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3D Printing For Dummies®

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Learn to:

- Use 3D printing software, hardware, and tools
- Work with the different types of 3D printing processes and services
- Follow best practices for 3D printing
- Create your own RepRap 3D printer

Kalani Kirk Hausman
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3D Printing FOR DUMMIES®

A Wiley Brand

by Kalani Kirk Hausman
and
Richard Horne

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Contents at a Glance

Introduction 1

Part I: Getting Started with 3D Printing 7

Chapter 1: Seeing How 3D Printers Fit into Modern Manufacturing 9

Chapter 2: Exploring the Types of 3D Printing 23

Chapter 3: Exploring Applications of 3D Printing 41

Part II: Outlining 3D Printing Resources 61

Chapter 4: Identifying Available Materials for 3D Printing 63

Chapter 5: Identifying Sources for 3D-Printable Objects 81

Part III: Exploring the Business Side of 3D Printing...... 99

Chapter 6: Commoditizing 3D Printing 101

Chapter 7: Understanding 3D Printing's Effect on Traditional Lines of Business 117

Chapter 8: Reviewing 3D Printing Research 131

Part IV: Employing Personal 3D Printing Devices 143

Chapter 9: Exploring 3D-Printed Artwork 145

Chapter 10: Considering Consumer-Level 3D Printers 157

Chapter 11: Deciding on a RepRap of Your Own 169

Part V: Creating a RepRap 3D Printer 199

Chapter 12: Assembling Structural Elements 201

Chapter 13: Understanding RepRap Control Electronics 231

Chapter 14: Assembling the RepRap Extruder and RepRap Upgrades 265

Chapter 15: Identifying Software and Calibrating Your 3D Printer 295

Part VI: The Part of Tens 331

Chapter 16: Ten Ways That Rapid Prototyping Will Disrupt Traditional Manufacturing 333

Chapter 17: Ten Examples of Direct-Digital Manufacturing and Personalization 339

Chapter 18: Ten Impossible Designs Created Using Additive Manufacturing 345

Index 349

Table of Contents

Introduction 1

About This Book 1
Foolish Assumptions 2
Icons Used in This Book 2
How This Book Is Organized 3
Part I: Getting Started with 3D Printing 3
Part II: Outlining 3D Printing Resources 3
Part III: Exploring the Business Side of 3D Printing 3
Part IV: Employing Personal 3D Printing Devices 4
Part V: Creating a RepRap 3D Printer 4
Part VI: Parts of Tens 4
Beyond the Book 4
Where to Go from Here 5

Part I: Getting Started with 3D Printing 7

Chapter 1: Seeing How 3D Printers Fit into Modern Manufacturing 9

Embracing Additive Manufacturing 10
Defining additive manufacturing 11
Contrasting traditional manufacturing 12
Understanding the advantages of additive manufacturing 16
Exploring the Applications of 3D Printing 20
Working with RepRap 21

Chapter 2: Exploring the Types of 3D Printing 23

Exploring Basic Forms of Additive Manufacturing 24
Photopolymer 25
Granular 28
Lamination 31
Fused deposition modeling 33
Recognizing Specialized Forms of Additive Manufacturing 34
Manufacturing with a variety of materials 34
Printing in color 35
Seeing the Limitations of Current Technologies 37
Considering fabrication rates 37
Exploring size constraints 38
Identifying object design constraints 39
Understanding material restrictions 39

Chapter 3: Exploring Applications of 3D Printing 41

Creating Objects Directly Using 3D Printing Today 42
Rapid prototyping 42
Direct digital fabrication 44
Restoration and repair 45

Fabricating Tomorrow Using 3D Printing 47
Household goods 48
Buildings 49
Extreme recycling 51
Examining Molding and Casting through 3D Printing 52
Lost-material casting 53
Sintered metal infusion 53
Applying Artistic Touches and Personalization 53
Medical implants 54
Item personalization 55
Clothing and textiles 56
Deploying Technology to Strategic Locations 58
Military fabrication 58
In space 59

