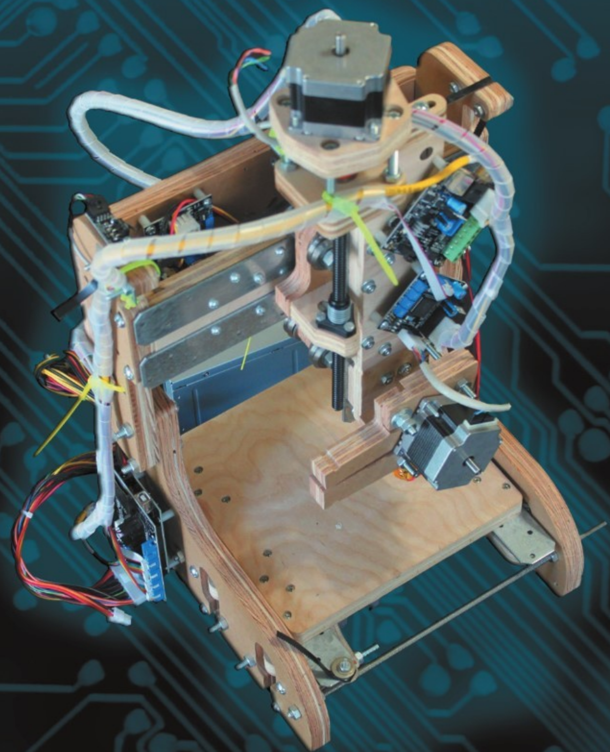
TECHNOLOGY IN ACTION™

Printing in Plastic

Build Your Own 3D Printer



James Floyd Kelly and Patrick Hood-Daniel

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Patrick Hood-Daniel

James Floyd Kelly

Printing in Plastic: Build Your Own 3D Printer

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JFK: For Decker and Sawyer—we're gonna have some fun!

PHD: I would like to thank my family, especially Ana, my wife, for enduring my insanity during the development of this 3D printer project.

Contents at a Glance

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About the Authors

Patrick Hood-Daniel's interest in technology started in 1979 at the age of 11 when his father bought him his first computer, the TRS-80 Model 1 Level 1. Patrick's first program was a 3D CAD program written for the Model 4, a more advanced computer featuring much better graphics capability. Patrick continued to develop this and many programs for the IBM XT and 286 computers; he started programming professionally after graduating high school. Knowing that he needed some formal education to continue designing and developing visually stimulating subject matter, Patrick began his university career at a community college in Tampa, Florida, graduating with honors; he immediately transferred to the University of Miami to study Architecture and Urban Design under the great minds of New Urbanism, graduating again with honors and receiving the Henry Adams Medal for excellence. Patrick then focused on assisting the development of the many buildings being built in the Miami area with the City of Miami Planning Department. He also pursued a Master's degree from the University of California; upon graduation, he began work with Downtown Houston as the Director of Planning, Urban Design and Development. Patrick also developed embedded systems for robotics plus linear motion mechanics and control systems for CNC and related developments. Patrick has a strong desire to disseminate this information, so he created `buildyourcnc.com` and `newbiehack.com`; he shares ideas with others at `buildyourtools.com`. Patrick has interests in personal fabrication with CNC, 3D printing, laser cutting and engraving, PCB manufacturing, and various other forms of robotics. With a desire to continue his knowledge of computer programming, Patrick is still learning and providing solutions under C# and WPF to clients.

James Floyd Kelly is a writer from Atlanta, Georgia. He has written books on a wide variety of subjects, including Open Source software, LEGO robotics, and various tablet devices, as well as a book detailing how to build a CNC machine (with Patrick Hood-Daniel). James has an English degree from The University of West Florida and an Industrial Engineering degree from Florida State University. He has an extremely patient and understanding wife who is concerned that their two sons will also develop a strong interest in tools and tinkering.

About the Technical Reviewers

Tony Buser began his technology career in 1995 by writing HTML code. From there, he moved into web site and intranet application development and now works as a web developer for MakerBot Industries in Brooklyn, NY. Tony loves turning virtual digital information into physical reality, and he believes that the affordable and easy-to-use 3D printing and personal fabrication technology might very well be the most significant new technology since the World Wide Web. He is excited to be a part of its development at such an early stage and can typically be found spending untold hours in his basement workshop in Reading, PA with his four 3D printers: two Makerbots, a RepRap, and a whiteAnt. And he's always building more.

