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3rd Edition

# 3D Printing

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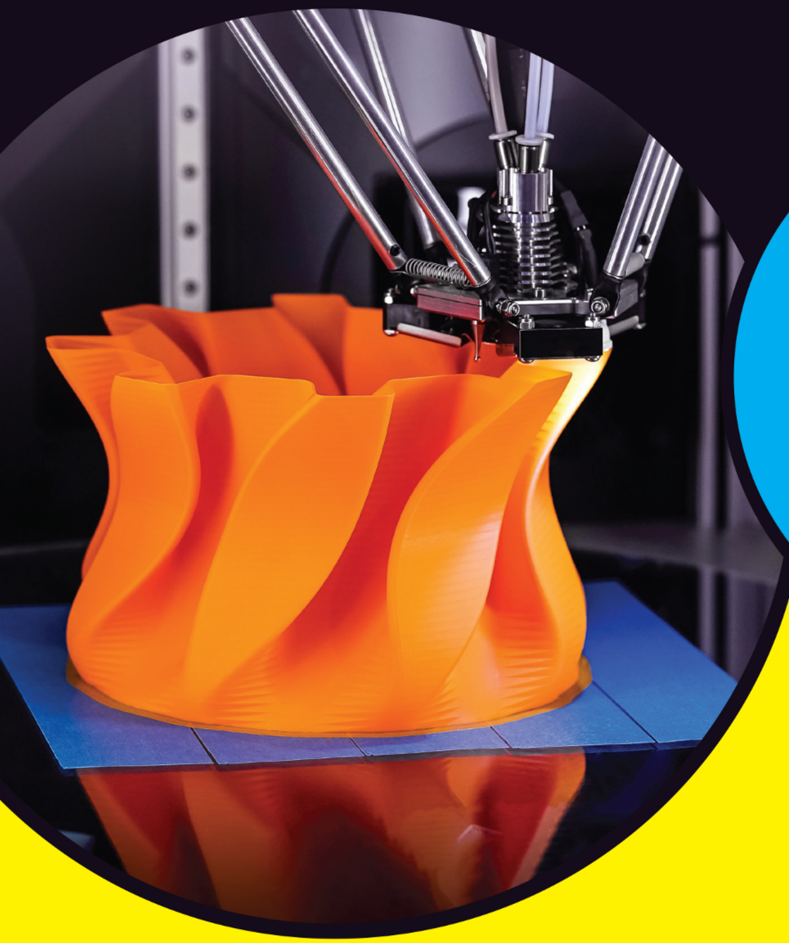

Design for the 3D printing process

Explore practical 3D printing

Learn how 3D printing can work for you

Richard Horne

# 3D Printing

3rd Edition

by Richard Horne

for dummies
A Wiley Brand

## 3D Printing For Dummies®, 3rd Edition

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# Contents at a Glance

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# Introduction

3D printing has been around for more than 30 years, but for much of that time it would have been inconceivable for anyone without corporate backing to even think of taking advantage of this technology. Recently, however, the core technology for 3D printers has developed to the point where it is now available at prices many individuals and smaller companies can afford.

Three key things make 3D printing stand out from almost any other manufacturing process:

- **Printed parts are "grown" in layers.** Many complex objects that have internal structures or are comprised of interlocking sub-assemblies can be manufactured in a single run, with no further intervention, whereas previously they would be made from many separate parts, some of which could not be made by fully automated machining processes or more traditional means. Multiple materials can be used together to improve the performance or overall integration of the finished part. For example a simple referee's whistle needs to have a hollow inside with a slot and pea inserted that will not fall out. All traditional methods for manual or automated manufacture would require at least three separate parts to be connected together. With 3D printing, the hollow shell of the whistle can be made as a seamless object and the pea inside can be printed and designed to release and form the rattle all in a single operation where the finished whistle is ready to use directly after 3D printing.
- **Material is added rather than subtracted.** This method of manufacturing adds raw materials to build an object rather than removing material. Machining away 90 percent of a metal block to make a cooling system for a race car is far less efficient than adding the 10 percent or so of metal powder needed to make a more compact and efficient design that couldn't have been machined in the first place.
- **3D printing often eliminates the need for complex or expensive production tooling.** This benefit is becoming significant as 3D printers are being used for mass manufacturing runs in which individual tooling or hand-crafting would make customized products far too expensive (such as solid gold jewelry).