Part II: Outlining 3D Printing Resources 61

Chapter 4: Identifying Available Materials for 3D Printing 63

Enumerating Extruded Materials 64
Thermoplastics 64
Experimental materials 69
Extruded alternatives 69
Identifying Granular Materials 70
Plastic powders 71
Sugar and salt 71
Metal powders 73
Sand and natural granular materials 73
Exploring Photo-Cured Resins 74
Understanding Bioprinting 74
Bioprinting food and animal products 76
Replacement tissues and organs 76
Identifying Alternative Materials 77
Recycled materials 77
Storing food 79
Caring for people 79

Chapter 5: Identifying Sources for 3D-Printable Objects 81

Exploring Object Repositories 82
Vendor repositories 82
Community repositories 84
Designing in the Computer 85
Scanning Objects 88
Capturing Structure from Photographs 92
Preparing Models for Printing 94
3D model viewers 96
Mesh modelers 97
Mesh repairers 97

Part III: Exploring the Business Side of 3D Printing 99

Chapter 6: Commoditizing 3D Printing 101

Democratizing Manufacturing 101
Derived designs 102
Curated artifacts 102
Creating models 103
Crafting Personal Storefronts 106
Creating a unique design 107
Fabricating a unique product on demand 109
Creating Impossible Objects 111
Building New Tools 112
Moving beyond solid blocks 112
Creating the tool that will create the tool 114

Chapter 7: Understanding 3D Printing's Effect on Traditional Lines of Business 117

Transforming Production 117
Displacing the production line 118
Abbreviating the manufacturing chain 120
Providing local fabrication 121
Eliminating traditional release cycles 122
Challenging Intellectual Property Laws 122
Threatening IP protections 123
Assigning legal liability 125
Leveraging Expired Patents 126
Innovating around intellectual property 127
Protecting intellectual property rights 128
Imposing Ethical Controls 129

Chapter 8: Reviewing 3D Printing Research 131

Building Fundamental Technologies 131
Crafting educational tools 132
Expanding 3D printing options 133
3D-printed electronics 134
Creating Functional Designs 135
Drones, robots, and military applications 136
Von Neumann machines 136
Expanding Material Selection 137
Providing for Long Space Voyages 138
Creating Medical Opportunities 140

Part IV: Employing Personal 3D Printing Devices 143

Chapter 9: Exploring 3D-Printed Artwork 145

Adorning the Body 145
Personalizing Our Environment 147
Returning to Personal Creation 148
Visualizing the Abstract 151

Chapter 10: Considering Consumer-Level 3D Printers 157

Examining Cartesian 3D Printers 158
Exploring Delta Options 161
Understanding Polar Fabrication 164
Building Emerging Alternatives 166

Chapter 11: Deciding on a RepRap of Your Own 169

Evaluating Your 3D-Printing Needs 169
Do I want a RepRap or another 3D printer? 170
Do I buy a ready-built 3D printer or use a kit? 171
Open, Closed, and Licensing 172
Selecting a 3D Printer Design 175
RepRap designs 175
Home 3D-printer kits 179
The experimental designs 182
Further machine arrangements 184
Choosing Print Media 184
Thermoplastic 184
PLA / PHA plastic 185
ABS 189
Paste 189
Identifying Components 190
Structural framework 191
The extruder 191
Build plate 194
Control electronics 195
Software 196

Part V: Creating a RepRap 3D Printer 199

Chapter 12: Assembling Structural Elements 201

Locating Materials 201
Kits 202
Self-sourcing 204
Printing your own 204
eBay 205
Obtaining the Printed Parts for Machine Assembly 205
Understanding the Machine Motion 207
Z-axis motion 208
X and Y axis motion 210
Building the Frame Structure 212
Assembling the Prusa i3 Y Axis Frame 217
Assembling the Moving Axis 218
Assembling the Prusa i3 moving Y axis 221
Assembling the Prusa i3 moving Z and X axes 223
Joining the Z, X and Y axis all together 227
Sensing the Home Position 227