Dr. Darrell A. Kelly, (PhD, Chemistry) is an avid tinkerer and DIYer. A retired chemist with over 30 years at Monsanto/Solutia, he now divides his time between teaching chemistry part time at Pensacola State College and tinkering in his workshop building toy trains, 3D printers, CNC machines, and other "special projects" that his son, co-author James Floyd, somehow manages to talk him into joining.

Acknowledgments

Writing a book isn't easy. Writing a book that require readers to cut wood, drill holes, wire up electronics, and install software? If you listen carefully, you can almost hear the Mission Impossible theme song. What would have been (should have been) an impossible task was made possible thanks to a large collection of folks that, fortunately, lent their time and talents to make this book a reality.

First and foremost is the Apress staff. Like an acceptance speech, we worry we'll overlook someone, so we'll start by thanking Apress as a whole for giving this book the green light. There are dozens of folks at Apress who work behind the scenes to publish great books and you can read a complete list of their names a few pages earlier.

But we want to offer up special thanks to the following individuals who have simply gone above and beyond what was expected.

Thank you, Jonathan Gennick, for your excitement and interest when we pitched the idea. You stuck with us, asked the right questions, and pushed for the right content.

Thank you, Kelly Moritz! Kelly should get hazard pay for this book; long days, long nights, hundreds of e-mails, many phone calls, and two authors to deal with as well as two technical editors. Kelly, you are awesome.

Thanks you, Dominic Shakeshaft. Somehow you developed amnesia about the *Build Your Own CNC Machine* book and allowed us to pitch the *Build Your Own 3D Printer* book. Dominic, we have this idea for a third book…

We had two technical editors for this book and this, although not typical, made our jobs easier by having two pairs of eyes checking and re-checking our work: Darrell Kelly (James Floyd's dad) and Tony Buser. We've not been given enough pages to properly thank these two for building their own 3D printers and providing essential feeback about the process. We'd just like the two of them to know that their hard work is appreciated and their offered help is more than we can ever repay. (And Tony's been making quite a name for himself in the 3D printing community, so be sure to follow him on Twitter or check out his blog at `tonybuser.com` where he posts all sorts of stuff (videos, photos, commentary) related to 3D printing.)

Introduction

The book you're holding in your hands is going to show you how to build your very own 3D Printer. It's not science fiction. It's a device that will allow you to print out (in plastic) whatever you can imagine. (Okay, that's a bit of a stretch – there are size limitations when using this machine.)

Read the book – build the machine – print stuff that you can actually hold in your hands, use for prototyping your own inventions and replacing worn out parts, and basically taking something in your mind (or at least on a computer screen) and make it real. Congratulations – you've got a little bit of science fiction sitting on your desk.

What Exactly Do I Get?

You've obviously picked the book up and we can only hope you've read the cover – "Printing in Plastic: Build Your Own 3D Printer." It's not too difficult to guess what the book is about, is it? Well, if you're still a bit confused, let's clear it up right here by giving you the most basic explanation of what this book is going to teach you… and here it is:

> *You are going to be provided with the building plans, a list of required supplies and tools, and step-by-step instructions to cut, drill, assemble, and wire-up your very own machine that prints in plastic. But wait! There's more!*
>
> *You are also going to be provided with instructions on how to connect your new machine to a computer so that you can print out (in plastic) things you design using freely available software. But if you act now, we'll also throw in a few bonus items!*

We'll not only cover the software and how to use it in the book, we'll also provide you with some sample items to print with your machine so that you can test it and show off your 3D objects to your friends and family.

As a Thank You Bonus for purchasing the book, we'll also be providing you with a great website and forum where you can post questions, share pictures, and learn how to push your machine's capabilities even further.

Does that sound good? Do you want one? Are you ready to start?

Welcome to the Future!

Take a look at Figure I-1. If you've got the time, some patience, and, let's face it, some spending money, that little bit of the future can be yours. Your very own three-dimensional printer!