In short, 3D printing turns a digital model in a computer data file into a physical representation of the object or product. The term *3D printing* is now widely used by media and communities to help communicate the idea that an object is being produced in a similar way as a paper printer, but as a physical three-dimensional part. The term 3D printing is often disliked in the wider industry, as it's a poor representation of what this technology can achieve. A more professional name is *additive manufacturing,* which covers a vast array of sectors, materials, and processes used to produce physical objects from data.

Since the first edition of this book was released in 2013, desktop 3D printing and various forms of industrial additive manufacturing have been through the rise and fall of a technology hype cycle. Reports about 3D printing applied to biomedical research anticipated the leap from lab to patient too soon, rather than focusing on the possibility of printing tissue samples for medical research. Researchers and individuals are still working out appropriate uses of 3D-printing technology. Often, they come to the conclusion that there are still vastly better ways to produce many things without 3D printing.

Much of the media hype surrounding 3D printing was exactly that: hype. But we are now approaching the end of that hype cycle, and 3D printing is stronger than ever. Most 3D-printing equipment vendors realize that not everyone needs or wants a home 3D printer. The desktop 3D-printing market has returned its focus to people who need and want to explore this technology.

# About This Book

*3D Printing For Dummies,* 3rd Edition, was written with the average reader in mind. It's a survey of the existing capabilities of additive manufacturing for both private and commercial purposes and a consideration of the possibilities of its future.

In this book, I review many current additive manufacturing technologies. Some are early uses of a technology or process with numerous limitations and caveats regarding their use. I also explore what types of desktop machines are available to buy and use straight away while also looking at those kits that require some assembly on the user's part. I dive into the software you will need (often as freely available open-source downloads) and then look at the tips and tricks needed to design for the 3D-printing process. This book won't make you an expert in all aspects of 3D printing, but it will give you a good overall starting point for learning the art of 3D printing and an opportunity to explore additive manufacturing systems. I hope that you'll be excited by the amazing potential of 3D printers — excited enough to buy your own desktop machine and learn how to design and make useful, practical, and fun objects for you to use and share.

Every time this book has been updated, it's always wonderful to see many of the things discussed as early concept ideas and research turned into realities, now being used in everyday life. 3D printing is truly changing the way we design and make products as individuals and extensively in wider world industries. It's a technology that's already touched your life even if you haven't realized it yet.

## Foolish Assumptions

You may find it difficult to believe that I've assumed anything about you; after all, I haven't even met you! Although most assumptions are indeed foolish, I made these assumptions to provide a starting point for this book.

- You have the ability to download or access programs in a web browser if you want to try some of the applications I review in this book. (It also helps to have an open mind and enthusiasm about the future and what additive manufacturing can produce.)
- If you want to buy and use a desktop 3D printer of your own, you need to be familiar with using hand tools like spanners and screwdrivers. We are still at the point where regular maintenance, servicing, and changing consumable items are a part of owning a 3D printer. You will also need a computer and software, much of which is free to download and use.
- You do not need any experience with 3D design. However, it helps to have a basic understanding of how a 3D model is just like any other digital model; we're just using that digital data to reproduce physical objects.
- It is important to understand that the current level of sophistication of 3D printers is close to the first dot-matrix paper printers. They're slow, and most are still limited to a single material; many offer only a single color or one type of plastic type at a time. Just as the evolution of dot-matrix printers led to inkjet and laser technologies that added speed and full color to paper printers, 3D printers are adding capabilities quickly. But please don't assume that all 3D printers will follow the same rapid adoption of full color and astonishing print speeds that 2D printers experienced in the past. That would be foolish indeed. We are still working with physically melting or solidifying resin materials and not at an atomic level of manufacturing.
- I try to use two common terms for separating a 3D printer you could use at home (desktop 3D printing) and many of the vastly more complicated and expensive machines used by industry (industrial 3D printers). The main difference between the two types, apart from the cost, is that industrial 3D printers tend to be able to use more robust materials such as metal and produce a higher level of detail, accuracy, or repeatability in the finished parts.
- I also don't expect you to know all about product design or the fundamental properties of materials. Where possible, I'll try to explain the most common materials used by both desktop and industrial 3D printers.
- Working with 3D printers is very rewarding, but you should learn how to adjust and tune your own desktop 3D printer. 3D printers are all different, so when things go awry you will be able to fix the issues yourself. It is not necessary to be a do-it-yourself handyman. However, a certain familiarity with basic tools and methods will help you to use your 3D printer, whether you assemble it yourself or buy a fully built and tested machine.

