

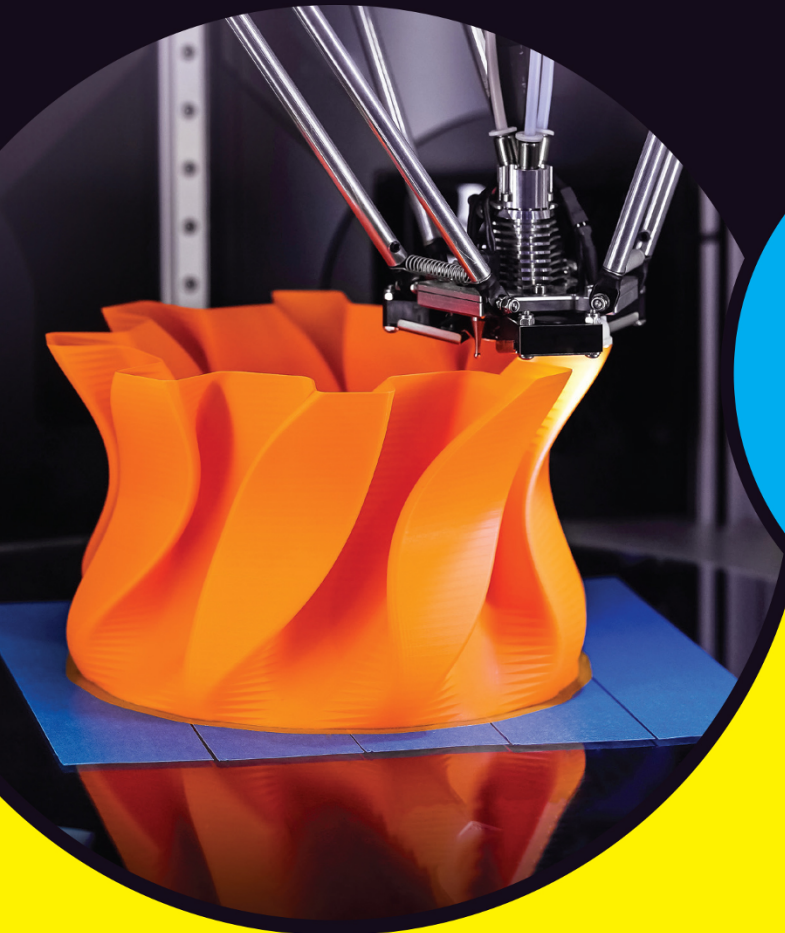
LEARNING MADE EASY



3rd Edition

3D Printing

for
dummies[®]
A Wiley Brand



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

Published by: **John Wiley & Sons, Inc.**, 111 River Street, Hoboken, NJ 07030-5774, www.wiley.com

Copyright © 2024 by John Wiley & Sons, Inc., Hoboken, New Jersey

Published simultaneously in Canada

No part of this publication may be reproduced, stored in a retrieval system or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, scanning or otherwise, except as permitted under Sections 107 or 108 of the 1976 United States Copyright Act, without the prior written permission of the Publisher. Requests to the Publisher for permission should be addressed to the Permissions Department, John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, (201) 748-6011, fax (201) 748-6008, or online at <http://www.wiley.com/go/permissions>.

Trademarks: Wiley, For Dummies, the Dummies Man logo, Dummies.com, Making Everything Easier, and related trade dress are trademarks or registered trademarks of John Wiley & Sons, Inc. and may not be used without written permission. All other trademarks are the property of their respective owners. John Wiley & Sons, Inc. is not associated with any product or vendor mentioned in this book.

