Additive Manufacturing

3D Printing, and the Coming Stock Market Boom

Dr. Alexander Elder

3 expanded edition

Additive Manufacturing, 3D Printing, and the Coming Stock Market Boom

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DEAR READER: If you need any assistance with the e-book files or have any suggestions on improving this book, please write to the author. This e-book has a number of **links** to various websit and videos; please let us know if any of them stop working, and we'll change them.

Books by Dr. Alexander Elder

in chronological order:

Trading for a Living
Study Guide for Trading for a Living
Rubles to Dollars
Come into My Trading Room
Study Guide for Come into My Trading Room
Straying from the Flock: Travels in New Zealand
Entries & Exits: Visits to 16 Trading Rooms
Study Guide for Entries & Exits
The New Sell & Sell Short (with Study Guide)

To Trade or Not to Trade: A Beginner's Guide (e-book)

Two Roads Diverged: Trading Divergences (e-book)

The New High – New Low Index (e-book), with Kerry Lovvorn

The Trading Puzzle – Book One (e-book), with Kerry Lovvorn

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Foreword to the 3rd edition

Additive manufacturing is an exploding field. So much new information is coming in, that only two months after first publishing this book in July 2012, I felt compelled to bring forth an updated second edition. In January 2013 additive manufacturing was mentioned by the president in his State of the Union speech. Now, in April 2013, I am releasing this updated edition.

I maintained the basic structure of the first book, but expanded some chapters and added several new ones. If you're a first time reader, please read the book from cover to cover. If, on the other hand, you've read the second edition, you may want to zero in on the new and expanded parts.

The new chapters are:

* Education
* Fashion
* Recycling
* Fun & games
* For the young

The expanded chapters are:

* Medicine and dentistry
* Home-building
* The military
* The AM stocks to watch (more stocks and all updated charts)

Many slight additions are sprinkled throughout other chapters of this book.

I also updated the cover of the book. The first edition showed a stone axe and the second a 3D jewelry design. Now I want you to see a model of a 3D-printed moon base (not science fiction but an actual project of the European Space Agency).

Many changes in this 3rd edition came about thanks to emails from readers and friends who keep sending me links to AM news. I am grateful to William Gordon, Jonathan (Jock) Gunther, Daniel Keane, Rick Lipkin, Peter Maich, Jeff Parker, Rasmus Sommerskov, Andy Webb, and John Weir. Keep those links coming for the future 4th edition! AM is a hugely exciting field, and we need to move as fast as we can to keep up with it.

Dr. Alexander Elder
New York City, April 2013

Are you in this e-book?

We salute the pioneers of additive manufacturing – inventors and designers who shape this field, as well as journalists and videographers who publicize it. Thank you for being on the front lines of this revolution.

This e-book contains many links to websites, videos, and other resources. We aim to be scrupulous i giving credit where credit is due. If you feel we've either overlooked or misquoted you, please contact us for an immediate response and a correction if needed.

Free updates and the honor code

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And now, let's embark on our journey.

Dr. Alexander Elder
New York City, April 2013

Figure 01 – A stone axe.
Approximately one million years old.

PART 1: THE DAWN OF A NEW ERA

Which tool have humans used the longest? Certainly not a computer, nor a screwdriver, not even a hammer. That distinction belongs to a stone axe, like the one pictured above. In *History of the Worl in 100 Objects*, Neil McGregor of the British Museum tells us that early humans began making such axes by striking one rock with another over a million years ago and continued to make them until about ten thousand years ago.

We are not that far from that stone axe. To this day, most manufacturing is based on the same principle: we take something big and make it useful by cutting, chiseling, drilling, polishing, and otherwise reducing it. If you could bring a Neanderthal to a factory, he would grasp the basic principle of taking a large piece of metal and drilling it to make, say, an engine block. Our technolog has changed, but the basic principle hasn't: take something big and work to make it smaller and useful. This process generates a huge amount of waste, which we accept as inevitable. We also acce severe technical limitations: for example, it may be impossible to drill an S-shaped passage through solid piece of material.

