



THE SHAPE OF THINGS TO COME

How 3D printing is impacting design and manufacturing

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INTERACTIVE QUIZ

Can you match the images to their descriptions?

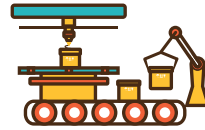
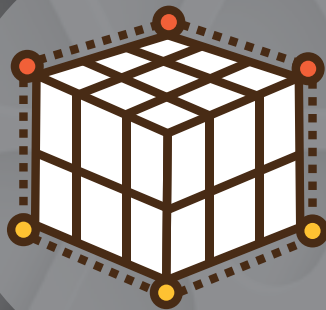
3D printing — also called additive manufacturing — can make skin and bone, food and flowers, and shirts and shoes (or at least parts of them). As new machines print faster and use a wider array of materials, industry watchers predict that printers will move from making prototypes to enabling mass customization. “This technology will change how products are imagined and designed, and it will change how we tool our factories,” says Andreas Saar, vice president of manufacturing engineering solutions at global technology company Siemens. “It is having a major impact on how products are designed and manufactured.”

This book shows you that impact. It presents some of 3D's most amazing recent achievements, plus glimpses of the future, quizzes to test your 3D smarts, and a few surprises. The information here comes from the trade journals Design News, Medical Device and Diagnostic Industry, Packaging Digest, PlasticsToday, and Powder & Bulk Solids, which offer a clear, smart view of 3D printing's rising power. As a PlasticsToday article noted, “It's going to be a 3D-printed world — we'll just live in it.”

*“It's going to be a
3D-printed world —
we'll just live in it.”*

Solid Growth in Every Dimension

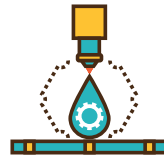
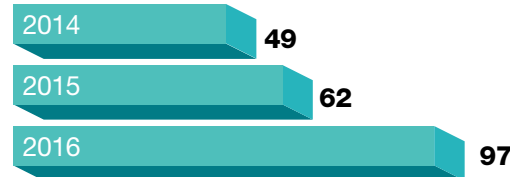
Infographics on sales and growth in 3D printing



More manufacturers are making industrial 3D printing systems

The number of 3D printer manufacturers has nearly doubled since 2014, rising from 49 in that year to 97 in 2016, according to a report by consulting firm and 3D printing authority Wohlers Associates. The industry grew by 17.4% in 2016 alone, the report said. Terry Wohlers, founder and CEO of Wohlers Associates, noted that the rise of new companies is putting pressure on established 3D printer makers such as Stratasys and 3D Systems.

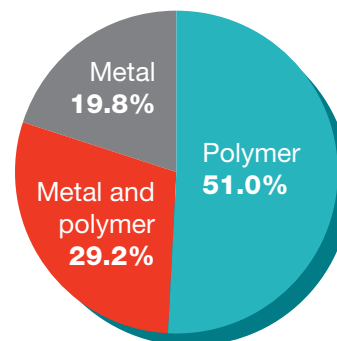
Number of 3D printer manufacturers



Here's what they use in their machines

More than half of industrial 3D printing service providers make objects exclusively from polymers, although metals are catching up. Nearly half of all 3D printing service providers produce metal parts. Wohlers Associates discovered these facts by asking 100 service providers for data on their operations.

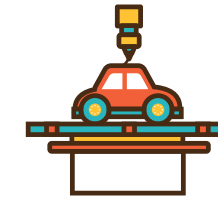
Materials used by industrial 3D printing service providers



They're getting bigger and richer

The global 3D printing market is expected to grow to at least \$20 billion by 2020, according to research firm Deloitte Poland. And Wohlers Associates says that while 3D printing accounts for only 0.04% of today's global manufacturing, it will eventually capture 5%, which would make 3D printing a \$640 billion industry.

Global 3D printing market in billions of dollars



One of the strongest growth areas is automotive manufacturing

In 2021, makers of cars, trucks, and parts will pay \$2.3 billion for 3D printers, software, materials, and services. The prediction comes from SmarTech, which offers industry analysis and market forecasts for the 3D printing industry. SmarTech notes that the 2021 amount is a huge jump from the estimated \$0.6 billion that the auto industry spent on 3D printing in 2016.

Revenues from 3D printing in the auto industry in billions of dollars



Breaking the Mold

New and unexpected products made possible by 3D printing



Human skin

Researchers in Spain have developed a 3D printer that can create human skin. The invention marks the first time that anyone has created a living human organ from a 3D printer and presented it to the commercial market. Doctors can use the skin for patient transplants, and corporations can use it to test cosmetics, chemicals, and pharmaceuticals.