LIMIT OF LIABILITY/DISCLAIMER OF WARRANTY: WHILE THE PUBLISHER AND AUTHORS HAVE USED THEIR BEST EFFORTS IN PREPARING THIS WORK, THEY MAKE NO REPRESENTATIONS OR WARRANTIES WITH RESPECT TO THE ACCURACY OR COMPLETENESS OF THE CONTENTS OF THIS WORK AND SPECIFICALLY DISCLAIM ALL WARRANTIES, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. NO WARRANTY MAY BE CREATED OR EXTENDED BY SALES REPRESENTATIVES, WRITTEN SALES MATERIALS OR PROMOTIONAL STATEMENTS FOR THIS WORK. THE FACT THAT AN ORGANIZATION, WEBSITE, OR PRODUCT IS REFERRED TO IN THIS WORK AS A CITATION AND/OR POTENTIAL SOURCE OF FURTHER INFORMATION DOES NOT MEAN THAT THE PUBLISHER AND AUTHORS ENDORSE THE INFORMATION OR SERVICES THE ORGANIZATION, WEBSITE, OR PRODUCT MAY PROVIDE OR RECOMMENDATIONS IT MAY MAKE. THIS WORK IS SOLD WITH THE UNDERSTANDING THAT THE PUBLISHER IS NOT ENGAGED IN RENDERING PROFESSIONAL SERVICES. THE ADVICE AND STRATEGIES CONTAINED HEREIN MAY NOT BE SUITABLE FOR YOUR SITUATION. YOU SHOULD CONSULT WITH A SPECIALIST WHERE APPROPRIATE. FURTHER, READERS SHOULD BE AWARE THAT WEBSITES LISTED IN THIS WORK MAY HAVE CHANGED OR DISAPPEARED BETWEEN WHEN THIS WORK WAS WRITTEN AND WHEN IT IS READ. NEITHER THE PUBLISHER NOR AUTHORS SHALL BE LIABLE FOR ANY LOSS OF PROFIT OR ANY OTHER COMMERCIAL DAMAGES, INCLUDING BUT NOT LIMITED TO SPECIAL, INCIDENTAL, CONSEQUENTIAL, OR OTHER DAMAGES.

For general information on our other products and services, please contact our Customer Care Department within the U.S. at 877-762-2974, outside the U.S. at 317-572-3993, or fax 317-572-4002. For technical support, please visit <https://hub.wiley.com/community/support/dummies>.

Wiley publishes in a variety of print and electronic formats and by print-on-demand. Some material included with standard print versions of this book may not be included in e-books or in print-on-demand. If this book refers to media such as a CD or DVD that is not included in the version you purchased, you may download this material at <http://booksupport.wiley.com>. For more information about Wiley products, visit www.wiley.com.

Library of Congress Control Number: 2023943991

ISBN: 978-1-394-16947-4 (pbk); 978-1-394-16948-1 (ebk); 978-1-394-16949-8 (ebk)

Contents at a Glance

Introduction	1
Part 1: Getting Started with 3D Printing	5
CHAPTER 1: Seeing How 3D Printers Fit into Modern Manufacturing.	7
CHAPTER 2: Exploring the Types of 3D Printing.	19
CHAPTER 3: Exploring Applications of 3D Printing	31
Part 2: Outlining 3D-Printing Resources	47
CHAPTER 4: Identifying Available Materials for 3D Printing	49
CHAPTER 5: Identifying Sources and Communities for 3D-Printable Objects	67
Part 3: Exploring the Business Side of 3D Printing	83
CHAPTER 6: 3D Printing for Everyone	85
CHAPTER 7: Understanding 3D Printing's Effect on Traditional Lines of Business.	97
CHAPTER 8: Reviewing 3D-Printing Research.	107
Part 4: Employing Personal 3D-Printing Devices	119
CHAPTER 9: Exploring 3D-Printed Artwork.	121
CHAPTER 10: Considering Consumer-Level Desktop 3D Printers	129
CHAPTER 11: Deciding on a 3D Printer of Your Own	157
Part 5: Understanding and Using Your 3D Printer	197
CHAPTER 12: Assembling Kits and Reviewing Machine Setup.	199
CHAPTER 13: Understanding 3D Printer Control Electronics.	219
CHAPTER 14: Understanding, Using, and Servicing 3D Printers	251
CHAPTER 15: Identifying Software and Calibrating Your 3D Printer	293
CHAPTER 16: Refining the Design and 3D-Printing Process.	337
Part 6: The Part of Tens	371
CHAPTER 17: Ten Examples of Direct Digital Manufacturing and Personalization	373
CHAPTER 18: Ten Impossible Designs Created Using Additive Manufacturing	379
Index	385