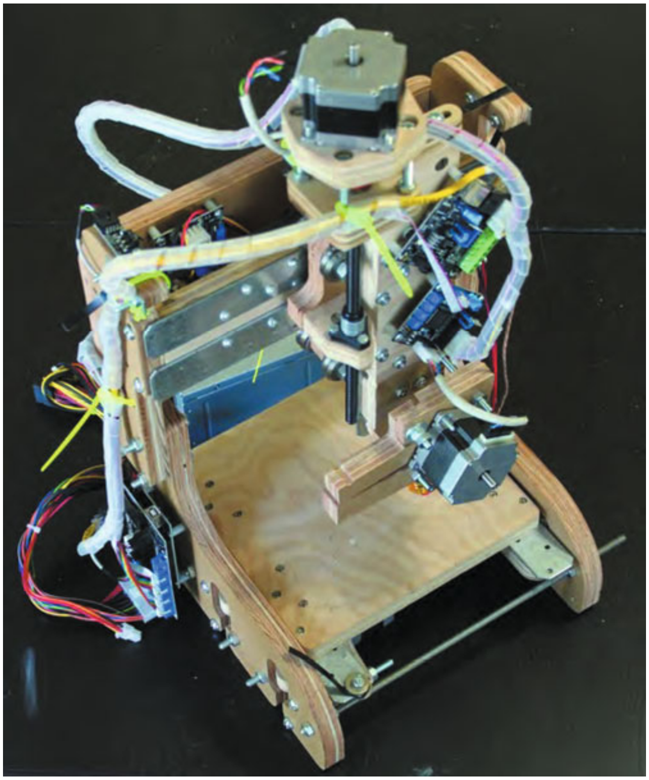

Figure I-1. *Your very own 3D Printer.*

If you take this book and follow its instructions, you'll end up with your very own three-dimensional printer, sitting on your desk or worktable, connected to a computer, and capable of printing (again, in plastic) whatever you can come up with and design (using some specialized software).

What kind of stuff might you want to print? Well, the first thing you need to know is that whatever you print, it isn't going to be very large. Look back at Figure I-1 and you'll notice that the device isn't that large to begin with – so you won't be printing dining room chairs or the world's first all-plastic Zamboni. Nope – think smaller. Keychain dongles. Coat hooks. A replacement side mirror for your child's horribly damaged remote control car. A bobble-head figurine of your spouse. A small 3x5 picture frame. Drink coasters customized with your family crest. Small stuff, okay?

Not feeling creative? That's okay – you can also print out designs from others. If someone has created the perfect little plastic army man figure and shared it on the Internet with the world, go ahead and download it and print it. Print sixteen and have your own little platoon on your bookshelf! Or modify the design a bit if you're feeling experimental. You really can't go wrong here.

No, you can't use it to make coffee. No, it won't print a medium-rare steak. And, no… it won't fabricate a solid-metal replacement gear for your fishing rod. 3D printers like this one are machines in their infancy, with the same expectations a parent might have for a child – in time, it'll grow up, be able to perform more advanced tasks, and, attend a good college (okay, maybe not that last part, but we promise you'll definitely be seeing these on campuses in the future).

Good science fiction always feels plausible – as if the future is just around the corner. We may not have all the Wonder Devices from books, TV, and movies, but we're on our way. In the future, people will tell a computer what they want and a magical machine will provide it. But getting to the future seems to always take small steps. And that's exactly what this book is about – small steps. Building your own 3D Printer is your first step (later steps include having your printer print out its own replacement parts or even upgraded parts to turn it into a more capable 3D printer) to having a bit of the future in your own home or office – a machine that prints what you request from it.

Welcome to the future – we hope you like it.

Patrick Hood-Daniel
James Floyd Kelly

CHAPTER 1

Before You Begin

Look at the cover of this book again. What is that unusual looking device pictured there? Yes, it's a 3D printer, but what exactly does that mean?

This chapter will tell you. We're not going to bore you with a lot of techno mumbo-jumbo or a complete machine-by-machine history of how we got here; you can find all that on `Wikipedia.com` or another web site. Instead, this chapter will provide a simple (and short) discussion on what this device is, what it does best, how it works (again, in simple terminology), and how to proceed through the following chapters to begin building your own 3D printer.

What is a 3D Printer?

Let's start with the easiest part first: the word "printer." For most people, the term *printer* is fairly obvious. It's a small, medium, or large device that folks use to create a hard copy (i.e. paper) of their digital files (Word documents, photos, brochures, PDF files, Internet receipts for online purchases, web articles, and more). Printers come in a variety of shapes and sizes; there are several methods of putting ink to paper.

The two most common printer technologies used today are referred to as ink jet and laser. An ink jet sprays a bit of ink (black or color) on the paper, and after a few seconds, spits out the latest chapter of your novel, the report your boss wanted ten minutes ago, or directions to the nearest computer repair shop. Laser printers use a different, more complicated method of applying an electric charge to a round drum that picks up toner (a laser printer's "ink") and then applies that toner to a page.

