high resolution when absolutely necessary or for small parts, as print times are approximately doubled from a medium and tripled from a low resolution print.

For More Information:
The most important specification to note is the XY precision (11 microns) and Z precision (2.5 microns). These are absolute limits which must be considered during part design. Also, note how Z precision is over 4x that of XY. For the majority of applications, this will not make a difference; however, if you are desperately seeking a little more precision, this is a fact that can be exploited.

MakerBot Replicators uses a 1.75 mm filament. It will not accept a 3.00 mm filament and often times cheaper 1.75 mm filament will in actuality be closer to 2.00 mm and jam the extruder.

**MakerBot Replicator 2X limitations**

MakerBot is considered the leader in consumer 3D printers; however, FDM/FFF technology still faces many limitations, including stepping, precision, time, and supports.

**Stepping**

Physical steps between layers are caused by having to slice the model and use a 2D cross section to print each layer. Stepping on curved surfaces is the most noticeable feature, but this will also occur on any surface where, looking normal to the z-axis, we see an angular increase or decrease in the cross section. In general, lower precision will cause more prominent steps between layers, but can reduce print time, freeing up machines, and increasing throughput. Stepping can been seen in the following image:

![Stepping](image)

**Precision**

Precision is largely the difference between a 3D printer that costs thousands of dollars and a printer that costs hundreds of thousands of dollars. The Replicator 2X has the best precision of any previous printer made by MakerBot, but we need to keep in mind its limitations.

For More Information:

As a rule of thumb, we will require a minimum of 2 layers to form a wall, as any less than this has the tendency to produce unexpected results.

**Time**
The first person/company to create a 3D printer that prints similarly to injection molding will become extraordinarily wealthy; currently, time is not our ally. It would take a couple of days to print a solid cube that fills the entire MakerBot build volume. Size, precision, and infill will all add time to a print. Fortunately, we have control over these print settings.

**Supports**
As mentioned earlier, supports are required to support sharp overhangs. The supports are printed differently so that when the part is finished, they can simply be broken away. However, there may be some remnants, which a little bit of sanding or a utility knife can easily remove.

**MakerBot Replicator 2X material options**
MakerBot Replicator 2 can only print in PLA. The Replicator 2X has a wide range of materials for printing, including ABS, PLA, PVA, and Nylon; however, we are going to focus on the two most common plastics: ABS and PLA. Additionally, Replicator 2X has two heads which can be loaded with two different materials.

**ABS**
If you have ever played with LEGO or have taken a look at the pipes under your sink, you’ve come across ABS. ABS has high impact resistance, is tough and resilient, and costs fractions of pennies per gram. This material has been used in nearly all FFF applications up until the recent adoption of PLA.

The drawback to ABS is curling upon cooling, which can pose big problems for larger objects. Curling can cause large flat objects to "banana boat" up, where the corners will curl as the materials cools. MakerBot has addressed this problem by adding a heated build platform and enclosing the sides, keeping the build volume warm to avoid cooling until the print is completed. These measures have helped substantially, though the problem still exists.

For More Information:
The amount of curling is largely dependent on the geometry of the part, and it will vary on a case-by-case basis.

PLA

PLA has similar properties to ABS but with the distinct advantage of minimal shrinking while cooling. This property is fundamental, as we no longer require a heated build platform or maintenance of a higher constant temperature while cooling, saving up to 32 percent on electricity use.

This book will be using PLA as the material choice for all examples, which will begin in the next chapter.

Summary

In this chapter, we have covered a brief history of 3D printing, including a generalized introduction to the different processes of 3D printing. We covered the birth of MakerBot and learned about the wide usability of 3D printing in everything from medicine to food. Next, we learned about our MakerBot Replicators’ specifications, and we touched on some of the limitations that these impose. We ended by talking about the most common material choices, leading into the next chapter, where we will learn briefly about solid modeling and designing to print on the MakerBot Replicator.

For More Information:
Where to buy this book


Free shipping to the US, UK, Europe and selected Asian countries. For more information, please read our shipping policy.

Alternatively, you can buy the book from Amazon, BN.com, Computer Manuals and most internet book retailers.