This principle – making smaller things out of big chunks – is about to change.

After a million years of cutting, chiseling, and drilling we're stepping into a new era whose technology allows us to create objects by programming and then building or growing them layer by layer.

Think of printing a page on a dot-matrix color printer. You can draw anything on your screen, and th printer will quickly deliver a multitude of color dots to a blank page, which will coalesce into an image. Now imagine that this printer works in 3D, printing one level on top of another, building not flat page but a three-dimensional object, layer by layer.

Such technology already exists. It is still at an early stage, but today you can already buy and use a 3
printer.

Video 01 – The Shape of Things to Come, 04:54 (*National Geographic*).
A scientist visits a firm that scans his wrench and prints him a duplicate.

This technology is advancing very fast, getting ready to overturn the key manufacturing principle of the past million years. Our ability to create new objects will be limited only by our ability to progra them. We can create objects that are as complex on the inside as they are on the outside.

Rather than driving to the hardware store to buy a wrench, we'll have a printer and buy an image file to print the tool we need. Not only will we save energy, but we will also buy less: for example, you won't have to buy a complete socket set when all you need is a single size. Manufacturing will retur to the US since it will cost roughly the same to print something in Detroit as in China but the shippin cost will be lower and time will be saved.

The coming technological revolution will change our lives. It'll change the way our civilization produces things, the very way we live. Along the way it'll fuel a stock market boom. I wrote this e-book to help prepare you for the ride.

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No more bashing!

A recent cover story in *The Economist* included Additive Manufacturing (AM) in what they called "the third industrial revolution." According to that magazine, the first revolution was the mechanization of the textile industry in 18th century Britain, while the second was the introduction o the assembly line in 20th century America.

Figure 02 – AM going mainstream

The cover story of the April 21, 2012 issue of *The Economist*

I think that *The Economist*, the wonderful magazine that it is, didn't give AM enough credit. It's not the third, nor the second, but rather the first real revolution in how we make things since a prehistori man picked up two rocks and started banging them against one other, trying to shape them into something useful.

From the days of that pre-historic man until today all manufacturing has been spending a huge amou of energy and generating mountains of waste, while struggling against harsh limits of what's possibl to achieve with old methods.

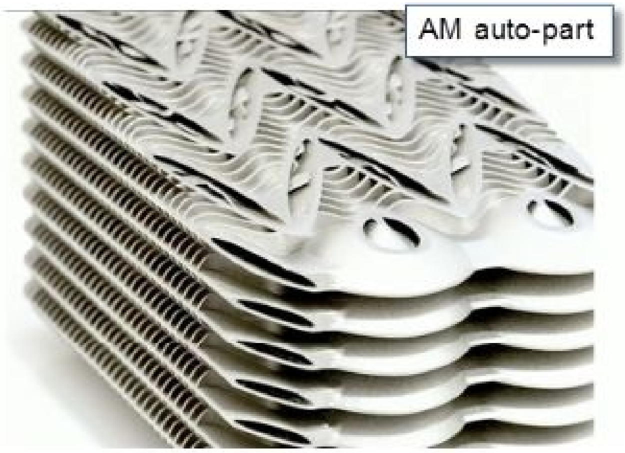
Video 02 – [The new industrial revolution](#) 02:46 (Sky News)

An introduction to AM by a UK TV channel – "you are only limited by your imagination".

Your regular ink-jet printer probably works at 300 dpi – it puts 300 droplets per one inch line. If, aft printing an image, your printhead could shift a fraction of a millimeter higher and print another image, based on the next slice of the object, on top of the first one and then keep on moving higher and printing more images, one on top of the other, it would print you a three-dimensional object.

