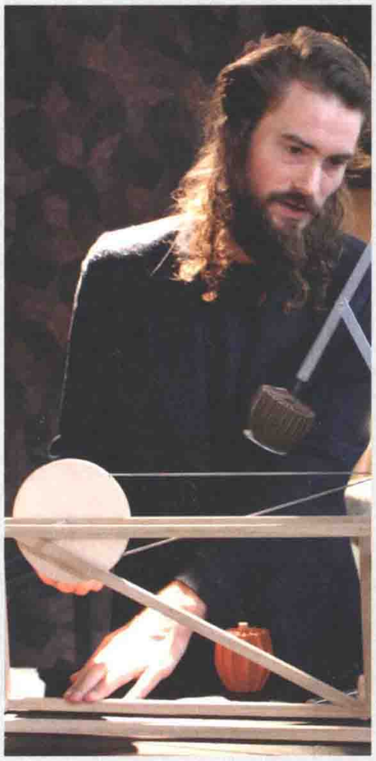
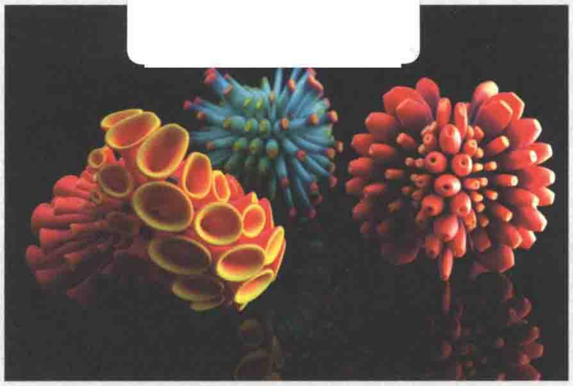
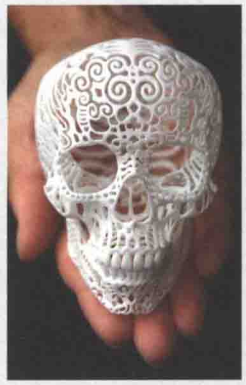
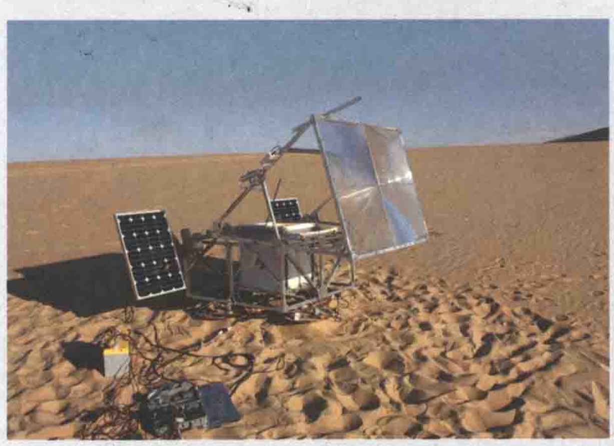
PRINTING THINGS





Visions and Essentials for 3D Printing


gestalten

PRINTING THINGS

Visions and Essentials for 3D Printing

Edited by Claire Warnier, Dries Verbruggen,
Sven Ehmann, Robert Klanten

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Printing Things:
Visions and Essentials for 3D Printing

This book was conceived, edited, and designed by Gestalten.

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Cover and layout by Floyd E. Schulze
Typeface: LL Replica by Norm

Proofreading by Wieners + Wieners
Printed by Nino Druck GmbH, Neustadt an der Weinstraße
Made in Germany

Published by Gestalten, Berlin 2014
ISBN 978-3-89955-516-5

For more information, please visit www.gestalten.com.

Bibliographic information published by the Deutsche Nationalbibliothek.
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available online at http://dnb.d-nb.de.

None of the content in this book was published in exchange for payment by commercial parties or designers; Gestalten selected all included work based solely on its artistic merit.