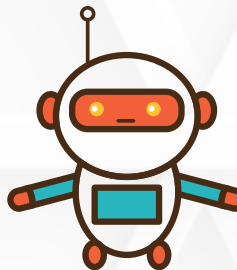
Flower petals that open under sunlight

A team of researchers has 3D printed a daisy with petals that bend under sunlight — and each layer of petals responds differently. Scientists and engineers from Georgia Institute of Technology, Singapore University of Technology and Design, and China's Xi'an Jiaotong University laid down layers of materials that “remember” one shape but change to another under heat. The technology could help to create medical devices such as stents.



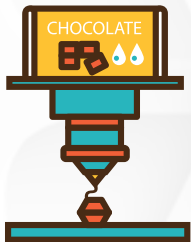
Electronic tattoos

3D-printed electronic tattoos may replace wearable body monitors such as fitness trackers. Researchers at Japan's Waseda University have developed a process that sandwiches circuitry between flexible sheets of film that can stick comfortably to skin. Electronic tattoos may not only replace wearables but may also be useful as human-machine interfaces and as sensors in medicine and sports.



Soft robots

Robots with soft bodies are more flexible, more adaptable, and less likely to hurt humans than old-fashioned metal bots. In creating one of these innovative machines — called Octobot because it looks like an octopus — Harvard University researchers used 3D printing throughout the robot's body to embed channels where its fuel flows.



Food

NASA has been researching a 3D-printed food system for astronauts. Meanwhile, other innovators are exploring the potential of custom-printed dishes for groups such as soldiers and the elderly. 3D-printed foods include ice cream, pizza, pancakes, and pastries. Some confectioners are imagining sweets in complex geometric shapes that no human hand can weave.

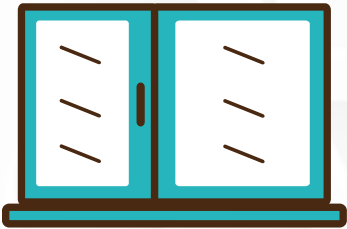


Cars

The world's first 3D-printed electric car, from Local Motors of Chandler, AZ, took just 44 hours of 3D printing and 10 hours of milling to produce. Vehicle assembly required no more than 50 parts, much fewer than most cars; the tires, drivetrain, and electrical components were made by traditional means. While Local Motors is a small operation, auto titans such as Honda are also looking into 3D-printed cars.

It's Not All Plastic and Metal

Surprising 3D-printable materials



Glass

Thanks to researchers at Germany's Karlsruhe Institute of Technology, glass can be 3D-printed. Bastian Rapp, the engineer who led the effort, has said that the breakthrough will lead to "countless applications," including camera lenses, eyeglasses, and architecture elements. Computer makers may use 3D-printed glass for optical components used in data processing, and health sciences companies may print miniature glass tubes for biological and medical applications.



Beer

North Dakota startup 3DomFuel uses recycled beer waste to make "Buzzed," a filament that 3D printers can turn into objects. "We get the byproduct from a local major label brewing plant. It's stuff that would otherwise just be placed in a landfill," says CEO Jake Clark. The company says that Buzzed has "a rich golden color and a noticeable natural grain" and adds, "A stein printed with Buzzed is a true 'beer stein.' "



Martian and lunar dust

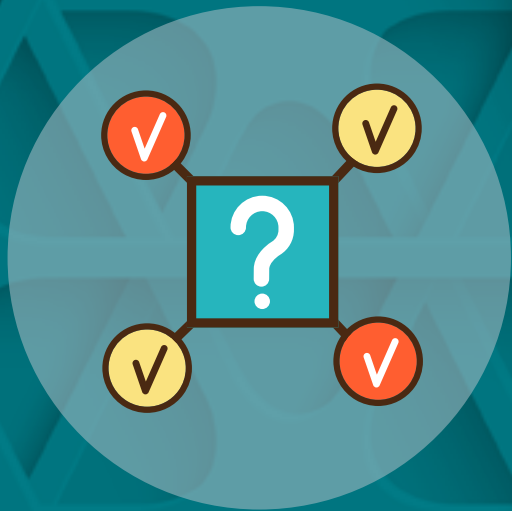
Using a substance similar to dust from Mars and the moon, Northwestern University materials engineering professor Ramille Shah led a team to create 3D paints that astronauts can use to print tough, flexible structures. "We even 3D printed interlocking bricks, similar to Legos, that can be used as building blocks," said Shah. The process may help astronauts build using the ground beneath their boots rather than bring materials with them.