This process of 3D printing poses **two key technical challenges**. We have to figure out how to deliv printing materials in thin layers which will then become one object. We also need to write code whic will enable computers to digitally slice objects into very thin layers and print those layers using 3D printers. Both challenges are well within the grasp of modern technology. One of the pioneers of the 3D industry whom you'll meet in a later chapter came to lunch with me wearing a t-shirt that said "Code or die!"

For another good illustration of additive manufacturing please view the video below from the famous TED educational series.



Video 03 - A primer on 3D printing 14:50 (TED)
Lisa Harouni is a co-founder of Digital Forming; her company allows customers to be directly involved in the design of products they wish to buy.

Additive manufacturing is not new. A friend of mine who made a small fortune by computerizing shoe-making told me they began using the first 3D printers some 30 years ago. Recent advances in technology have created much cheaper and effective solutions to the two challenges described above. Plus, a new highly positive factor has recently emerged.

We live in a very legalistic society, and the patents of early AM pioneers had long protected their turf. Those patents are now expiring, removing barriers to entry for new participants. The expiration of patents is throwing the field wide open for new entrants.

While basic application patents are expiring, protection is being created for AM and 3-D products. Patent 8,286,236, issued in 2012 extends the idea of digital rights management (DRM) to 3-D printers. In the future, when you load a file to print an object, your printer will be able to check whether you have the right to print that file, how many times, and out of what materials – just as with DRM for e-books or music.

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The tipping point

This term, popularized by Malcolm Gladwell, means "the moment of critical mass, the threshold, the boiling point." Today additive manufacturing is at this point – ready to explode from a state of relative obscurity into a transformative force of our society.

The December 10, 2011 issue of *The Economist* contained a report from the latest Euromold, a manufacturing trade fair in Hamburg, Germany. Titled "The Shape of Things to Come," it reported that amidst traditional manufacturers there were some 300 exhibitors of additive manufacturing.

Some of their 3D printers could fit on a desk, others were as big as cars. All worked by building products layer by layer from powdered metal, droplets of plastic, or other materials. Many printed items looked different from their conventional counterparts: they were more elegant and less clunky, with flowing lines.

Figure 03 - bespoke cycling helmets for Team GB, created by Crux Product Design. The UK firm took 3D laser scans of each individual athlete to ensure the best fit and used AM to tur the 3D models into prototypes overnight.

Additive manufacturing has been used for two decades in motor sports to make concept models and functional prototypes. Today a number of top racing teams have gone to the next level by using 3D printed parts for the race track. This practice has been developing for several years but only recently become widely known because early users considered direct digital manufacturing to be a closely guarded competitive advantage.

Video 04 – Will a Printed Plane Fly? 02:26 [*New Scientist*]

A group of British scientists prints and test-flies a radio-controlled pilotless printed aircraft

Researchers at Southampton University in Britain printed an unmanned aircraft whose body has a lattice-like structure, similar to fibrous proteins that hold a cell in shape. *The Economist* wondered whether the "…ability to create light, strong structures which have complex internal shapes may turn out to be additive manufacturing's killer app."

AM machines are very 'green' because they generate almost no waste and reduce transportation expenses: you can download a file and print a needed object in your own home. 3D printers are rapidly becoming more capable, while their prices are falling.

In May 2012 the US federal government issued a solicitation for proposals from teams led by non-profit organizations or universities to establish an Additive Manufacturing Innovation Institute, whic would serve as a pilot for their proposed National Network for Manufacturing Innovation.

Additive manufacturing grew by 29 percent in 2011, to a total market size of $1.7 billion worldwide, according to an industry report from Wohlers Associates Inc, a leading consultant in AM. They repo that the additive manufacturing industry has grown by double digits in most years. It declined by 9 percent during the recession in 2009, but then rebounded in 2010 to grow 24.1 percent. A report released by a research company Marketsandmarkets.com in October 2012 estimates the global size o additive manufacturing at $3.5 billion by 2017.

The shortcoming of many forecasts is that analysts tend to extrapolate an arithmetical progression, while in fact the angle of the growth curve is likely to rise. As the field goes exponential, the actual volume of AM business cannot be reliably forecast.