## Icons Used in This Book

As you read this book, you'll see icons in the margins that indicate material of interest (or not, as the case may be). This section briefly describes each icon in this book.

TIP

Tips are nice because they help you save time or perform some task without a lot of extra work. The tips in this book give you timesaving techniques or pointers to resources that you should check out to get the maximum benefit from 3D printing.

REMEMBER

Remember icons mark the information that's especially important to know. To extract the most important information in each chapter, just skim these icons.

TECHNICAL STUFF

The Technical Stuff icon marks information of a highly technical nature that you can normally skip.

WARNING

The Warning icon tells you to watch out! It marks important information that may save you headaches or keep you and your equipment from harm.

## Beyond the Book

In addition to what you're reading right now, this product comes with a free access-anywhere Cheat Sheet that covers the basics of 3D printing. There I've listed various 3D printers, control electronics, and aspects about the assembly of a RepRap 3D printer of your own. I also include common terms you'd come across in the software used in 3D printing and the definitions of common settings used by the model-processing software. This should all help you familiarize yourself with 3D printing as you journey through the book. To get this Cheat Sheet, simply go to `www.dummies.com/` and type **3D Printing For Dummies Cheat Sheet** in the search box.

## Where to Go from Here

The goal of this book is to get you thinking about 3D printing and the potential it offers in your own life, home, or work. We stand at the start of a new form of creative design and product creation, in which traditional mass manufacturing will give way to personalized, individualized, ecologically friendly, on-demand manufacturing close to home — or in the home. You don't have to read this book cover to cover, although you should find interesting and amazing items on each page. In any event, I hope that you take away dozens of ideas for new products and improvements to old ones made possible by 3D printers.

# 1

# Getting Started with 3D Printing

## IN THIS PART . . .

Explore the world of 3D printing, including many of the different types of additive manufacturing and their applications.

Discover current uses for the ever-growing spectrum of 3D-printing capabilities available today.

Examine options currently in existence for 3D printing.

Discover ways that you may be able to use additive manufacturing in personal and professional settings.

IN THIS CHAPTER

» Getting to know additive manufacturing

» Discovering applications for 3D printing

» Introducing RepRap

# Chapter 1

# Seeing How 3D Printers Fit into Modern Manufacturing

An amazing transformation is currently under way in manufacturing, across nearly all types of products — a transformation that promises that the future can be a sustainable and personally customized environment. In this fast-approaching future, everything we need — from consumer and industrial products to food production and even our bodies themselves — can be replaced or reconstructed rapidly and with very minimal waste. This transformation in manufacturing is not the slow change of progress from one generation of iPhone to the next. Instead, it's a true revolution, mirroring the changes that introduced the Industrial Age and then brought light and electricity to our homes and businesses. This *third Industrial Revolution* is all part of a much wider change in fully automated and intelligent-assisted global manufacturing, linking into what's now being called "the circular economy" or "Industry 4.0."

TIP

For a great introduction to what these terms *circular economy* and *Industry 4.0* actually mean, take a look at *Industry 4.0 and Circular Economy: Towards a Wasteless Future or a Wasteful Planet?* by Antonis Mavropoulos and Anders Waage Nilsen (also published by John Wiley & Sons).

New forms of manufacturing will give rise to new industries and allow for more efficient use of our dwindling natural resources. Like any truly fundamental change that spans all aspects of the global economy, the change will, by its very nature, be highly disruptive. But traditional, inefficient ways of producing new models of products have already given way to automated processes and precision-controlled equipment that was hard to imagine decades ago. The new technology behind this transformation is referred to as *additive manufacturing, 3D printing,* or *rapid prototyping*. Whatever you call this technology, in future decades, it will be used to construct everything from houses to jet engines, airplanes, food, and even replacement tissues and organs made from your own cells! Every day, new applications of 3D printing are being discovered and developed all over the world. Even in space, NASA is testing designs that will function in zero gravity and support human exploration of other planets, such as Mars. Hold on tight, because in the chapters ahead, we cover a lot of incredible, fantastic new technologies — and before the end, I show you how you can assemble, test, and run your own desktop 3D printer.