Ink jet and laser printers print on flat paper. The output of these devices is two-dimensional. Paper has a length and a width. A standard paper size in the U.S. is referred to as 8.5" x 11"; this means the paper is 8.5 inches wide and 11 inches long. Technically, paper does have a third dimension, thickness (or height), but we're not going to worry about that right now; paper is thin enough that we'll be safe referring to it as a 2D. Figure 1-1 shows a piece of 8.5 x 11 paper. We are limited to applying ink on this paper in four directions: left, right, towards the top, and towards the bottom.

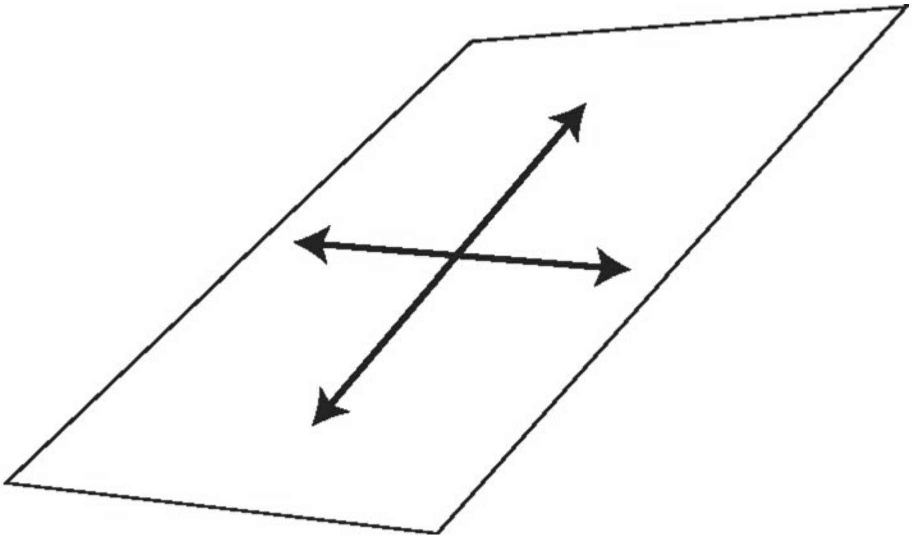

Figure 1-1. *Ink and paper allow for only two-dimensional printing.*

So, knowing that an ink jet or laser printer creates 2D output, we can hazard a guess that a 3D printer would print in that third dimension: up off the paper!

But ink doesn't stack well. Yes, ink can build up (you can run your fingers over some types of paper and feel the ink), but it doesn't come up and off the piece of paper high enough to be noticeable. If 3D printing is to be truly possible, it needs to substitute ink for some other material that will *stack* or *build up* in layers.

One of the materials that can be printed in the third dimension is plastic. The term "plastic" covers a wide variety of materials and is considered to be a generic term, so we'll get a bit more specific a little later in book. For now, let's define the 3D printer as a device that can apply melted plastic (that cools down and hardens) in all three dimensions on a flat surface: left and right on the surface, up and down on the surface, and vertically going upwards away from the surface. (Yes, down should be allowable, but since we're dealing with a device that applies melted plastic to a work surface, the only direction we can really go is up, away from the surface.)

Take a look at Figure 1-2. Instead of ink, plastic would allow us to print up from a flat surface, creating three-dimensional output. The 3D printer applies the plastic in layers that build up, creating the 3D effect. Layering is the method used by a 3D printer to turn a two-dimensional object into a three-dimensional one.