All revolutions have a similar dynamic: they start out slowly, almost imperceptibly, then enter a stag of gathering speed, and later explode in a parabolic move. The technology of additive manufacturin has been in development for the past 30 years. In 1986, Chuck Hill, the founder of 3D Systems (stoc symbol DDD), invented a system for making three-dimensional objects which he called ‘stereolithography.’ Now there are hundreds of companies in this exploding field. We’re not yet in the parabolic stage, during which a stock market boom is likely to occur, but we’re definitely movin in that direction.

Professor Neri Oxman of MIT compares the impact of 3-D printing to a revolution launched some 50 years ago by Johannes Gutenberg who invented the movable type and began printing Bibles. Prior to that, all books were copied by hand, which made them extremely expensive, while literacy was pretty much limited to clergy and nobility. Printing democratized literacy, and now 3-D printing will democratize our society in ways that we are just starting to grasp.

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PART 2: AM TECHNOLOGIES

The basic principle of AM is simple: create a three-dimensional object out of multiple very thin layers. To view a surprisingly lively PowerPoint presentation of this concept, please click on this link. Give it time to load – you’ll be downloading a 5mb file. Its author – Dr. Adrian Bowyer from the UK is an AM pioneer who created the RepRap Project for 3D printing, which we’ll review in a later chapter.

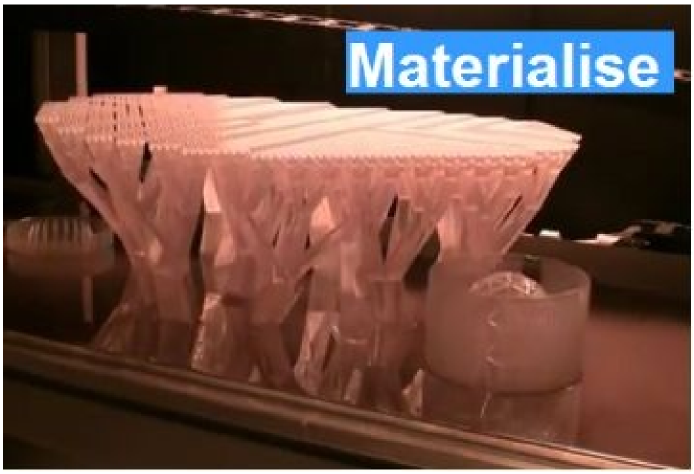
While the basic concept of AM is universal, companies implement it using different technologies. Some ‘print’ with melted plastics, others with metal dust, and still others shine an ultraviolet light into a jar of liquid polymers, forcing them to harden in a controlled manner to create the shapes they want.

AM technologies include but are not limited to the following:

- Direct Metal Laser Sintering (DMLS) – can use almost any metal
- Electron Beam Melting (EBM) – uses titanium alloys
- Fused Deposition Modeling (FDM) – uses thermoplastics
- Laminated Object Manufacturing (LOM) – uses paper or plastic film

- Selective Laser Sintering (SLS) – uses thermoplastics or either ceramic or metal powder
- Stereolithography – uses photopolymers

An excellent guide to AM technologies was created and is being maintained by Travis Hessman, an editor of *IndustryWeek*. His recent review describes 16 printers made by 3D Systems – from a high-volume industrial product to a basic consumer model. A company named envision TEC produces ter various models of 3D machines using stereolithography. Since most popular 3-D printers use variou plastics, a company called Vistatek produced a 3-minute video using time-lapse photography to demonstrate relative strength of eight different materials.



Video 05 – Would Queen Victoria be impressed? 01:24 [Materialise Group]
AM gives creative freedom to artists who make three-dimensional objects.

One of the largest players in AM is a Belgian company called Materialise. Its 3D products are even exhibited in London's fabled Albert & Victoria Museum (watch a snazzy video above). A German company named EOS, with six machines to its name is considered a world leader in AM technology called laser sintering.