# Embracing Additive Manufacturing

What is additive manufacturing? It's a little like the replicators in the *Star Trek* universe, which allow the captain to order "tea, Earl Grey, hot" and see a cup filled with liquid appear fully formed and ready for consumption. We're not quite to that level yet, but today's 3D printers perform additive manufacturing by taking a 3D model of an object stored in a computer, translating it into a series of very thin layers, and then building the object one layer at a time, stacking material until the object is ready for use. (The "one layer at time" is the additive part.)

TIP

3D printers are much like the familiar desktop paper printers you already use at work or in your home to create copies of documents transmitted electronically or created on your computer, except that a 3D printer creates a solid 3D object layer-by-layer from a variety of materials rather than producing a flat paper document.

Since the time of Johannes Gutenberg, the ability to create multiple printed documents has brought literacy to the world. Today, when you click the Print button in a word processing application, you merge the functions of writers, stenographers, editors, layout artists, illustrators, and press reproduction workers into a single function that you can perform. Then, by clicking a few more buttons, you can post the document you created on the Internet and allow it to be shared, downloaded, and printed by others all over the world.

3D printing does exactly the same thing for objects. Designs and virtual 3D models of physical objects can be shared, downloaded, and then printed in physical form. It's hard to imagine what Johannes Gutenberg would have made of that.

## Defining additive manufacturing

Why is additive manufacturing called *additive*? Additive manufacturing works by bringing the design of an object — its shape — into a computer model and then dividing that model into separate layers that are stacked to form the final object. The process re-imagines a 3D object as a series of stackable layers that forms the finished object. (See Figure 1-1.) Whether this object is a teacup or a house, the process starts with the base layer and builds up additional layers until the full object is complete.

TECHNICAL STUFF

Before 3D printers were commonplace, another computer-controlled technique called subtractive manufacturing was developed. Almost exactly the opposite of 3D printing, this method cuts and mills a solid block of material — often metal — into the desired shape by the use of a computer program and series of instructions called GCODE. This same expanded instruction set is now also used for additive manufacturing.

An easy way to imagine the difference between additive and subtractive manufacturing is to think of building up a model by pressing and molding strips or coils of clay on top of each other, Alternatively, the same model could be carved from a block of stone (subtractive).

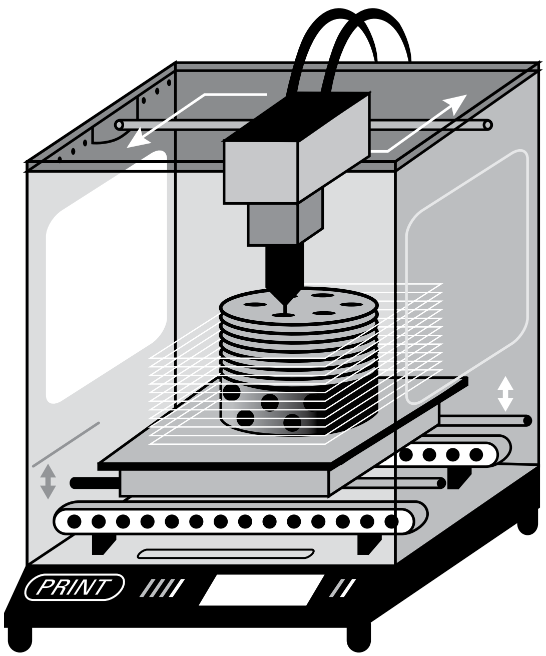



**FIGURE 1-1:** A line drawing showing how 3D printing works.

When we were young, many of us built structures like houses using toy bricks. We placed a row of bricks to form the outer walls and then added more rows until we reached the height we wanted. A 3D printer does pretty much the same thing — laying down an extrusion of material (most often molten plastic) to achieve the same starting perimeter and then adding layers upon layers on top of the cooled plastic underneath.

3D printers build up layers of material in a few ways: by fusing liquid polymers with a laser, binding small granular particles with a laser or a liquid binding material, or extruding melted materials in the same way that toothpaste is squeezed from a tube onto a toothbrush. 3D printers, however, perform their additive manufacturing with many more materials than just toothpaste or cheese in a can. They can fabricate items by using photo-curable plastic polymers, melted plastic filaments, metal powders, concrete, and many other types of materials — including biological cells that can form amazingly complex structures to replace, repair, and even augment our own bodies.