Stem cells

Researchers at Sahlgrenska Academy, a Swedish health sciences college, have fed stem cells into a 3D bioprinter to turn them into a structure of living cartilage, the connecting tissue in joints and other body parts. Stem cells readily change into cartilage within the body, but the Sahlgrenska team claims to be the first to change them via mechanical means.

So You Think You Know 3D Printing: QUIZ



True or false: Is stereotaxis a term used in 3D printing?
What about voxel? Or laser sintering?

That's the question for each of the terms below.

Answer "True" for each term that 3D printing pros use in their work, and "False" for each one that they don't.

TRUE	FALSE	4D printing
TRUE	FALSE	Anaglyph 3D
TRUE	FALSE	Fused deposition modeling
TRUE	FALSE	Inertial confinement fusion
TRUE	FALSE	Laser sintering
TRUE	FALSE	Multi-jet fusion
TRUE	FALSE	Stereolithography
TRUE	FALSE	Stereotaxis
TRUE	FALSE	Voxel

**Turn to page 7
to see how many
you answered correctly!**

So You Think You Know 3D Printing: ANSWERS

TRUE 4D printing

4D printing is 3D printing with materials that change shape in response to changes in light, heat, water, air pressure, or other factors.

4D-printed materials could become medical implants customized for each patient, products that are shipped flat or compressed, and even aircraft designed to change their aerodynamic profile in flight.

FALSE Anaglyph 3D

Anaglyph 3D is the effect used in old-fashioned 3D movies that required viewers to wear glasses with one red lens and one green lens.

TRUE Fused deposition modeling

Fused deposition modeling is 3D printing that builds parts layer by layer from the bottom up by heating and extruding plastic filaments. This technology has a wide range of uses in sectors such as automotive, healthcare, aerospace, and consumer products. It's so versatile that the International Space Station uses its own FDM printer to make replacement parts.

FALSE Inertial confinement fusion

Inertial confinement fusion is research into initiating nuclear fusion reactions by heating and compressing a fuel target.

TRUE Laser sintering

Laser sintering is a form of 3D printing that builds parts with high strength and temperature resistance. It can produce concept models and

sample pieces; jigs and fixtures; and pieces of components used in the aerospace, medical, and automotive industries. Auto maker Daimler, for instance, has used laser sintering to produce spare parts for its Mercedes-Benz trucks.

TRUE Multi-jet fusion

Multi-jet fusion is a type of 3D printing that uses heat to fuse nylon powder into shapes. Manufacturers use multi-jet fusion for brackets, clips, housings, and parts requiring high strength or temperature resistance. Scott Dunham, Vice President of Research at SmarTech Markets Publishing, says that multi-jet fusion "will no doubt play a huge role in the growth of polymer 3D printing."

TRUE Stereolithography

Stereolithography is a method of 3D printing using a liquid polymer that hardens on contact with laser light. It's suited for prototype parts, visual aids, and concept models, where cosmetic attributes such as fine features or smooth finishes are important. Stereolithography can offer varying levels of resolution, color, clarity, stiffness, texture, impact resistance, temperature tolerance and water resistance.

FALSE Stereotaxis

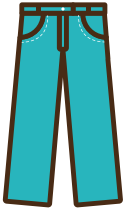
It's a surgical technique using 3D imaging.

TRUE Voxel

The word means volumetric pixel. A voxel is a 3D pixel, the smallest piece of a 3D printed object. HP Inc. claims that its multi-jet fusion 3D printing process can control materials down to the voxel. The word has also inspired the name of a German 3D printing firm, voxeljet.

3D Printing Meets Legendary Brands

Notable names involved in 3D printing



Levi Strauss

Over 50 years ago, Levi Strauss & Co. introduced the classic “Trucker” jacket. Now, the company is experimenting with 3D printing to design this and possibly other denim products in the future. Levi’s Head of Global Product Innovation, Paul Dillinger, said that the goal was to “capture the real essence of a pair of Levi’s and convert it into digital collateral.”



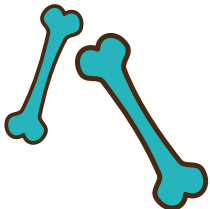
Adidas

Adidas has teamed with Silicon Valley-based startup Carbon to develop a sneaker partly made via 3D printing. It’s the first time that an athletic-footwear company has used 3D printing in mass production. Adidas creates the midsole of the new Futurecraft 4D athletic shoe via Carbon’s Digital Light Synthesis process, which manipulates an ultraviolet-sensitive resin by projecting light onto it.