Figure 04 – Art and design.
A lamp created using AM.

If you’re interested in the nuts and bolts of AM, consider visiting one of the growing numbers of trac shows that feature AM technologies. Some are run by the Society of Manufacturing Engineers (SME which offers this link to a brief presentation on AM (it includes a link to RepRap, mentioned above). Even if you are not an engineer, educating yourself about AM today will prepare you to be a more confident investor when a mass of additive manufacturing IPOs start coming to market in the years ahead.

Still, it’s easy for a non-techie person to become overwhelmed by an avalanche of technological terms, descriptions, abbreviations, and claims to superiority. As the field of AM grows, you can expect to hear the deafening volume of competing claims.

What’s a non-techie to do?

Stock market investors and traders can do very well without becoming technology experts. Once masses of AM companies start getting listed and the boom gets going, the rising tide will lift all the boats. Every cat and dog will have its day in the sun. In the long run, key technologies will emerge, while others will fade away, but this will take years. In the more realistic short run, we want to sprea our bets.

Remember the Internet bubble? Today the Internet is an integral part of our lives, but in the late 199 it was huge news. Almost every stock that added a dot-com to its name went through the roof. Furniture.com, Pets.com, Amazon.com, and countless others exploded on the charts. In due time survivors, such as Amazon.com, emerged, while many dot-com companies eventually went bust. Th key thing to remember is that early on in that boom all dot-com stocks went up.

Today we’re in a pre-boom stage. Don’t give yourself a headache trying to sort out competing claim of various AM technologies – just wait for a wave of listings to emerge. We will review suggested investing and trading approaches in a later section of this e-book.

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What’s AM good for?

In a phrase – almost everything. Let’s go on a whirlwind tour of industries that are starting to use AM. Without a doubt, this chapter will be expanded in future editions of this e-book.

Figure 05 – Objects created using AM.
From a TED presentation by Lisa Harouni.

Rapid prototyping

In the beginning, the main use of AM was rapid prototyping – quickly fabricating scale models of physical parts or even assemblies of parts. An engineer with a 3D printer can model anything from shoes (which is what my friend did, mentioned above) to airplane parts for testing in wind tunnels. T this day, rapid prototyping remains one of the main uses of AM.

A friend recently invited me to visit Avon’s AM department to see how this consumer goods compan uses 3D machines to create prototypes of their famously flash packaging. I was not allowed to take photos of any products because they were in development and had to settle on having my own photo taken next to an industrial strength 3D printer. It was made by an Israeli company called Objet whic recently merged with a listed US company called Stratasys – we will re-visit them later in this book. In 2013 Objet 3D printers won Design World’s Leadership in Engineering program.

The small, elaborately detailed bottles coming out of the printer were gorgeous – I kept admiring the details and did not want to put them down. ‘Why do you print them?’ – I asked. ‘To make one by han would take me more than two days, but I can design and print one in two hours – an engineer answere – and my time is worth $120/hour.’ I quickly calculated that it cost $240 for a 3D printed bottle prototype vs. $2,400 for a hand-made one. And of course 3D gives him the ability to tweak any desig which would be impossible if he had to carve everything by hand.

‘These 3D machines, printing in plastic, are essentially glorified glue guns’ – the engineer said. The magic is in their software and the metal parts that move the nozzles on the tool paths. The thickness o a layer can be set between 64 and 32 microns (31 to 62 layers per millimeter).’ The final product is ‘cured’ with ultraviolet light.

I asked about the differences between his $350,000 machine and an under $2,000 unit for home use. I
was due primarily to the thinness of layers, the maximum size of printed objects, the number of objects that can be printed at the same time, and the speed of the machine.

In the final part of this e-book we’ll review a listed company that specializes in rapid prototyping and short print runs. We will examine its stock chart and discuss how to handle it.