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January 28, 2014, marked the seventeenth anniversary of the invention of selective laser sintering, one of the three most common processes in 3D printing. In a lifetime of a human being, a seventeenth birthday wouldn't carry much meaning; you would be approaching adulthood but couldn't enjoy the benefits of it just yet. But in the lifetime of a patented invention, it means you've expired and your inventor-parents are no longer able to keep you chained to the nest. You're free to wander wherever you want, to experiment with dubious materials, and many other creative things your parents never had in mind when you were born.

In 2009 something similar happened to fused deposition modeling or FDM, one of the other major 3D printing processes. A few years earlier, Adrian Bowyer, a senior lecturer in mechanical engineering at the University of Bath, had begun working on an affordable 3D printer which used FDM to print things. He shared the plans for the printer online for others to replicate and innovate upon. A community of enthusiasts, including our own design studio Unfold, kept toiling away, exploring 3D printing on the workbenches, convinced that it would revolutionize the way things are made. It wasn't until 2009, when the FDM patent expired, that a cottage industry of consumer 3D printer manufacturers would emerge and start commercializing open source-based printers. These first 3D printers usually came as plywood building kits that required a small feat of engineering from their early adopters. By 2011 this industry had really taken off to the point where new companies were popping up every week on popular crowd funding platforms, each on a mission to bring 3D printing to the masses. At the same time as the advent of such "do-it-yourself" 3D printers came the first online 3D printing services that did not only target the business-to-business market, as was the case before, but also hobbyists, makers, and creatives. Both events – the increased availability of industrial 3D printers to an online creative community and the development of open-source 3D printers that make the technology accessible – triggered an unprecedented explosion of creative expression and experimentation with 3D printing. Not only as a tool, but also as a medium in its own right.

When carrying out research for this book, we came across a technique that was an early ancestor of 3D printing called photosculpture, dating back to 1860. Here, a revolving series of photographs was reconstructed into a three-dimensional sculpture. As so often happens in these hyperlinked days, we followed the breadcrumbs, looking further into this technology, and our search led us to an article from May 1958 in the *Journal of Photography and Motion Pictures of the George Eastman House*.

George Eastman, the founder of Kodak, developed the first flexible photographic roll film in 1884, replacing the large and heavy glass film plates and boxes of chemicals that a professional photographer would carry around. Six years later, Kodak introduced the Brownie, a very basic and inexpensive cardboard box camera that used the new roll film. Featuring the tagline "You press the button, we do the rest," the Brownie popularized low-cost, hassle-free photography and made it accessible to everyone. While Eastman's company has lost some of its former glory due to the disruption of digital cameras, his democratic vision of photography for everyone is alive and kicking: today's ubiquitous smartphones cameras can even make 3D scans, not too dissimilar to the photo sculpture process.

All of this makes us wonder whether 2009 will turn out to be for 3D printing what the year 1890 was for photography. Considering that photography, cinema and other moving pictures became cornerstones of cultural expression over the course of a century, one must wonder where we're heading with 3D printing and how it will influence our economical, social, and cultural ways of life. We've have only just begun our path down this road...

Claire Warnier and Dries Verbruggen
Unfold

1

→ Practice

What Is 3D Printing?

"3D printing" is the colloquial term for a group of technologies known as additive manufacturing. In order to print a three-dimensional solid object, a 3D printer reads the shape from a digital 3D model file before laying down and bonding successive layers of material. Each layer contains a cross section of the final object, which is formed by stacking these layers on top of each other.

Additive manufacturing is different from most of the traditional manufacturing processes that have existed for centuries because techniques such as milling, sawing, and cutting involve removing or subtracting material from a solid block to obtain to the desired shape. Since a subtractive manufacturing tool always needs a clear path to the area where material has to be removed, there are many restrictions on the types of shapes that can be achieved. The term "subtractive manufacturing" is a recently coined retronym to describe these more traditional methods and to set them apart from the newer paradigm of additive manufacturing. While there have been many "additive" processes in existence throughout history, including bricklaying and welding, these all lack the input of digital information that sets additive manufacturing apart.

3D printing or additive manufacturing is also referred to as rapid prototyping, rapid manufacturing, stereolitography, layer manufacturing, desktop manufacturing, and freeform fabrication. However, the use of such terminology is waning in favor of 3D printing, which has become the most popular term in the mainstream and refers to the low-end range of the additive manufacturing industry.