UPS

UPS has announced plans to install 3D printers at more than 60 of its stores across the United States. Designers and manufacturers can place orders on the website of 3D printing service Fast Radius, and UPS will do the printing and delivery -- in some cases, on the same day that the customer places the order.



Johnson & Johnson

This health-care giant owns a 3D printing technology that creates bone implants customized for individual patients. The implants have a mineral coating that promotes healing. Johnson & Johnson has also worked with 3D printer makers such as HP Inc. (formerly Hewlett-Packard) to create other medical products.



NASA

The National Aeronautics and Space Administration is holding a \$2.5 million competition to build a 3D-printed habitat for space exploration. One key part of the challenge is to use discarded plastic packaging and other recyclables as raw materials. The recently completed second phase of the competition awarded \$250,000 to a team from Chattanooga, Tennessee, that 3D printed a dome structure.



BMW

The car-making giant, an early adopter of 3D printing in making vehicles, includes 3D-printed parts in its Rolls-Royce Phantom. It also 3D prints devices designed to be comfortable for its workers to use. What’s more, BMW has invested in Desktop Metal, a startup that plans to make metal 3D printing simpler and more accessible to design and manufacturing teams.



Caterpillar

You might expect the tractor maker to use 3D printing for parts, but would you expect it to print hearts? Children’s Hospital of Illinois cardiologist Matthew Bramlet told a Caterpillar 3D printing engineer that the hospital could create images of patients’ hearts but didn’t have the technology to print them. Caterpillar did, though. The company prints replicas of patient hearts; surgeons practice on them before working on the patients.

Words to Carve in Stone — or Plastic

Notes, quotes, and predictions about 3D printing

Is 3D printing suited to manufacturing medical implants?

“3D printing is, hands down, the best method for creating a structure for the human body. Since the human body is a bespoke mechanical, chemical, and electrical organism, it requires a manufacturing method that can easily build for these requirements.”

— *Derek Mathers, Director of R&D, design firm Worrell Inc.*

What's the point of creating new and unfamiliar materials to be used in 3D printers?

“We want to enable technologies that have not existed before. People always ask what these will be used for, and simply these structures have never been reported, so our imagination is the limit right now.”

— *Timothy Long, Professor of Chemistry, Virginia Tech*

What happens when innovators create new approaches such as a “printer farm” of teamed 3D printers?

“We can see a fundamental rethinking process in the minds of entrepreneurs. More and more it is considered whether additive production can be used instead of the injection molding and milling processes ... 3D printing will play a very important role in tomorrow's production.”

— *Florian Bautz, Managing Director, 3D printer manufacturer German RepRap*

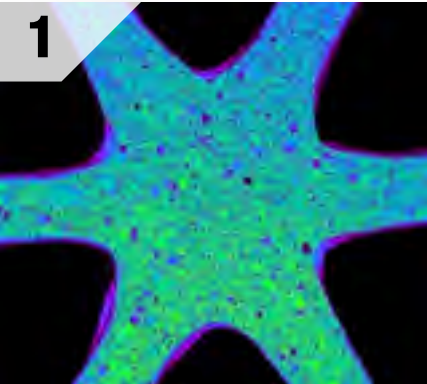
What will happen if 3D printers can mass-produce products that injection molders can't make?

“Designers and engineers will have to learn to think differently. All of those drawings that designers used to make for things that could never be molded now can be made.”

— *Rene Polin, President, design firm Balance Inc.*

What Do You See in 3D?

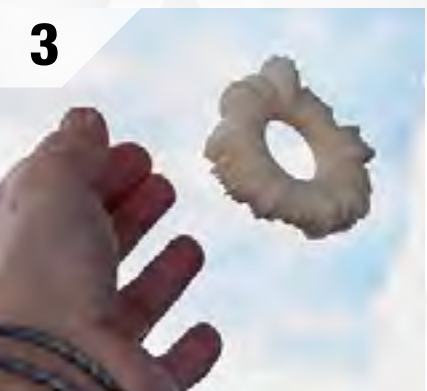
Can you match the images to their descriptions?