Chapter 13: Understanding RepRap Control Electronics 231

Overview of RepRap Electronics....231
RAMPS....232
RAMBo....233
Sanguinololu....233
Minitronics....234
RUMBA....234
Elefu-RA V3....235
Megatronics....237
Adding Electronics to Your RepRap 3D Printer....238
Preparing for electronics assembly....238
Modular Components, Sensors,and Motors....245
Computer-free printing....245
Using motor-driver modules....246
Selecting your position sensing modules....248
Identifying power-supply requirements....250
Adding fans and lighting....252
RepRap Wiring and Connections....254
Firmware Configuration....256
Prusa i3 firmware configuration....256
Uploading the Marlin firmware to the RAMPS electronics....262

Chapter 14: Assembling the RepRap Extruder and RepRap Upgrades. 265

Thermoplastic Extrusion....265
Prusa i3 Extruder and Hot-End Assembly....272
Fitting the filament drive to the motor shaft....273
Assembling the extruder idler pressure bearing....273
Fitting the J-head hot-end....274
Syringe and Paste-Based Extrusion....275
Multi-Color Printing....279
Extruder Operation and Upgrades....285
Fixing a blocked hot-end or extruder....287
Acquiring an assortment of extruders....289
Cooling extruders with fans....291

Chapter 15: Identifying Software and Calibrating Your 3D Printer. 295

3D Design Software and Model Resources....295
Using design software....301
Model verification with Netfabb....303
Working with Slic3r....304
Configuring Slic3r....304
Model processing with Slic3r....307
Calibrating Your 3D Printer....314
Leveling your print bed....316
Tuning your hot-end temperature control....318
Extruder distance calibration....318
3D-Printing Objects....322
Printing vases, pots, and cups....325
Printing large single-piece objects....328

Printing tiny or highly detailed objects 328
Printing many objects at once 329
Improving print quality 329

Part VI: The Part of Tens 331

Chapter 16: Ten Ways That Rapid Prototyping Will Disrupt Traditional Manufacturing 333

Reducing Time to Market 333
Eliminating Mass Manufacturing 334
Displacing Transportation Industries 334
Consuming Alternate Materials 335
Reducing Material Requirements 335
Going Green 335
Curtailing Planned Obsolescence 336
Eliminating One-Size-Fits-Most 336
Crafting What You Wish 337
Providing Basic Necessities 338

Chapter 17: Ten Examples of Direct-Digital Manufacturing and Personalization 339

Producing 3D-Printed Food 339
Printing Tissues and Organs 340
Fashioning Biological Replicas 340
Crafting Clothing and Footwear 340
Customizing Artwork 341
Making Hollywood Spectacular 342
Creating Structures 342
Reaching Beyond the Sky 342
Constructing Robots 343
Printing 3D Printers 343

Chapter 18: Ten Impossible Designs Created Using Additive Manufacturing 345

Personalized Objects 345
Medical Implants 345
Self-Deploying Robots 346
Printed Aircraft 347
On-Demand, On-Site Manufacturing 347
Custom Objects Created in Space 347
Printed Finger Foods 347
Locally Fabricated Items 348
Body Parts 348
Custom Drugs 348

Index 349

Introduction

Unlike traditional manufacturing which involves injecting material into a pre-formed mold or removing material from base material objects, additive manufacturing (3D printing) starts with a virtual 3D model that is transformed into solid form one layer at a time. Each layer is built on top of the layer before, creating a solid form representing the virtual 3D model in all of its complexity and detail without requiring additional forms of machining and treatment necessary in traditional forms of manufacturing.

Although 3D printers have been available for years, only recently have they become available at a price most home users can afford. Because they are becoming more widespread, and because innovations in this technology now permit the creation of products in a much wider array of materials — and even combinations of materials — 3D printing is poised to make an impact on average consumers in a big way. *3D Printing For Dummies* 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.

About This Book

In this book, we review many different technologies currently available for additive manufacturing. These are early-generation technologies with numerous limitations and caveats to their use and the selection of materials available for use in 3D printers in both commercial-scale and consumer-grade options. We also explore the process by which you can build your own 3D printer using the open-source self-REPlicating RAPid-prototyping (RepRap) family of designs. This will not make you an expert in all aspects of 3D printing, but will provide you with an opportunity to explore the many types of additive manufacturing systems. Hopefully, you will be excited by the amazing potential of 3D printers – excited enough to build your own printer and start sharing your own creativity with friends and family!