Industry & manufacturing

Making parts using current methods requires several employees running multiple machines and using hundreds of tools. Most machines require specialized training; they also tend to be loud, expensive and potentially dangerous. AM eliminates these problems, plus, quoting a price to a customer becomes simpler since processing time is based on the amount of material deposited at a certain density.

Today, companies have to make tools (dies) for making tens of thousands and even millions of parts. Frequently, the design and development of a die can take 12 weeks or more. Using AM to create the die could reduce the time and cost of this process, offering an enormous competitive advantage. This could be a reasonable intermediate step on the way to complete additive manufacturing.

A recent article in *USA Today* was headlined 3D printing could remake U.S. manufacturing. “About 20 miles east of Pittsburgh, the former heart of the nation's steel industry, a small company called ExOne is churning out a new generation of stainless steel boat propellers, oil pump parts and door knobs. But there are no clanging hammers, wheezing presses or even computer-controlled milling machines. Instead, a dozen 3D printers quietly stitch together industrial parts by meticulously spreading hundreds or thousands of layers of powdered metal onto a canvas until they form three-dimensional shapes.” In 2013 ExOne sold its shares in an IPO – it is now a publicly traded company, reviewed in the AM Stocks to Watch chapter of this e-book.

The article continued: “Since just a few employees run dozens of printers — vs. several hundred or thousands of workers in traditional factories — some experts say the technology can neutralize the low-cost labor advantage that countries such as China and India enjoy over the U.S. That, along with 3D printing's ability to accommodate quick product launches, is expected to accelerate a trend that ha
seen a growing number of manufacturers bring some production back to the U.S.” It quotes Christine

Furstoss, the head of General Electric's manufacturing and materials technology group, who says that in 10 years up to half of the parts in GE's energy turbines and aircraft engines could be 3D printed. A few months after the 2nd edition of this e-book appeared, GE Aviation acquired Morris Technologies, a precision-engineering firm involved in printing aircraft engine parts using aerospace-grade titanium

The spread of AM will restructure entire supply chains. The need for transportation will be reduced and many distribution networks eliminated. Retail shops will become not just transaction centers, bu production areas, capable of delivering huge choices of inventory from relatively limited spaces.

Marcel Rosenbach and Thomas Schulz write in *Der Spiegel*: “Changing a product's design no longer means the entire assembly line must be reworked as well. This shortens product cycles considerably and makes it possible to introduce improvements more quickly.”

A good model is the progress of printing on paper. A generation ago, if you wanted a quality print, you’d need to hire several experts. An artist would prepare a drawing, a specialist would create mechanicals and an expert in printing would make high quality prints with the help of several assistants. Today all of the above can be done using a low-power laptop and a $100 printer. The quality of your printed output is limited only by your imagination. AM will follow a similar course towards automation and bringing everything in-house.

Personalize your product design

While rapid prototyping was the main focus of AM during its early stages, the technology is now evolving in the direction of ‘mass customization.’ Historically, designing and producing a single object has been very expensive, but production costs fell sharply with mass production. Such economies of scale do not matter much with AM because every single object in a production line can be easily individualized with a few clicks of a mouse.

A UK company called Digital Forming has created a system that allows the general public to become involved in the design process. You can choose not only colors and textures of the products you orde but also modify their shapes, as long as your changes are within safety limits set by the manufacturer

Medicine and Dentistry

A friend of mine was told by his doctors that he needs a hip replacement. The old way would have been to find a titanium hip of approximately his size and chisel it down a bit. Not any longer – now my friend is looking for an AM company that will "print" a perfectly sized titanium bone for him.

AM's ability to create very complex shapes is becoming increasingly popular for making prosthetics

Figure 06 – A patient-specific knee implant by Stryker Orthopaedics.
Created using an EOS machine for direct metal laser sintering with bio-compatible cobalt-chrome alloy.

In 2013 Oxford Performance Materials (OPM), a company in Connecticut, received FDA clearance fo its 3D printed "OsteoFab" Patient Specific Cranial Device. These are used to fill in holes in the skull due to trauma or disease.