Table of Contents

INTRODUCTION	1
About This Book	2
Foolish Assumptions	3
Icons Used in This Book	4
Beyond the Book	4
Where to Go from Here	4
 PART 1: GETTING STARTED WITH 3D PRINTING	 5
 CHAPTER 1: Seeing How 3D Printers Fit into Modern Manufacturing	 7
Embracing Additive Manufacturing	8
Defining additive manufacturing	9
Contrasting additive manufacturing with traditional manufacturing	10
Understanding the advantages of additive manufacturing	13
Exploring the Applications of 3D Printing	18
 CHAPTER 2: Exploring the Types of 3D Printing	 19
Exploring Basic Forms of Additive Manufacturing	19
Photopolymers	20
Granular powders	24
Laminates	27
Filament-based production	27
Understanding the Limitations of Current Technologies	28
Considering fabrication rates	28
Exploring size constraints	29
Identifying object design constraints	29
Understanding material restrictions	30
 CHAPTER 3: Exploring Applications of 3D Printing	 31
Looking at Current Uses of 3D Printing	32
Rapid prototyping	32
Direct digital fabrication	33
Restoration and repair	34
Designing for the Future with 3D Printing	36
Household goods	36
Buildings	36
Bridges	39

Examining Molding and Casting through 3D Printing	39
Lost-material casting.....	40
Sintered metal infusion	40
Applying Artistic Touches and Personalization	41
Medical implants	41
Biological implants (organs).....	42
Item personalization	42
Clothing and textiles	44
Customizing Designs on the Fly.....	45
Military operations	45
Space.....	46
PART 2: OUTLINING 3D-PRINTING RESOURCES	47
CHAPTER 4: Identifying Available Materials for 3D Printing	49
Exploring Extruded Materials	50
Thermoplastics	52
Experimental materials.....	56
Extruded alternatives	58
Identifying Granular Materials.....	59
Plastic powders	59
Sugar and salt	59
Metal powders.....	60
Sand and natural granular materials	60
Exploring Photo-Cured Resins.....	62
Understanding Bioprinting	62
Bioprinting food and animal products.....	63
Replacement tissues and organs	64
Identifying Other Uses for Materials	65
Recycling materials	65
Sustainable large-scale 3D printing with local materials.....	66
Producing food	66
Caring for people.....	66
CHAPTER 5: Identifying Sources and Communities for 3D-Printable Objects	67
Exploring Object Repositories	68
Vendor repositories.....	68
Community repositories.....	69
Designing in the Computer	70
Scanning Objects.....	73
Capturing Structure from Photographs.....	77

Preparing Models for Printing	79
3D model viewers	80
Mesh modelers	81
Mesh repairers.	81
PART 3: EXPLORING THE BUSINESS SIDE OF 3D PRINTING	83
CHAPTER 6: 3D Printing for Everyone	85
Democratizing Manufacturing.	85
Derived designs	86
Curated artifacts	86
Expanded opportunities.	87
Establishing personal storefronts.	90
Creating a unique design	90
Fabricating a unique product on demand	91
Creating “impossible” objects	93
Building New Tools	93
Moving beyond solid blocks.	94
Creating the tool that will create the tool	94
CHAPTER 7: Understanding 3D Printing’s Effect on Traditional Lines of Business	97
Transforming Production.	98
Displacing the production line.	98
Abbreviating the manufacturing chain.	99
Providing local fabrication	100
Eliminating traditional release cycles	101
Handling Challenges to Intellectual Property Laws	101
Threatening IP protections.	101
Assigning legal liability	102
Leveraging Expired Patents	103
Working around patents.	104
Protecting intellectual property rights	105
Imposing Ethical Controls	105
CHAPTER 8: Reviewing 3D-Printing Research	107
Building Fundamental Technologies	107
Crafting educational tools	108
Expanding 3D-printing options	110
Fabricating 3D-printed electronics	111
Creating Functional Designs	111
Drones, robots, and military applications	112
Von Neumann machines	113

Expanding Material Selection	114
Supporting Long Space Voyages.....	115
Creating Medical Opportunities	117

PART 4: EMPLOYING PERSONAL 3D-PRINTING DEVICES

119

CHAPTER 9: Exploring 3D-Printed Artwork.....

121

Adorning the Body	121
Personalizing Your Environment.....	123
Incorporating Individualism in Design	124
Visualizing the Abstract	126
Sharing Art	127

CHAPTER 10: Considering Consumer-Level Desktop 3D Printers.....