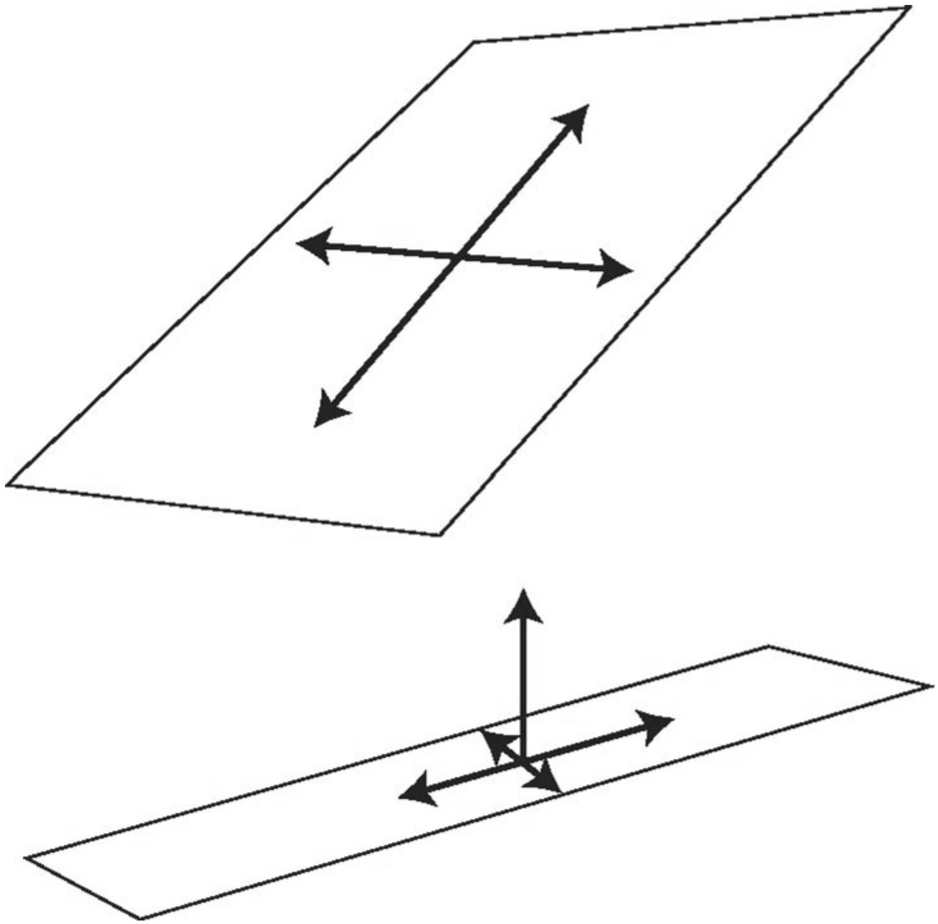

Figure 1-2. *Plastic and a flat surface allow for three dimensional printing.*

Are you starting to understand what a 3D printer can do? Sure, you can use it to print TOP SECRET in two inch tall letters on a piece of paper, but let's move away from the idea of printing words in 3D and consider other options. Printing in plastic will allow you to print all sorts of things in 3D that would otherwise have to be represented in a 2D drawing. You could print a replacement gear for the one that cracked in that little wind-up robot toy. Or how about a set of buttons (using colored plastic that is readily available) to give your favorite jacket a new look? And yes, you could even print yourself a plastic mug or teacup. The possibilities are exciting.

There are some advanced uses for a 3D printer as well. A jeweler could print some small medallions (in plastic) to use as molds for custom silver jewelry. An inventor might use a 3D printer to create an inexpensive prototype of a handle for a new screwdriver, testing it in plastic first to make certain the design feels comfortable. A robotics hobbyist would find a 3D printer useful for printing out small gears or wheels that are unique in size or shape and can't be purchased in stores. The list doesn't end, and it's likely you have your own ideas for how you might use a 3D printer.

But simply having this device on your desk isn't enough. It's not going to magically read your mind and print out the plastic object you need. A 3D printer is a computer-controlled device and therefore must be connected to your computer to do its job. And in order to actually get the 3D printer to print something, you'll need to install some special software on that computer, which will be covered later in the book.

Questions and Build Help

We have tried to include everything that you will need to know and buy to build your own 3D printer in the pages of this book. But we can't predict every question that a reader might have. And, to be honest, it's not unknown for technical errors to creep into a book of this nature. We've done our best to have multiple sets of eyes go over the material. We've also had multiple editors build the machine—more than 4 in all! (Patrick Hood-Daniel has built several machines, James Floyd Kelly built one, and Darrell Kelly and Tony Buser (the book's tech editors) have also each built their own machine.)

Even knowing that the machine works properly if assembled correctly, you may still have questions. That's okay. There is a web site managed by Patrick that hosts a variety of videos and files plus a discussion forum. Readers can log in to the forum, post questions (or read other questions), and find answers. We encourage readers to not only post questions but to submit pictures and notes about their own experiences building the machine (and maybe even modifying it).

You can find everything related to the 3D printer in this book at `www.buildyourtools.com`. Post your questions there and you'll likely receive some fast responses from the growing 3D printer community.

The 3D Printer is Evolving

This book took over five months to complete; late into the book's progress an occasional change was made to the machine, requiring some of the chapters to be updated. For example, we discovered that some of the electronics used were going to be retired. We were able to update previous chapters with the new information.

