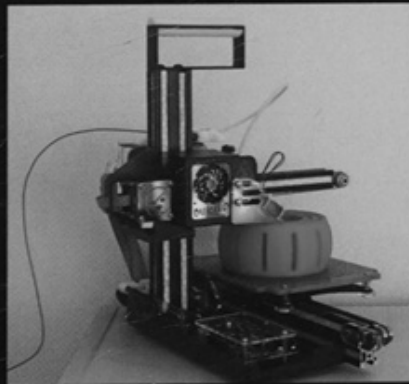
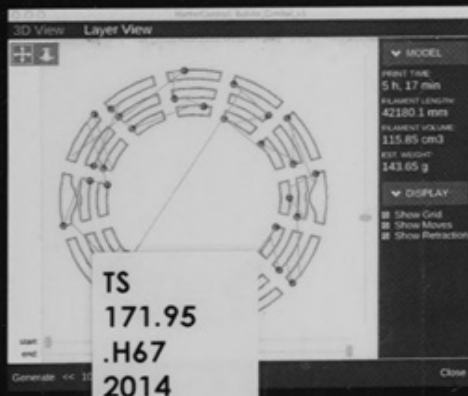




TECHNOLOGY IN ACTION™

# Mastering 3D Printing

MODELING, PRINTING,  
AND PROTOTYPING WITH  
REPRAP-STYLE 3D PRINTERS



Joanath

Deezmaker  
3D PRINTERS

## Mastering 3D Printing

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## Kits vs. Assembled Printers

Many 3D printers are sold as kits, and you assemble the printer. This has the virtue that you end up understanding the printer and how it works as a system much better than you would had you just bought the system off the shelf. Putting together a kit enables you to be better prepared to make adjustments in hardware and software later on, because the reality is that, to be able to print well, most printers require significant knowledge of how the system works.

The counterargument of course is that someone (or some robots) who assemble electronics all the time are more likely to do a good job than you are. This area is in flux too; as software gets more sophisticated and printer designs continue to improve, knowing the details may become less important. But for now, it really helps to know how the machine was built and what the likely culprits are when there are problems.

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■ **Tip** If you are deciding whether to buy an assembled printer or a kit, note that most manufacturers post assembly instructions online. You can always look at the instructions before you buy and decide whether the assembly is within your skill and time limitations.

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## 3D Printer Design Considerations

In the rest of the book we will talk about parts of the printer, and we will introduce them now with some pictures so that you know what we are talking about later on. A filament-based 3D printer has been called a computerized hot glue gun: basically it takes plastic filament, melts it, and puts it down in layers. There are several key components in this requiring many design tradeoffs among the various options.

### Filament

Chapter 7 discusses filament and its handling in great detail. Filament typically comes on spools (for open source printers) or, in some cases, in proprietary cartridges. Printers need to have some means of getting filament off the spool by allowing the filament to turn on a spindle or a lazy-susan-type tray. In some cases, this is part of the frame or attached to it; in other cases, the filament rests on a lazy susan next to the printer.

### Frame

As noted earlier in the chapter, the frame of a printer needs to be stiff and sturdy for the prints to build up accurately. If the frame is sloshing around, it is unlikely that you will be able to have an accurate print. Various types of aluminum, extruded rails typically make up frames. Laser-cut or 3D-printed joints typically make up the rest of the frame.

### Build Platform

Every 3D printer needs to have a flat surface to build the print. This surface is commonly called *the build platform*, or sometimes just the *platform* or *bed*. Some printers have a heated platform to allow printing of materials that need to be kept warm during building. Others just have a glass or other plate that needs to be covered with tape of some sort to ensure that the first layer of the print will stick.

The printer in Figure 2-1 has a heated platform covered with Kapton high-temperature tape. The one in Figure 2-2 is unheated and covered with blue painter's tape to allow printing of a plastic called PLA (polylactic acid). Chapter 7 details what type of build platform surface is necessary for different filament types.

## Extruder Design

The extruder is the part of the printer that melts and moves the filament. The extruder has several parts. One is an extruder drive mechanism, which is a motor and a mechanism that pushes the filament into the hot end. The hot end in turn is comprised of a heater, a nozzle, and a sensor (a thermistor) to sense how hot the bed is. You can see two extruders on the printer in Figure 2-1, which is a dual-extruder machine capable of printing objects out of two materials.