Foolish Assumptions

You might find it difficult to believe that we have assumed anything about you — after all, we haven't even met you yet! Although most assumptions are indeed foolish, I made these assumptions to provide a starting point for the book.

It is important to understand that the current level of sophistication in 3D printers is close to the first automated looms that found their way into factory settings in the early 1700's. Commercial 3D printers have less variance, but for consumer-grade equipment a certain amount of "tinkering" will be needed from time to time to keep things running. Working with 3D printers is very rewarding, but you should learn how to adjust and tune your home or office printer so that when things go awry you will be able to fix them yourself. It is not necessary to be a do-it-yourself handyman, but a certain familiarity with basic tools will help you when you build, assemble, or use your own 3D printer.

The book assumes you will have the ability to download or access programs in a web browser if you want to try out some of the applications we review, such as TinkerCAD. However, it is not necessary to have a computer of your own to enjoy this book — all you need is an open mind and enthusiasm about the future and what additive manufacturing can produce!

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.

WARNING!

I don't want to sound like an angry parent or some kind of maniac, but you should avoid doing anything marked with a Warning icon.

Whenever you see this icon, think *advanced* tip or technique. You might find these tidbits of useful information just too boring for words, or they could contain the solution you need. Skip these bits of information whenever you like.

If you don't get anything else out of a particular chapter or section, remember the material marked by this icon. This text usually contains an essential process or a bit of information that you must know.

How This Book Is Organized

We divide this book into several parts based on topic. The following sections describe what you can expect to find in each part.

Part I: Getting Started with 3D Printing

Part I explores fundamental 3D printing technologies and options for additive manufacturing within the current state of the art. It is intended to provide you with a general overview of what additive manufacturing provides today.

Part II: Outlining 3D Printing Resources

Part II expands your exploration of additive manufacturing to include different materials that can be used in current and near-future 3D printing technologies, and examines options available to create new virtual 3D object models to be printed.

Part III: Exploring the Business Side of 3D Printing

Part III examines the potential for disruption in existing businesses and new business opportunities that becomes possible through new additive manufacturing capabilities. We also explore current lines of research, building new options to the current state of the art.

Part IV: Employing Personal 3D Printing Devices

Part IV explores consumer-level 3D printer options including both commercial and open-source alternatives available for home and small business uses in fabricating creative and artistic designs exploring this magnificent new capability. We discuss considerations you should take into account when building your own RepRap-style 3D printer.

Part V: Creating a RepRap 3D Printer

Part V walks you through the creation, assembly, and calibration of a RepRap style printer.

Part VI: Part of Tens

Part VI offers lists of ten interesting, disruptive, or impossible (in traditional manufacturing) applications of additive manufacturing.

Beyond the Book

A lot of extra content that you won't find in this book is available at `www.dummies.com`. Go online to find the following:

- **Online articles covering additional topics at**

  `www.dummies.com/extras/3dprinting`

  Here you'll find examples of how to use available software to design and prepare 3D models for printing and to set up your own personal digital storefront using free services already in place.

- **The Cheat Sheet for this book is at**

  `www.dummies.com/cheatsheet/3dprinting`

  Here you'll find a roadmap to additive manufacturing and the construction of your own RepRap-style 3D printer.

- **Updates to this book, if we have any, are also available at**

  `www.dummies.com/extras/3dprinting`

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 Industrial Age, where traditional mass manufacturing will give way to personalized, individualized, ecologically-friendly and on-demand manufacturing close to home. You do not have to read this book cover-to-cover, although I think you will find interesting and amazing items on each page. In any event, we hope you walk away with dozens of ideas for improvements, uses and new capabilities made possible by the emerging capabilities of 3D printers.

Part I

Getting Started with 3D Printing

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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 alternatives available today.
- Examine alternatives currently in existence for 3D printing.
- Discover ways that you may be able to use additive manufacturing in personal and professional settings.