But as a book gets closer to the final deadline, it becomes difficult to go back and retro-fit changes or update information. There were some discoveries that we couldn't add to the appropriate chapters, so we're including an Addendum chapter at the end of the book; this chapter will contain the latest comments and notes regarding the build. For instance, late in the project, we found that shaving a small notch off of a key part would allow the Plastic Extruder (the piece of the machine that does the plastic printing) to be held more firmly in place; this information has been added to the Addendum because, although it's not required, it adds an improvement to this machine that we would otherwise not have been able to offer to you so late into the book's writing.

We recommend that you read the entire book front-to-back before beginning the project. We especially recommend that you review the Addendum.

Videos, Building Instructions, and Parts

Again, we'd like to direct your attention to the book's web site at `www.buildyourtools.com` where you'll find the building instructions (as PDF files) that you will use to cut and drill all the plywood pieces that make up the 3D printer.

You'll also find videos that Patrick has filmed to show how to assemble the 3D printer, mount all the electronics, and install and configure the software used to print out 3D models. These videos don't go into the level of detail found in the book, but they offer Patrick's helpful commentary; also, seeing the construction can assist you during your own machine's assembly.

You'll also be able to purchase pre-cut and pre-drilled components for the machine should you decide not to tackle cutting and drilling your own plywood pieces. The parts sold on the web site are cut and drilled using a CNC machine, reducing human error when it comes to measuring, cutting, and drilling. The web site will also sell most, if not all, of the electronics components. Right now, most of the electronics must be bought from third party sources such as `Makerbot.com` or other electronics suppliers; that will change (or may have changed by the time you read this), making `www.buildyourtools.com` your one-stop source for everything you need to build a 3D printer.

We Want to Hear from You

We love to get feedback (we like the praise better, but we understand that there are occasional gripes). Visit the book's web site at `www.buildyourtools.com` and let us know what you think of the book, of the 3D printer (Patrick's name for it is WhiteAnt; he gives all the machines he develops names), and of your results.

3D printers are a new game for DIYers; these machines are still in their infancy, so keep that in mind as you use your device. Your 3D Printer is designed to allow for upgrades (to the motors, circuit boards, and more) as you'll likely find yourself wanting to make changes over time if you really get into the 3D printing hobby. You'll find a strong community of hobbyists and companies (such as Makerbot) sharing what they know, creating new products, and just pushing the 3D printing hobby further.

We wish you luck as you start down the path to building your own 3D printer!

CHAPTER 2

Hardware and Tools

Unlike a lot of DIY projects, the 3D Printer you're going to build isn't going to require a large number of tools, just those that can cut the structure of the machine from plywood and drill the holes for bolting parts together. (The electronics portion of the build will be covered in later chapters, along with any specialized tools that you may need.)

Caution As with any project that requires tools, we want to issue the standard warnings and recommendations: read the manuals, handle all tools with care and respect, and never rush things.

If you're unfamiliar with the proper usage of a power tool, find the manual and read it, or ask someone knowledgeable for assistance. Also remember that the Internet is your friend. If you've lost a manual, you can probably find it on the manufacturer's web site as a downloadable PDF file. There are also videos galore (on sites like `www.YouTube.com`) that provide tutorials on how to use tools properly—maybe even the exact tool you're using.

Tools are dangerous if you don't respect them. With parts that move at hundreds or thousands of RPMs (revolutions per minute), your eyes and fingers and other body parts are no match for power tools. Wear goggles (get in the habit of putting them on anytime you enter your work area) and always be aware of where your hands and fingers are with respect to the business ends of power tools.

And finally, this isn't a race. Yes, we know you're anxious to build and finish your 3D Printer. But take your time. Working with a table saw, for example, is much faster than using a handsaw. But table saws are hundreds of times more likely to remove a finger than a handsaw (where you're holding the tool in one hand and the part to be cut with the other). The benefits of power tools are, of course, power and speed and accuracy, so balance these out with a good bit of patience and awareness of what you're doing and, most importantly, where your fingers are located.

Respect the tools you're using, and you won't be one of the over 175,000 people who end up in the Emergency Room each year from improper power tool usage. We're not trying to scare you away from building a 3D Printer, but we hope we've convinced you to spend some time learning how to properly use the required tools.

And what tools are those? Glad you asked.

The Power Tools

We're going to list the tools you need for this project, but keep in mind that when it comes to tools, there seems to always be something better in someone else's garage. If you've got a handsaw, your best friend probably has a circular saw. And his neighbor probably has table saw. The grass is always greener, right?