129

Examining Cartesian 3D Printers	130
Exploring Delta Options	133
Understanding polar Fabrication	137
Getting to Know SCARA and Robot Arm Motion.....	138
CoreXY – High Speed FDM 3D Printing.....	139
CoreXY – Voron2	139
Tool-changing 3D printing	139
Building Emerging Alternatives	141
Working with Open Innovation and Community Designs.....	143
Examining Printers for More Flexible Materials	145
Understanding Shore ratings.....	145
Printing with soft filaments	146
Sampling 3D Food Printers	147
Going beyond RepRap	152
Prusa i3 MK3S+ / MK4	152
Sigma.....	153
LulzBot Taz 6	154

CHAPTER 11: Deciding on a 3D Printer of Your Own

157

Evaluating Your 3D Printing Needs.....	158
Do you want an open-source RepRap or another 3D printer? ..	159
What is your 3D printer budget?.....	160
Do you buy a ready-built 3D printer or assemble a kit?	161
Running a 3D Print Farm	162
Licensing and Attribution.....	166
Selecting a 3D Printer Design	169
RepRap and open-source designs.....	169
Home 3D printer modular kits and self-sourcing.....	174
Experimental designs	176

Choosing Print Media	178
Thermoplastic	178
PLA/PHA plastic	179
ABS	181
PET / PETG	181
Composite or filled materials	182
Paste	183
Identifying Key Components	185
Structural framework	185
Extruders	185
Build plates	190
Control interface electronics	192
Software	192

PART 5: UNDERSTANDING AND USING YOUR 3D PRINTER..... 197

CHAPTER 12: Assembling Kits and Reviewing Machine Setup	199
Sourcing a Kit 3D Printer	200
Working with kits	200
Know before you go	202
Obtaining Printed Parts for Machine Assembly	203
Printing your own	203
Asking the community	204
Understanding the Machine Motion	204
Z-axis motion	204
X and Y motion	206
Building the Printer Frame	209
Assembling the Moving Axis	214
Connecting the Y Carriage to the X and Z Assembly	216
Sensing the Home Position	218
CHAPTER 13: Understanding 3D Printer Control Electronics	219
3D Printer Control Electronics	220
Adding RAMPS	221
Going the RAMBo route	222
Selecting Sanguinololu	222
Minimizing with Minitronics	223
Rolling with RUMBA	223
Expanding with Elefu-RA V3	224
Total control with Megatronics	226
Prusa i3 electronics	227
Advanced 32-bit, arm-based electronics	227

Adding Electronics to Your 3D Printer	229
Preparing for electronics assembly	229
Connecting up cables and wiring	230
Moving axis positional sensors	232
Checking and fitting the filament sensor	233
Connecting to the control electronics	233
Doing Your First Power On Check	237
Selecting position-sensing modules	237
Understanding power-supply requirements	240
Configuring Firmware	241
Looking at one configuration example (Prusa i3 firmware)	242

CHAPTER 14: **Understanding, Using, and Servicing 3D Printers**

Examining Thermoplastic Extrusion	251
The filament drive mechanism	252
The idler wheel	256
Working with the Prusa MINI Bowden Extruder and Hot-End Assembly	259
Disassembling and servicing the Prusa MINI extruder	260
Disassembling and servicing the Prusa MINI hot-end and nozzle	262
Examining the Prusa i3 MK3 and Hot-End Assembly	264
Disassembling and servicing the Prusa i3 MK3 Extruder	264
Disassembling and servicing the Prusa i3 MK3 hot-end and nozzle	267
Taking a closer look at the hot-end and the sizes of extrusion nozzles	269
Comparing fixed nozzle and quick-change systems	270
Nozzle sizes for different print jobs	271
Alternative Extrusion Systems for Paste and Edible Materials	272
Multicolor Print Methods	276
Looking at the toothpaste effect	276
Three-way color mixing	277
Two-color printing	277
Layer-selective color printing	279
Cut-and-follow-on printing	280
Multi-input feeder	280
Automatic tool-changers	283
Extruder Operation and Upgrades	284
Fixing a blocked hot-end or extruder	286
Acquiring an assortment of extruders	288
Cooling extruders with fans	289