Chapter 1

Seeing How 3D Printers Fit into Modern Manufacturing

In This Chapter

- Embracing additive manufacturing
- Defining additive manufacturing
- Contrasting traditional manufacturing
- Recycling and planned obsolescence
- Exploring the application of 3D printing

An amazing transformation is currently under way in manufacturing, across nearly all types of products — a transformation that promises to remake the future into a sustainable and personally customized environment. In this fast-approaching future, everything we need — from products to food, and even our bodies themselves — can be replaced or reconstructed rapidly and with very minimal waste. This is not the slow change of progress from one generation of iPhone to the next, but instead a true revolution, mirroring the changes that introduced the world to the Industrial Age and then bought light and electricity to our homes and businesses.

This will not be a "bloodless coup" by any means; any truly fundamental change that spans all aspects of the global economy will, by its nature, be disruptive. But traditional inefficient ways of producing the next year's model will surely give way to entirely new opportunities impossible to imagine before. The technology behind this transformation is referred to as *additive manufacturing, 3D printing,* or *direct digital manufacturing.*

By whatever name, in the coming decade this technology 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. And even in space: NASA is testing designs that will function in zero gravity, on the airless moon, and even to support human exploration of other planets like Mars. (See Figure 1-1 for a glimpse.) Hold on tight, because in the chapters ahead we cover a lot of incredibly new and fantastic technologies — and before the end, we show you how you can get involved in this amazing transformation yourself by building and using a 3D printer at home.

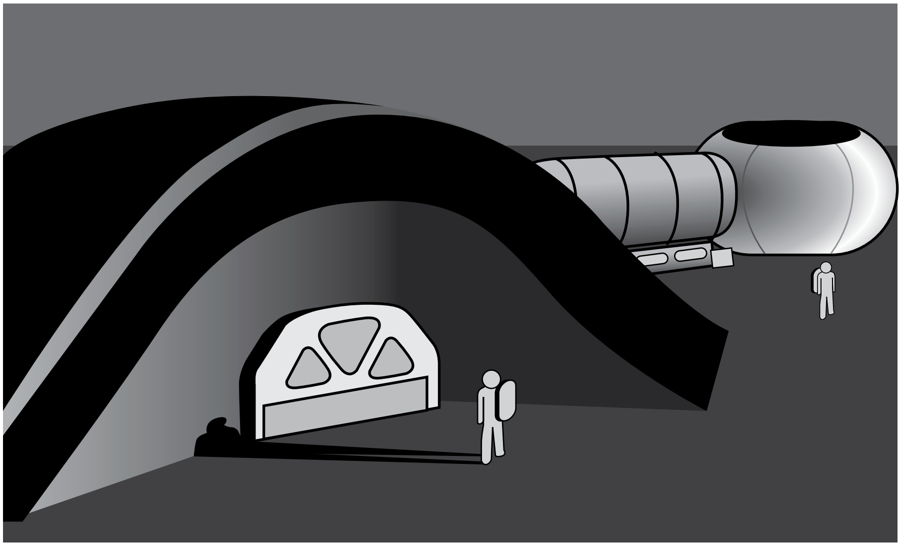

Figure 1-1: A line drawing of NASA's planned 3D-printed lunar construction.

Embracing Additive Manufacturing

So, what is "additive manufacturing," you might ask? Additive manufacturing is a little like the "replicators" in the *Star Trek* universe, which allow the captain to order "Tea, Earl Grey, hot" and have a cup filled with liquid appear fully formed and ready for consumption. We are not quite to that level, but today's 3D printers perform additive manufacturing by taking a 3D model of a 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 up material until the object is ready for use.

TIP: 3D printers are much like the familiar desktop printer 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 three-dimensional object out of a variety of materials, not just a simple paper document.

Since the time of Johannes Gutenberg, creating multiple printed documents has brought literacy to the world. Today, when you click the Print button in a word processor application, you merge the functions of writers, stenographers, editors (spellcheck), layout, illumination (coloring and adding in images), and press reproduction all into a single task, and with the click of a few more buttons, you can post the document you create onto the Internet and allow it to be shared, downloaded, and printed out by others all over the world.