## Bowden and Direct-Drive Extruders

There are many different extruder designs, which fall into two major categories. A *direct-drive extruder* (like the one on the machine in Figure 2-1) has a motor and drive gear pushing the filament right next to the hot end. A Bowden extruder (like the one on the machine in Figure 2-2) has a drive gear that is separated from the hot end with a guide tube.

The main reason for using a Bowden extruder is that it moves the heavy motor away from the nozzle, which can make the part of the extruder that is moving a lot lighter. This can allow for faster printing speeds, but at the cost of a more complex extrusion system.

## Retraction

When the printer is creating a layer, there are holes and filled areas. Some of the holes can be made by having the nozzle zip around the edge of the hole. Sometimes, though, it is necessary to stop extruding across a gap in the layer. In that case the extruder has to *retract* the filament. The drive gears need to be able to pull filament back as well as push it forward to make this work. How much to retract during a print is something a user can set during the process of slicing a model into layers (discussed in Chapter 5). Retraction has a strong effect on print quality.

## Nozzles

The nozzle is one of the most critical pieces of the printer and one of the more delicate ones. The holes are tiny and easily clogged. To a degree, the nozzle material and quality define what materials your printer can safely melt and therefore print. Good-quality nozzles can handle polycarbonate, nylon, and other higher-temperature plastics. The nozzle is part of the hot end, which includes the nozzle, the heater block, the thermal break (barrel), and, in many designs, a heat sink to cool the top part of the thermal break. Some designs depend on the insulating properties of high-temperature plastics or, occasionally, ceramics (at the cost of being able to extrude higher-temperature materials).

## Moving Parts

3D printers need to move some combination of the extruder and the build platform to be able to create objects. They achieve this with a combination of stepper motors attached to drive screws or cable, belt, or other systems attached to pulleys.

A stepper motor (Figure 2-4) is a precise, brushless, direct current (DC) motor that moves the shaft in predefined angular steps. Motors for 3D printers typically have 200 steps per revolution. The stepper motor is then coupled to a drive screw (like the z-axis motors for the printer in Figure 2-1) or to a belt or cable.

## Directional Strength

How strong is something made on a 3D printer? The answer depends on the filament material, but also on the details of the print. Prints are weakest in the z direction (because the layers can pull apart), so the orientation of a print on the print bed also has implications for strength of the printed object. Design of an object should take into account the following:

- The inherent strength of the material
- Whether the object's operating environment will get hot
- Whether the object's operating environment will contain any chemicals that affect the material
- The direction in which the object will need to be strongest
- Support structure needed in various build orientations
- Thickness of the outer shell of the model
- Infill pattern and density
- Any connections with other (non-3D-printed) parts
- Brittleness— the ease with which a part (particularly a small part, or support) will break off
- Tolerances and clearances

It is tempting to create a 3 mm hole in a part and print a peg that is exactly 3mm in diameter to fit in that hole if you are looking at an idealized computer model of your peg and your hole. This will not work in the real world, though (as opposed to computer-screen world) because small clearances are needed for one part to actually go through another. For a consumer-level printer, a clearance of half a millimeter or so is probably about the smallest practical space required between parts.

As discussed in Chapter 5, many settings in slicing software specify the external and internal structure of a part. Chapter 8 discusses some typical case studies to make it more concrete how these factors interact.

## The Right Print Bed

Prints need to stick solidly to the build platform so that they do not shift or fall off while the piece is printing. On the other hand, the platform or the print may be damaged if the print is stuck down too firmly.

For many materials (like ABS and polycarbonate), the platform has to be kept warm so that the print sticks to it. Some 3D printers have heated platforms; ones that do not probably cannot print in these materials. Materials that need a heated bed will warp while printing if the bed is not adequately heated. As the lower layers cool, they will shrink and pull up from the bed at the corners. The hot layers on top will be a bit bigger, and as they cool the part will warp more and more as the upper layers also contract.

Beyond heating, the surface of the platform needs to be a material that is compatible with the print material. At the moment figuring out what sticks to what is fairly empirical. Blue painter's tape (3M seems to work best) and high-temperature Kapton tape (transparent gold-colored tape) are common printer bed materials. Glass, often with glue or some other adhesive coating, is becoming a more popular printing surface. Follow your manufacturer's directions, but generally the following rules of thumb hold:

- PLA will stick well to blue painter's tape. Typically, we think of this tape as something that pulls off a wall easily, but interestingly the 3M tape in particular seems to be just the right surface for PLA to stick to sturdily. Blue tape is available in wide rolls that can cover a smaller print bed in one shot, which avoids tape edge lines in the first layer of the print.