Just as the rings of a tree show the additive layers of the tree's growth each year, additive manufacturing builds objects one horizontal layer at a time in a vertical stack. In this way, you can create a small plastic toy and even a dwelling; someday you'll be able to create complete airplanes with interlocking parts. Today's research on conductive materials is already proving successful with early 3D-printed electronic circuits and embedded printed components being printed directly in an object instead of being installed later.

## Contrasting additive manufacturing with traditional manufacturing

How does this newfangled additive manufacturing compare to the traditional methods of subtractive production that have worked just fine since the first Industrial Revolution in the 1700s transformed manufacturing from hand production to automated production, using water and steam to drive machine tools? Why do we need to take up another disruptive technological shift after the second Industrial Revolution in the 1800s transformed the world through the increased use of steam-powered vehicles and the factories that made mass manufacturing possible?

In answering such questions, it helps to realize what the third Industrial Revolution that is coming our way actually entails: It means mass manufacturing and the global transfer of bulk goods will be set aside in favor of locally produced, highly personalized, individual production, which fits nicely with society's transition to a truly global phase of incremental local innovation.

The first Industrial Revolution's disruption of society was so fundamental that governments put in place trade restrictions in a desperate attempt to protect domestic wool textiles from power-woven cotton textiles being imported from other countries. The spinning jenny and automated flyer-and-bobbin looms allowed a small number of people to weave hundreds of yards of fabric every week; whereas hand weavers took months to card plant fibers or shorn hair, spin the material into thread, and weave many spools of thread into a few yards' worth of fabric. Suddenly, new industrial technologies such as the automated loom were putting weavers out of work, sparking the formation of the Luddite movement that tried to resist this transformation by smashing the textile machines they saw as destroying their livelihood. Fortunately, the capability of the new technologies to bulk produce clothing eventually won that argument, and the world was transformed.

A few years later, the second Industrial Revolution's disruption of society was even more pronounced, because automation provided alternatives not limited by the power of a man or horse, and steam power freed even massive industrial applications from their existence alongside rivers and water wheels, allowing them to become mobile. The difficulties traditional workers faced due to these new technologies are embodied in the tale of folk hero John Henry. As chronicled in the powerful folk song "The Ballad of John Henry," Henry proved his worth by outdigging a steam-driven hammer by a few inches' depth before dying from the effort. This song and many like it were heralded as proof of mankind's value in the face of automation. Yet the simple fact that the steam hammer could go on day after day without need for food or rest, long after John Henry was dead and gone, explains why that disruption has been adopted as the standard in the years since.

Here at the edge of the transformation that may one day be known as the third Industrial Revolution, the disruptive potential of additive manufacturing is obvious. Traditional mass manufacturing involves the following steps, which are comparatively inefficient:

1. Making products by milling, machining, or molding raw materials
2. Shipping these products all over the world
3. Refining the materials into components
4. Assembling the components into the final products in tremendous numbers to keep per-unit costs low
5. Shipping those products from faraway locations with lower production costs (and more lenient workers' rights laws)
6. Storing vast numbers of products in huge warehouses
7. Shipping the products to big-box stores and other distributors so they can reach actual consumers

Because of the costs involved, traditional manufacturing favors products that appeal to as many people as possible, preferring one-size-fits-most over customization and personalization. This system limits flexibility, because it's impossible to predict the actual consumption of products when next year's model is available in stores. The manufacturing process is also incredibly time-consuming and wasteful of key resources such as oil, and the pollution resulting from the transportation of mass-manufactured goods is costly to the planet.

## Machining/subtractive fabrication

Because additive manufacturing can produce completed products — even items with interlocking moving parts, such as bearings within wheels or linked chains — 3D-printed items require much less finishing and processing than traditionally manufactured items do. The traditional approach uses subtractive fabrication procedures such as milling, machining, drilling, folding, and polishing to prepare even the initial components of a product. The traditional approach must account for every step of the manufacturing process — even a step as minor as drilling a hole, folding a piece of sheet metal, or polishing a milled edge — because such steps require human intervention and the management of the assembly-line process, which, therefore, adds cost to the product.