How Does it Work?

Every 3D print starts with a digital 3D model of the item you want to create. This can be rather something you've downloaded from a sharing site, bought from an online marketplace, captured from an existing physical object using a 3D scan, or modeled from scratch using 3D design software. After the necessary checks to ensure the model is printable or "watertight," a final step is needed to translate the 3D model into a language that the 3D printer will understand. The model is sliced into horizontal layers, and each layer is converted into X and Y coordinates for the printhead. The 3D printer then reads these coordinates and prints the object layer by layer, fusing the material to form a solid physical object.

During the printing process, the partially finished object has to be supported to prevent overhanging geometries or disconnected features in the model from falling over.

Most processes allow you to print in different resolutions. The print resolution describes both the layer thickness and the precision of the outlines of each layer. These layers are always visible, even with a very high resolution, which gives the object a somewhat ridged surface. In many cases, the rough surface of a finished print is smoothed out using post-processing techniques such as sanding, waxing, and polishing.

A Processes, Materials, and Printers

Additive Manufacturing Process

Over the last 40 years, a wide range of additive manufacturing technologies have been developed with the same goal: to print things. While each of these approaches essentially builds up objects out of individual layers, there is great variety between the different technologies in terms of which material is used, and how the layers are solidified and bonded together. New technologies are being developed all the time, but most can be traced back to just a handful of methods that involve creating objects layer by layer on the basis of a digital file.

Broadly speaking, 3D printing processes fall into two categories. The first group prints objects by using a printhead to bind a pre-spread layer of material, each time tracing and binding the cross sections of the object. The second group uses a printhead to deposit the material itself on the previous section of extruded material.

Today, the most widely used 3D printing processes are the trio of SLS (selective laser sintering), FDM (fused deposition modeling), and SLA (stereolithograhpy).

Unfortunately, there are as many terms and abbreviations to describe the various processes as there are manufacturers and printer models. For this overview, the most common and well-known terms are used to describe each process. Where necessary, alternative terms for the same process are supplied together with the more generic industry standard term.

A.1 Binding Processes

Binding processes work by spreading a complete layer of a powdered, liquid, or sheet material across the entire build volume before a tool head draws and binds the contours of the object. An entire layer of material is deposited each cycle, so the printed object is supported by unused build material at all times, which mitigates the requirement of extra generated support structures – except in the case of stereolithography.

A.1.1 Stereolithography (SLA)

Stereolithography (SLA) was the first 3D printing process to make the leap from lab experiments to commercialization. Stereolithography is a process that uses photopolymerization, a technique which was also used in the traditional paper printing industry to produce embossed flexographic printing plates. A photopolymer is a liquid polymer, a resin that solidifies when exposed to light. A laser draws the sections of the object on the surface of a bath of a liquid photopolymer resin, solidifying the cross section. The first cross section is built on top of a platform, which is immediately submerged below the surface and lowers a fraction after each completed layer.

SLA is very suitable for printing highly detailed smooth parts at a reasonable speed and is mainly used for "look and feel" prototypes. The popularity of SLA in the early years of additive manufacturing explains why it is commonly referred to as rapid prototyping.

A variety of resins are available with different properties resembling those of common engineering plastics, including rubber-like materials. Color ranges are very limited, and many resins are transparent or translucent for optimal curing using light exposure. There are also opaque resins, but these are typically limited to black, gray, white, or brownish tints.

Unlike other binding processes, there is no support material inherent to this technique. Although the resin bath gives some amount of support to the printed layers, it is too liquid. This means that large overhangs and disconnected parts need support structures. Such structures are always produced using the same material and are of the break-away type because the SLA process does not allow for multi-material printing.

SLA was developed by Chuck Hull in the mid 1980s and was commercialized by 3D Systems, Inc., which he founded in 1986. In 2012 FormLabs introduced the first desktop-class 3D printer based on a stereolithographic process, the Form 1. The industry standard term for stereolithography is vat photopolymerization.