3D printing does the exact same thing for objects: Designs and virtual 3D models for physical objects can be shared, downloaded, and then printed out into 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, then dividing that model into separate layers that can stack atop another to form the final object. It reimagines a three-dimensional object as a series of stackable layers that, when added together, forms the finished object. (See Figure 1-2.) Whether this object is a tea cup or a house, the process starts with the base layer and then builds up each additional layer until the full object has been completed.

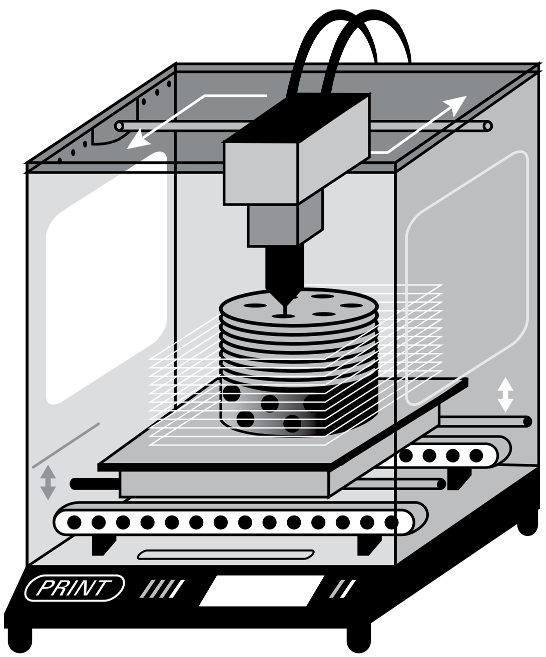

Figure 1-2: A line drawing of how 3D printing works.

My children did this before they ever saw my first 3D printer. They discovered they could use crackers and cheese spray for more than just a snack — they could build towers and grand designs simply by layering crackers and cheese on top of each other. These edible structures show the potential in additive manufacturing. Each cracker was given a personalized application of cheese to spell out names, draw designs, and even to build shapes and support tiny pyramids. The resulting snacks were both unique and also customized to exactly the design each child wanted.

3D printers build up layers of material in a few different ways: Either they fuse liquid polymers with a laser, bind small granular particles using a laser or a liquid binding material, or they extrude melted materials out like a tube of toothpaste squeezed onto a toothbrush. However, 3D printers perform their additive manufacturing using many more materials than just toothpaste or cheese spray. They can fabricate items using photo-curable plastic polymers, melted plastic filament, metal powders, concrete, and many other types of material — 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 growth to the tree each year, additive manufacturing builds up objects one layer at a time. In this way we can create a small plastic toy, a whole car, and very soon an entire house (with all of its furnishings), or even complete airplanes with interlocking parts. Research today on conductive materials suggests that wires will soon become just another part of the additive manufacturing process, by allowing them to be printed directly into an object itself instead of having to be installed later.

Contrasting traditional manufacturing

How does this additive manufacturing compare to the traditional methods of production that have worked just fine since the First Industrial Revolution in the 1700's 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 1800's transformed the world through the increased use of steam-powered vehicles and the factories that made mass manufacturing possible? Today, we stand at the opening moment of the next transformation, a Third Industrial Revolution, where mass manufacturing and global transfer of bulk goods will be set aside in favor of locally-produced and highly personalized individual production fitting society's transition to a truly global phase of continuous self-upgrade and incremental local innovation.

The First Industrial Revolution's disruption of society was so fundamental that governments had to pass laws to protect domestic wool textile production in England against new power-woven cotton textiles being imported from the East Indies. 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 then weave many spools of thread into a few yards' worth of fabric. Suddenly, these new industrial technologies like the automated loom shown in Figure 1-3 were putting weavers out of work, sparking the formation of the Luddite movement that tried to resist this transformation. Fortunately, the capability for the new technologies to provide clothes to families eventually won that argument and the world was transformed.

Figure 1-3: An example from past industrial revolutions.