- A** A section of a 3D-printed starfish
- B** A piece of 3D-printed foam
- C** The reaction as laser light strikes a liquid polymer to harden it into a 3D object



- A** An attempt at a 3D-printed yellow tomato
- B** An attempt at a 3D-printed yellow squash
- C** A 3D-printed replica of a brain



- A** A 3D-printed model of human laughter
- B** A 3D-printed mold for making doughnuts
- C** A-3D printed part for an undersea vehicle



- A** A 3D printing shack, one of a chain planned for European cities
- B** A 3D-printed child's playhouse for schools or parks
- C** A 3D-printed mini-retreat from the stresses of city life



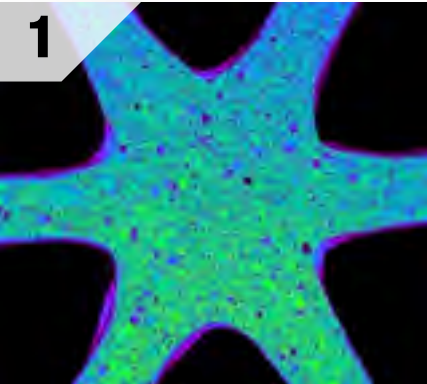
- A** A 3D-printed piece of a human kidney
- B** A length of 3D-printed pseudo-snakeskin fabric
- C** A 3D-printed route to North Carolina State University's Center for Additive Manufacturing



- A** Icelandic pop star Björk wearing a 3D-printed mask
- B** A Yale performance-art student wearing a 3D-printed sculpture
- C** A blind teenager testing a 3D-printed apparatus designed to help her see

What Do You See in 3D?

ANSWERS



1

B A piece of 3D-printed foam

It's part of a pattern of air surrounded by ceramic particles, a material developed at Harvard. While most 3D-printed materials are uniform -- all sections are equally strong, flexible, and porous -- this foam can form objects with higher or lower properties in different places. The ability to change properties within an object may be useful in making batteries, filters, and even bone tissue.



2

C A 3D-printed replica of a brain

St. Louis University and the Walter E. Dandy Neurological Society have printed replicas of patients' brains on which surgeons practice before operating on the patients' aneurysms. "If I can make [surgical decisions] beforehand by practicing on a model using the same tools and clips I plan to use in the final operation, it really makes a difference during surgery," neurological society president Saleem Abdulrauf said.



3

A A 3D-printed model of human laughter

A team led by Israeli artist Eyal Gever developed a means to convert sound waves into a digital 3D model called a "laugh star." Gever let people create their own laugh stars, and a contest yielded a laugh star that a crew member on the International Space Station printed on the station's 3D printer.



4

C A 3D-printed mini-retreat from the stresses of city life

Called the Urban Cabin and created by a team of Dutch architects called DUS, the structure has stood in a former industrial area in Amsterdam. Complete with a pocket park and outdoor bathtub, the project is intended as a study into possible on-demand housing solutions for fast-growing cities.



5

A A 3D-printed piece of a human kidney

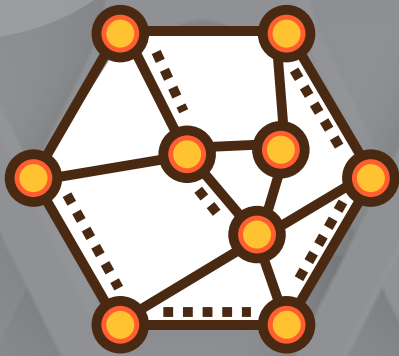
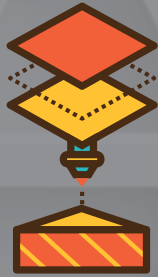
Harvard researchers bioprinted a functional structure that looks and acts like a proximal tubule, a part of the kidney that helps regulate the concentration of water in tissues. The researchers believe that the creation of this structure is a step toward making larger body parts.



6

A Icelandic pop star Björk wearing a 3D-printed mask

The mask was designed by MIT professor Neri Oxman to reveal the bone and tissue structure under Björk's skin. Björk performed in this mask during a concert in Tokyo. The mask is called Rottlace, a variation on an Icelandic word meaning skinless.



Whether 3D printing is working with Björk or BMW, the process is getting faster, more versatile, and more lucrative. In auto factories, 3D printers may become as common as robot arms. Your doctor may consider her 3D printer as important to her practice as her X-ray machine. 3D printing is touching aerospace companies, food and beverage packagers, clothes and shoe makers, and other companies. And the impact will only get bigger.

Welcome to a new world: a future in three dimensions.

Courtesy of UBM Advanced Manufacturing Group