TIP

Yes, fewer machining techs will be needed after the third Industrial Revolution occurs, but products will be produced very quickly, using far fewer materials. It's much cheaper to put down materials only where they're needed rather than to start with blocks of raw materials and mill away unnecessary material until you achieve the final form. Ideally, the additive process will allow workers to reimagine 3D-printed products from the ground up, perhaps even products that use complex open interior spaces that reduce materials and weight while retaining strength. Also, additive-manufactured products are formed with all necessary holes, cavities, flat planes, and outer shells already in place, removing the need for many of the steps involved in traditional fabrication.

## Molding/injection molding

Traditional durable goods such as the components for automobiles, aircraft, and skyscrapers are fabricated by pouring molten metal into casting molds or through extrusion at a foundry. This same technology was adapted to create plastic goods: Melted plastic is forced into injection molds to produce the desired product. Casting materials such as glass made it possible for every house to have windows and for magnificent towers of glass and steel to surmount every major city in the world.

Traditional mold-making, however, involves the creation of complex master molds, which are used to fashion products as precisely alike as possible. To create a second type of product, a new mold is needed, and this mold in turn can be used to create only that individual design over and over. This process can be time-consuming. 3D printers, however, allow new molds to be created rapidly so that a manufacturer can quickly adapt to meet new design requirements, to keep up with changing fashions, or to achieve any other necessary change. Alternatively, a manufacturer could simply use the 3D printer to create its products directly and modify the design to include unique features on the fly. General Electric currently uses this direct digital-manufacturing process to create 24,000 jet-engine fuel assemblies each year — an approach that can be easily changed mid-process if a design flaw is discovered simply by modifying the design in a computer and printing replacement parts. In a traditional mass-fabrication process, this type of correction would require complete retooling and lengthy delays.

## Understanding the advantages of additive manufacturing

Because computer models and designs can be transported electronically or shared for download from the Internet, additive manufacturing allows manufacturers to let customers design their own personalized versions of products. In today's interconnected world, the ability to quickly modify products to appeal to a variety of cultures and climates is significant.

In general, the advantages of additive manufacturing can be grouped into the following categories:

- Personalization
- Complexity
- Part consolidation
- Sustainability
- Recycling and planned obsolescence
- Economies of scale

The next few sections talk about these categories in greater detail.

### Personalization

Personalization at the time of fabrication allows additive-manufactured goods to fit each consumer's preferences more closely in terms of form, size, shape, design, and even color, as I discuss in later chapters.

The iPhone case, for example. (See Figure 1-2.) In no time, people within the 3D-printing community created many variations of this case and posted them to services such as the Thingiverse 3D object repository (`www.thingiverse.com`).

These improvements were rapidly shared among members of the community, who used them to create highly customized versions of the case.

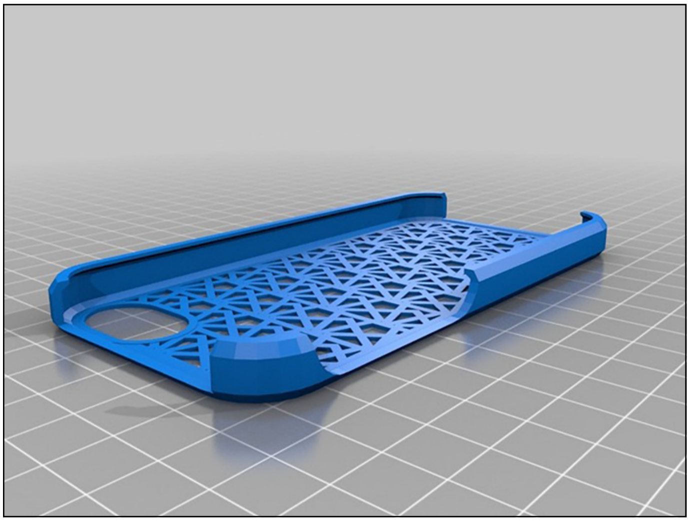
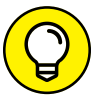


**FIGURE 1-2:** A free downloadable, 3D-printable phone case for the iPhone.

TECHNICAL STUFF

Sharing communities operate under what is known as Creative Commons licensing, which involves several copyright licenses developed by the nonprofit Creative Commons organization (`https://creativecommons.org/licenses/`), reserving some specific rights and waiving others to allow other creators to share and expand on the designs without the restrictions imposed by traditional copyright. In Part 4 of this book, I explain more about licensing and attribution.