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, and allowed them to become mobile. The difficulties traditional workers faced with these new technologies are embodied in the tale of folk hero John Henry, chronicled in the powerful folk song "The Ballad of John Henry," who 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, and 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, tells the tale of 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 ways of mass manufacturing, which makes products by milling, machining, or molding raw materials; shipping these materials all over the world; refining the materials into components; assembling the components into the final products in tremendous numbers to bring per-unit costs down; shipping those products from faraway locations with lower production costs (and more lenient workers' rights laws); storing vast numbers of products in huge warehouses; and finally shipping the products to big-box stores and other distributers so they can reach actual consumers, is comparatively inefficient in the extreme. (See Figure 1-4.)

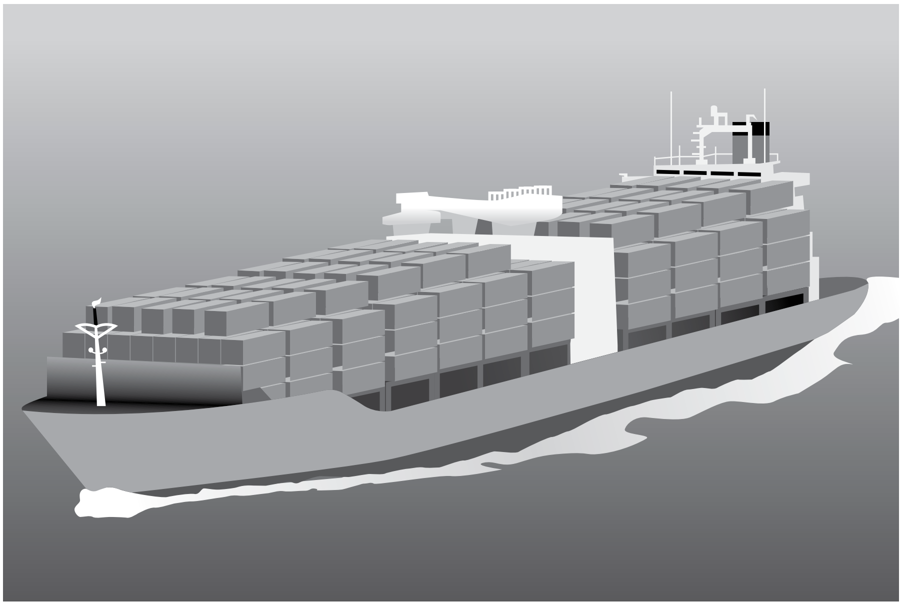

Figure 1-4: Cargo transportation required for traditional mass-manufactured goods.

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 limits flexibility, because it is impossible to predict what the actual consumption of products will look like by the time next year's model is available in stores. This process is also incredibly time-consuming and wasteful of key resources like 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. 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 management of the assembly-line process — which therefore adds cost to the end product.

Yes, this means that fewer machining techs will be needed after the Third Industrial Revolution occurs, but it also means that products can 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 you to reimagine 3D-printed products from the ground up, perhaps even allowing you to use complex open interior spaces that reduce materials and weight while retaining strength. And 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 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 molds or through tooled dies at a foundry. This same technology was adapted to create plastic goods: Melted plastic is forced into injection molds to produce the desired end product. Molding 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.

However, traditional mold-making involves the complex creation of 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, which can in turn be used to create only that individual design over and over. This can be a time-consuming process. 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. Or, 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. This direct digital manufacturing process is currently being used by GE to create 24,000 jet-engine fuel assemblies each year, an approach that can be easily changed mid-process if a design flaw is later discovered, simply by modifying the design in a computer and printing out replacement parts — something that would require complete retooling in a traditional mass-fabrication process.

Understanding the advantages of additive manufacturing

Because computer models and designs can be transported electronically or shared for download across 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 not insignificant.

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

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

The next few sections talk about these in greater detail.

Personalization

Personalization at the time of fabrication allows additive-manufactured goods to fit each individual consumer's preferences more closely — in terms of form, materials, design, or even coloring, as we discuss in later chapters.