CHAPTER 15: Identifying Software and Calibrating Your 3D Printer	293
Finding 3D Design Software and Models	294
Using design software	299
Verifying models with Netfabb	301
Working with PrusaSlicer	303
Configuring PrusaSlicer	303
Processing models with PrusaSlicer	308
Calibrating Your 3D Printer	316
Leveling your print bed	317
Tuning your hot-end temperature control	319
Calibrating extruder distance	320
Printing Objects	323
Printing vases, pots, and cups	327
Printing large single-piece objects	329
Printing tiny or highly detailed objects	330
Printing many objects at the same time	331
Improving print quality	331
Identifying Machine Problems When Print Jobs Fail	332
Improving Print Speed	335
CHAPTER 16: Refining the Design and 3D-Printing Process	337
Being Productive with 3D Printing	338
Refining Your Print Preparations	340
Examining a Design Example	344
Practical 3D Printing: Looking at Five Quick Examples of Practical 3D Printing at Home	347
Designing Parts for 3D Printing	351
Material	352
Orientation	353
Layer height	355
Nozzle size and perimeter outlines	355
Infill level	356
Environmental conditions for successful 3D printing	356
Postprocessing, Recycling, and Finishing an Object	358
Manual finishing	359
Rusting 3D prints	359
Filling, smoothing, and painting	360
Assisted finishing	360
Coatings	363
Printing Big: Bonding and Joining Parts	363
Adopting Green 3D Printing	366
Examining home filament extrusion	367
Aiming for sustainability	368

Using a Web-Based 3D-Printing Interface	369
OctoPrint.....	370
Duet.....	370
PART 6: THE PART OF TENS.....	371
CHAPTER 17: Ten Examples of Direct Digital Manufacturing and Personalization	373
Producing 3D-Printed Food	373
Printing Tissues and Organs	374
Fashioning Biological Replicas.....	374
Crafting Clothing and Footwear	375
Customizing Jewelry	376
Making Hollywood Spectacular	376
Creating Structures	376
Reaching beyond the Sky.....	377
Constructing Robots	377
Printing 3D Printers.....	378
CHAPTER 18: Ten Impossible Designs Created Using Additive Manufacturing	379
Personalized Objects	379
Medical Implants	381
Dental Repair	381
Self-Deploying Robots.....	382
Printed Drones and Aircraft Parts.....	382
High Performance, Lightweight Engine Cooling	383
Custom Objects Created in Space.....	383
Art on Demand	384
Locally Fabricated Items.....	384
Body Parts	384
INDEX.....	385

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.

- » 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.



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).

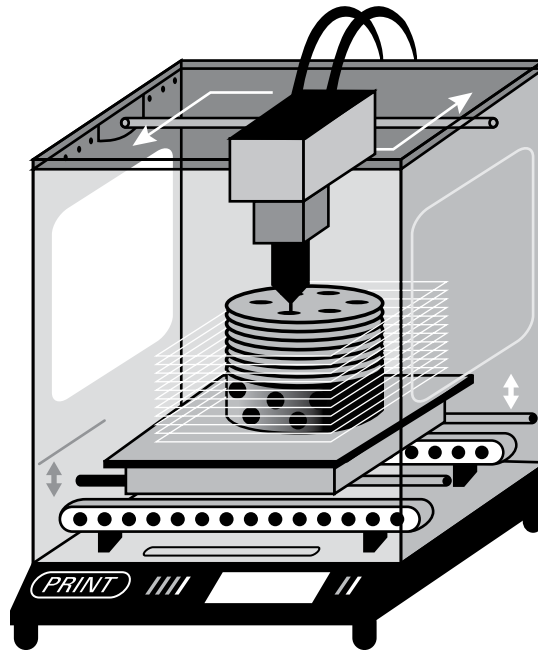


FIGURE 1-1:
A line drawing
showing how
3D printing
works.

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.

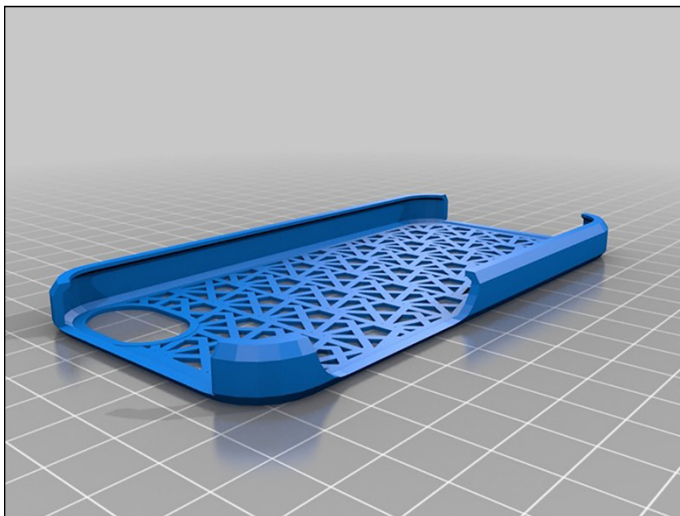


FIGURE 1-2:
A free
downloadable,
3D-printable
phone case
for the iPhone.



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.



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.