As you review the list of tools, keep in mind the following things:

- *It's often not wise to purchase a tool for just one project.* Purchase a tool if you believe it will benefit you with the 3D Printer project plus future projects down the road. (That said, your authors tend to follow the motto of *You can never have too many tools.*)
- *Consider tool rental.* Given that a good table saw can run $300 to $2000, depending on features and name brand, you may want to consider one of the many tool rental companies. For instance, you can rent a table saw for $50 to $75 per day (or less). The only caveat is you'll need to go pick it up and bring it back, so bring a buddy as they tend to be heavy. (And don't forget to ask for the operations manual. If they don't provide one, find another rental company.)
- *There's nothing wrong with asking to borrow a tool.* We all have friends who have a nice assortment of power and hand tools in their workshop or garage. Invite the tool owner over and show them what you're building; you may find they'd like to build one, too, so your tools borrowing is no longer an issue!
- *But don't be offended if the answer is no.* One of the authors (JFK) is very resistant to loaning out his tools after a bad experience a few years back when a semi-expensive hand sander was dropped by a borrower. Many tool owners are just as protective of their investments.
- Always clean a borrowed tool before returning it. It's just good manners.

So, with all that said, here are the tools that will be beneficial to your project. Some are absolutely required, others are recommended, and others are not necessary except for possibly adding some finesse or flair to the final look of your 3D Printer (also referred to as 3DP).

Table Saw

Can you cut out the 3D Printer parts from plywood with a handsaw? Sure you can. But the real question is should you use a handsaw? Probably not. The 3DP has some wood parts that require some fairly accurate cuts in order for parts to either match up or mate properly with other parts.

Using a handsaw inevitably leaves an uneven cut line. You could use something like a belt sander to smooth down the cut line, but you also risk taking away too much of the wood and reducing a measurement (such as a width or length).

We recommend using a table saw, as seen in Figure 2-1. Table saws come in a variety of designs with names like Contractor Saw, Benchtop, Cabinet, and Hybrid. (If you want to learn more, visit `http://en.wikipedia.org/wiki/Table_saw` for a breakdown of features as well as pros and cons.)

***Figure 2-1.** A table saw will make the accurate cuts needed for the 3DP.*

A table saw will allow you to cut some of the longer edges needed with more accuracy and a smoother cut surface. Make certain when you're using the saw fence that your cut will be square.

■ **Note** A good way to ensure that a cut part will be square is to simply measure before cutting. Measure the distance from the front of the saw blade to the fence. Then measure from the back of the saw blade to the fence. Check to be sure that both measurements are the same. If they are, then your fence is square. If not, then at least you know about the problem before making a cut.

Some of the parts used in the 3DP have a matching component (such as a left side and a right side piece), and a table saw with a cutting fence will allow you to cut duplicate parts with matching dimensions easily. Once you set the distance between the fence and the blade, you can be reasonably confident that a second piece will match the first piece in at least one dimension (length or width).

Are there options if you don't have access to a table saw? Yes. You can use a circular saw with the proper type of cutting blade (for plywood) like the one in Figure 2-2. Make certain that you clamp a level or other straight edge to the piece that you plan to cut to guide the circular saw. And if you're not completely familiar with circular saws, you should know that the best way to cut with them is to use a pair of saw horses, otherwise you cut into any material beneath the piece you're cutting.

■ **Note** You can also lay a sheet of foam insulation underneath a piece that you plan to cut using a circular saw. You can read more about this method at `www.woodworkingtips.com/etips/etip010810sn.html`.

Figure 2-2. *A circular saw will help with cutting individual parts.*

Keep in mind, however, that a circular saw or table saw won't be helpful with cutting some of the smaller, more detailed parts like the indentations seen on the building plan sheet in Figure 2-3. For the notches that are cut into a piece, you'll need a different tool.