Nokia, for example, recently released a 3D-printable case design for its Lumina 820 phone, making it available for free download and modification using the Creative Commons licensing model. (See Figure 1-5.) In no time, people within the 3D-printing community created many different variations of this case and posted them to services like the Thingiverse 3D object repository. These improvements were rapidly shared among members of the community, who used them to create highly customized versions of the case, and Nokia gained value in the eyes of its consumer base through this capability.

Creative Commons Licensing refers to several copyright licenses developed by the nonprofit Creative Commons organization to allow designers to share their designs with others, reserving specific rights and waiving others to allow other creators to share and expand on their designs without complex formal copyright licensing for traditional intellectual property controls.

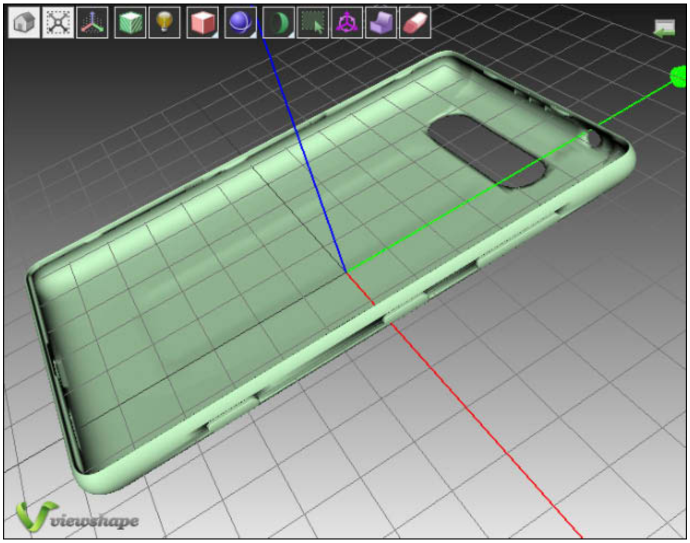

Figure 1-5: The free downloadable, 3D-printable phone case from Nokia.

Complexity

Because every layer of an object is created sequentially, 3D printing makes it possible to create complex internal structures that would be impossible to achieve with traditional molded or cast parts. Structures that are not load-bearing can have walls that are thin or even absent altogether, with additional support material added elsewhere 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 alternatives. Structures modeled from nature, mimicking (say) the bones of a bird, can be created using additive manufacturing techniques to create wholly new product capabilities not possible in traditional manufacturing.

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. Consider moving companies — in the future, moving from one house to another may be a simple matter involving transferring nothing more than a few boxes of personalized items (kid's drawings and finger-painting, Grandma's old tea set, and baby's first shoes) from one house to another. There may come a time when we don't need a moving company; we'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 previous 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 — for one aircraft manufacturer, for example, just the redesign of its seatbelt buckles is estimated to save tens of thousands of liters of aviation fuel across the lifetime of an aircraft. And by putting down materials only where they will need to be, additive manufacturing can allow a reduction in the amount of materials lost in post-production machining, which will conserve both money and resources.

Additive manufacturing also allows for the use of a variety of materials for many components, even for the melted plastic used in printers like the RepRap device we show you how to build later in this book. Acrylonitrile butadiene styrene (ABS), with properties that are well known from its use in the manufacture of toys like the LEGO brick, is commonly used for home 3D printing, but it is 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 or beets; however, the current research into producing industrial quantities of this material from algae may one day help reduce our dependence on petrochemical-based plastics.

Additionally, other materials — even raw materials — can be used. Some 3D printers are designed to print out objects 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 1-6.)

Recycling and planned obsolescence

The Third Industrial Revolution offers a way to eliminate the traditional concept of planned obsolescence that is behind the current economic cycle. In fact, this revolution goes a long way toward making the entire concept of "obsolescence" obsolete. Comedian Jay Leno, for instance, who collects old 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 would not even need to store copies of old parts; they would simply download the appropriate component design and print out a replacement when needed.

3D printers take advantage of sustainable construction methods, but beyond that, they can allow manufacturers to re-use existing materials and components, with personalized and customizable attributes added to retain consumer interest. This could easily impact the cycle of reinvestment for