Processes, Materials, and Printers | Binding Processes | A.1.2

A.1.2
Selective Laser Sintering (SLS)

Selective laser sintering is another major 3D printing process, and one in which a strong laser melts and bonds a powdered material together by heat. A thin layer of powdered material is deposited by a roller on the build platform, after which the laser draws the sections of the object on the powder, transforming it into a solid material. After each laser pass, the platform lowers and a new layer of powder is spread over the top of the object from a container on the side.

SLS is a relatively fast process that is well suited for printing structural parts and pieces that show limited layering. It is therefore a popular process for end-use manufacturing.

Creating objects by fusing powder has proven to be a very successful and adaptable 3D printing process. The machines from the main vendors mostly use plastic powders, especially nylon, which is strong and fairly flexible. However, almost any material that can be supplied in powder form and that melts under intense laser heat can potentially be used as 3D print medium. Many different processes have been developed based on SLS over the years, extending the field of application to composite materials, metals, ceramics, glass, and sand. These processes have sometimes adopted different names, such as direct metal laser sintering and selective laser melting. In most laser sintering processes, the materials used retain their natural color, but the nylon often used in the production of consumer goods can easily be treated using the same dyes used for textiles.

Support material is inherent to the process, so there is no need to add, or later remove, support structures. The object being printed is embedded in unfused powder, which also serves as a support structure. Because it is a powder, it can easily be removed using a vacuum cleaner and pressurized air, even from tiny crevices. This is a great advantage of powder-based processes, and one that means it offers the most design freedom of all processes. Any excess unfused powder is removed and to some extent recycled in the next print job.

SLS was developed by undergraduate student Carl Deckard and assistant professor Joe Beaman at the University of Texas in the mid 1980s. In 1988 both men founded DTM Corp. (a reference to desktop manufacturing), which went on to commercialize SLS. In 2001 DTM was bought by 3D Systems, inventor of the SLA process. Another large manufacturer of SLS 3D printers for plastics, metals, and other materials is German-based EOS. In early 2014 the original SLS patent expired, paving the way for more accessible SLS-based 3D printers. The industry standard term for selective laser sintering is powder bed fusion.

A.1.3
Inkjet Powder Printing (3DP)

Inkjet powder printing uses a similar powder bed approach to SLS. Instead of fusing the powder with a laser, however, a binder is sprayed over the material to glue the particles together. This process uses inkjet printheads that are very similar to those found in your desktop printer, and the process therefore looks very similar to printing on paper. Because of the use of an inkjet printhead, some inkjet powder printing machines offer full color printing. Parts produced by 3DP are more fragile than parts produced in processes that melt and fuse material. In a post processing step, the fragile objects are infused with resin to make them stronger and to enrich the color saturation.

3DP is mostly used as a cost-effective way of producing visual prototypes. Its biggest selling point is full color printing: this is a capability mostly unrivaled by other processes.

Most inkjet 3D printers use a gypsum-like powder which hardens when sprayed with a liquid binder. By adding multiple inkjet printheads to the machine, each filled with binder of a different color, inkjet 3D printers are able to produce full color objects, mimicking the visual appearance of other materials. This makes the technique ideal for the photorealistic reproduction of portraits or figurines. Fairly recently, people have started experimenting with the use of alternative powder compositions in standard inkjet powder printing machines in order to print ceramics and glass, for example. In such cases, clay or glass powder is temporarily glued together and later sintered in a kiln – a process in which the binder burns out. Professor Mark Ganter from the University of Washington maintains the Open3DP blog, which documents open-source recipes for a wide range of powdered materials and binders.

As with other binder-based processes, support material is inherent to 3DP, so there is no need for separately generated support structures.

3DP was developed at the Massachusetts Institute of Technology (MIT) in the early 1990s by Michael Cima and Emanuel Sachs, and later licensed to Z Corporation, which is now part of 3D Systems. The officially registered term for 3DP is "three-dimensional printing," but in order to not confuse this with 3D printing – a term that now describes the whole field – inkjet powder printing is used here for this specific process. The industry standard term for inkjet powder printing is binder jetting.