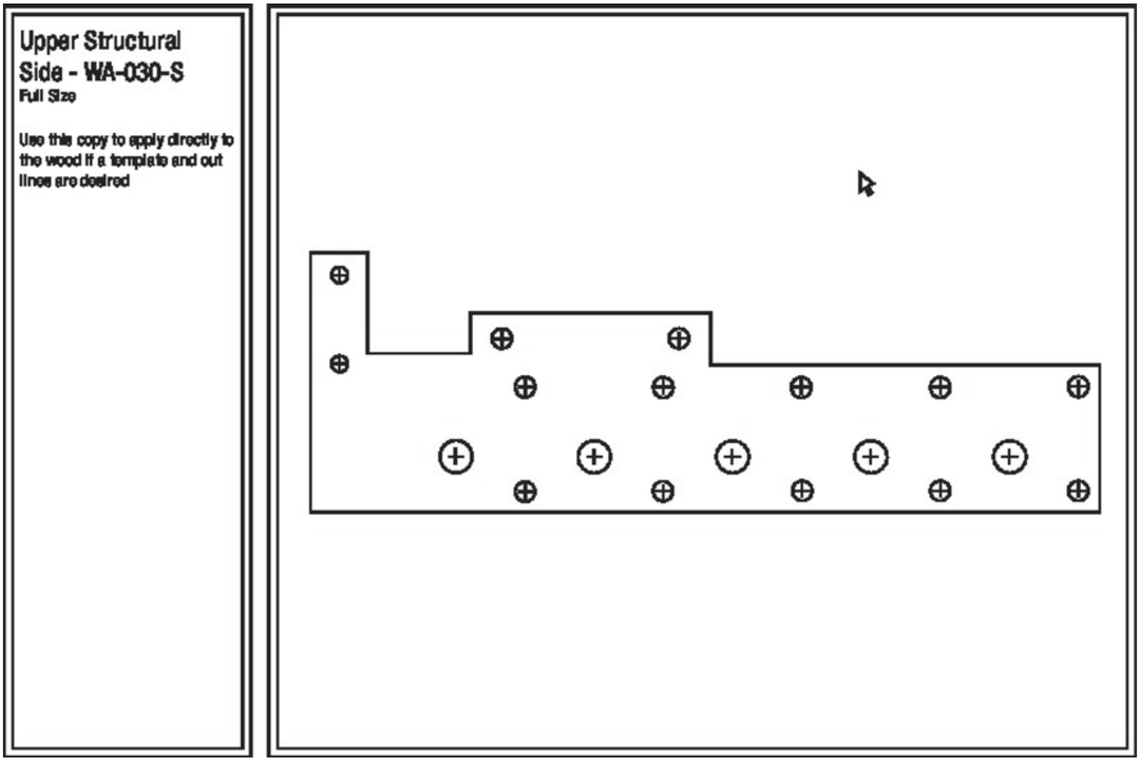

Figure 2-3. *Some parts have cuts that can't be made by table saws or circular saws.*

Bandsaw or Scroll saw

A bandsaw or scroll saw (see Figure 2-4) can be useful tools to have but are by no means required. They are helpful in making intricate cuts such as inside corners. They are also helpful in cutting notches because bandsaws and scroll saws give the straight up and down cuts that you need for that purpose.

Figure 2-4. *A bandsaw or scroll saw can be useful for cutting ninety degree corners.*

If you examine the building plans, you'll notice that parts cut do not have curves and angles; all cuts are right angle cuts. Some of those cuts (like the one seen in Figure 2-3) can be a bit tricky, and that's where a bandsaw comes in. Its small blade can get into corners and handle notches. But even a bandsaw or scroll saw has limits: because of the way the blade cuts and how you feed the piece into the blade, you'll be forced to curve the piece as the blade moves toward a corner. This will result in a small curve instead of a sharp ninety degree corner. If you look at the building plans in Figure 2-5, you can see that the notch has a crisp ninety degree corner.

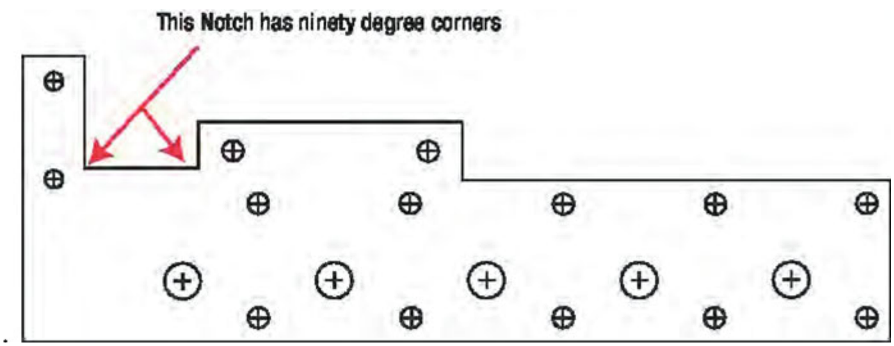

Figure 2-5. *The building plan shows notches with crisp ninety degree corners.*