Figure 07 – a replacement plate for the human skull: printed using PEKK polymer.

Some injured construction workers and wounded soldiers remain in danger of medical complications due to damage to their skull. An OPM implant is made from polymer which is biocompatible and translucent to X-rays. Its microstructure encourages bone cells to invade it and deposit bone tissue, blending the printed implant with the patient's own body. Other users of this polymer are dentists wh can implant in a patient's jaw to replace lost bone.

A recent article on a website called BioMed Central stated: "The design of foot and ankle orthoses is currently limited by the methods used to fabricate the devices, particularly in terms of geometric freedom and potential to include innovative new features. AM technologies, where objects are constructed via a series of sub-millimeter layers of a substrate material, may present the opportunity to overcome these limitations and allow novel devices to be produced that are highly personalized fo the individual, both in terms of fit and functionality."

Video 06 – a 3D printed exoskeleton

Returning the use of her arms to a child whose inborn condition makes her arms extremely weak.

Physicians and biomedical scientists can use 3D technologies to help normalize the lives of disabled people. Their 3D printed devices help restore some of the abilities taken away by illnesses. The use of such devices improves not only the patients' physical abilities, but also their mental health.

At a molecular level, scientists are designing programs that will drive 3-D printers to print patient-specific medicines. You can watch a TED Talk by Dr. Lee Cronin, a professor of chemistry in Edinburgh. He describes how chemical inks can be used to create medicines as printed output.

Figure 08 – Custom-printed orthodontic aligners by ClearCorrect, LLC
The company uses Objet printers for both rapid prototyping and additive manufacturing.

Imagine going to a dentist to have a bridge made. Most dentists today use soft plastic to take an imprint of your teeth and send it to a lab. Some 10 days later an unfinished model of your bridge arrives – metal only, no porcelain. You return to the office, and your dentist tests it in your mouth, makes a few adjustments, and sends the model back to a lab. In another 10 days the lab delivers a finished bridge, and if everything goes smoothly, the dentist will fit it into your mouth after a few minor final adjustments.

In the future, he'll simply stick the wand of a scanner into your mouth, and then print a perfect bridg right there in his office, while you wait. Customization is relatively inexpensive when it comes to AM. In the months since the first edition of this book, a Danish firm 3Shape, a pioneer in intraoral scans, integrated its scans with Stratasys' (SSYS) dental 3D printers.

One of the most exciting new uses of AM is 'bioprinting' – printing human tissue and even entire organs. An article in the November 16, 2012 issue of *Science* explains that the key to growing cells i 3-D printing of a microscopic scaffold on which cells donated by a patient can thrive and multiply. I becomes possible to control the distribution of cells by printing surfaces and structures in desired shapes.

In 2013 Cornell University researchers created a replacement ear using a 3-D printer and injections o living cells. After scanning an ear, a 3-D printer produced its soft mold into which scientists injectec cow cells that produce cartilage. After three months they had a flexible and workable outer ear. Whi the printing of organs, such as kidneys and hearts is still in the future, we will return to this revolutionary idea in the final part of this e-book when we review a company called Organovo, the makers of a bioprinter.

Fun & Games

AM is not only serious business – it allows people to exercise their playfulness and creativity. Some projects are sheer fun, while others may translate into serious business down the road.

Figure 09 – Up a creek in a printed boat

The November 3, 2012 issue of *The Economist* reported of an unusual entry in Seattle’s annual Milk Carton Derby. Entries have to be made from old plastic milk bottles; they compete for speed in crossing a lake in one of the city’s parks. Three local college students had shredded and melted thei bottles, then used a 3D printer to print themselves a plastic boat.

These students intend to use their prize money to bring 3D printing to poor countries – beginning wit printing rainwater collectors and composting toilets. A trial is being planned for Mexico, and while printers have to be bought, the raw materials will be old plastic bottles that fill garbage dumps aroun the globe – turning junk into construction materials at virtually no cost.