TIP

If you use a 3D object file designed by someone else, take care to check what license the model is being distributed under; there may be restrictions on how you can use the file — printing may be allowed, for example, but modifications may not. Sharing the file may be okay, but selling a 3D-printed object made from the file may be restricted.

## Complexity

Because all layers of an object are created sequentially, 3D printing makes it possible to create complex internal structures that are impossible to achieve with traditional molded or cast parts. Structures that aren't load-bearing can have thin or even absent walls, with additional support material added during printing. If strength or rigidity are desired qualities, but weight is a consideration (as in the frame elements of race cars), additive manufacturing can create partially filled internal voids with honeycomb structures, resulting in rigid, lightweight products. Structures modeled from nature, mimicking items such as the bones of a bird, can be created with additive-manufacturing techniques to create product capabilities that are impossible to produce in traditional manufacturing. These designs are sometimes referred to as *organic*.

When you consider that this technology will soon be capable of printing entire houses, as well as the materials therein, you can see how easily it can affect more prosaic industries, such as moving companies. In the future, moving from one house to another may be a simple matter of transferring nothing more than a few boxes of personalized items (such as kids' drawings and paintings, Grandma's old tea set, and baby's first shoes) from one house to another. There may come a time when you won't need a moving company at all; you'll just contact a company that will fabricate the same house and furnishings (or a familiar one with a few new features) at the new location. That same company could reclaim materials used in the old building and furnishings as a form of full recycling.

## Sustainability

By allowing strength and flexibility to vary within an object, 3D-printed components can reduce the weight of products and save fuel. One aircraft manufacturer, for example, expects the redesign of its seat-belt buckles to save tens of thousands of gallons of aviation fuel across the lifetime of an aircraft. Also, by putting materials only where they need to be, additive manufacturing can reduce the amount of materials lost in postproduction machining, which conserves both money and resources.

TECHNICAL STUFF

Additive manufacturing allows the use of a variety of materials in many components, even the melted plastic used in printers such as the RepRap devices described in Chapter 11. Acrylonitrile butadiene styrene (ABS), with properties that are well known from use in manufacturing toys such as LEGO bricks, is commonly used for home 3D printing, but it's a petrochemical-based plastic. Environmentally conscious users could choose instead to use plant-based alternatives such as polylactic acid (PLA) to achieve similar results. Alternatives such as PLA are commonly created from corn, beets, or potato starch. Current research on producing industrial quantities of this material from algae may one day help reduce our dependence on petrochemical-based plastics and lower the need to use food-based crops.

Other materials — even raw materials — can be used. Some 3D printers are designed to print objects by using concrete or even sand as raw materials. Using nothing more than the power of the sun concentrated through a lens, Markus Kayser, the inventor of the Solar Sinter, fashions sand into objects and even structures. Kayser uses a computer-controlled system to direct concentrated sunlight precisely where needed to melt granules of sand into a crude form of glass, which he uses, layer by layer, to build up bowls and other objects. (See Figure 1-3.)

**FIGURE 1-3:** A glass bowl formed by passing sunlight through the Solar Sinter to fuse sand.

*Image courtesy of Markus Kayser*

## Recycling and planned obsolescence

The third Industrial Revolution offers a way to eliminate the traditional concept of planned obsolescence that's behind the current economic cycle. In fact, this revolution goes a long way toward making the entire concept of obsolescence obsolete. Comedian Jay Leno, who collects classic cars, uses 3D printers to restore his outdated steam automobiles to service, even though parts have been unavailable for the better part of a century. With such technology, manufacturers don't even need to inventory old parts; they can simply download the design of the appropriate components and print replacements when needed.

Instead of endlessly pushing next year's or next season's product lines (such as automobiles, houses, furniture, or clothing), future industries could well focus on retaining investment in fundamental components, adding updates and reclaiming materials for future modifications. In this future, if a minor component of a capital good such as a washing machine fails, a new machine won't need to be fabricated and shipped; the replacement will be created locally, and the original returned to functional condition for a fraction of the cost and with minimal environmental impact.