Recycling

Organic Connections newsletter writes tongue-in-cheek: “Suppose you could replace “Made in Chin with “Made in my garage.” Suppose also that every time you polished off a jug of two percent, you would be stocking up on raw material to make anything from a cell phone case and golf tees to a toy castle and a garlic press.”

Joshua Pearce, an associate professor of materials science at Michigan Technological University, is working to reduce the cost of filament for 3D printing. He and his group are tinkering with a RecycleBot – a device that shreds milk jugs, melts the plastic, and then extrudes it as a filament that can be used for 3-D printing. Their unit is open-source and free for anyone to download from

Thingiverse.com (described in a later chapter).

Milk jugs are made from high-density polypropylene (HDPE), which is not the most ideal material fo 3-D printing, but Prof. Pearce says it is only a question of time before he solves this engineering challenge. “Three billion people live in rural areas that have lots of plastic junk. They could use it to make useful consumer goods for themselves. Or imagine people living by a landfill in Brazil, recycling plastic and making useful products or even just ‘fair trade filament’ to sell. Twenty milk jugs get you about 1 kilogram of plastic filament, which currently costs $30 to $50 online.”

Other people are working to turn plastic trash into 3-D treasure. Tyler McNaney, a college student, i developing a machine for turning plastic household waste into plastic for 3D printers. His Filabot is being built using funds raised on Kickstarter and he plans to release machine drawings to the public. This way hobbyists will be able to download his plans and build their own Filabots.

‘The Internet of things’

Computer chips can be printed as part of almost any AM object. A company named Kovio in San Jose, CA is already shipping printed radio-frequency identification (RFID) tags for tracking products as they move through a supply chain; they cost less than half of those made from silicon. A Norwegian company named Thinfilm is working to supply toy companies with trading cards for boar games that include printed memory chips; those cards can even keep game scores.

Some shippers attach strips to packages that change color if exposed to excessive heat. Thinfilm plan to print digital sensors at a comparable price that will tell at what time heat exposure occurred and how long it lasted. Similar strips can be used to track the timing of many other processes, including the wetting of diapers.

Household use

While industrial-strength 3D machines may cost tens and even hundreds of thousands of dollars, 3D printers for home use can be had for under $2,000. We will review some of the popular ones in the next chapter. The raw plastics from which home AM machines make things cost about $20 per poun

Brian Guptill is an American engineering executive who divides his time between homes in China an Florida. He owns a Makerbot 3D printer. He told me how one evening he needed a bottle opener; he went to the Makerbot website, found an opener he liked, downloaded and printed it. Another time he discovered a mouse in his house. He went to the same website, found several mousetraps, and downloaded one of them. Soon he caught a mouse that apparently had never before encountered a 3D printed mousetrap.

Art

Creative artists as well as copyists are discovering the unique possibilities of AM. At its most basic level, 3D can be used to create replicas of three-dimensional art objects.

Figure 10 – Getty Museum through a scanner, by Bruce Sterling
A 3D user scans and prints famous sculptures.

As photo-stitching software, including Autodesk's [123D Catch] becomes more powerful, you need to take only a few photos to capture and print a sculpture. In 2012, New York's venerable Metropolitan Museum of Art – the Met – held what they called a Hackathon, with folks photographing and printing their sculptures and creating derivative works.

Figure 11 - Moon Pi by Bathsheba Grossman
This sculptor used a composite material made from sintering powder to create a puzzle-sculpture made of three interlocking parts.

As the second edition of this e-book was being published, 3D Systems Corporation (DDD) entered in a major multi-year agreement with the Smithsonian Institution to provide 3D printing services and technology. The Smithsonian is the world's largest museum and research complex, consisting of 19 museums and galleries and nine research facilities.

Fashion

Modern designers are starting to adapt AM technology. Dutch designer Iris van Herpen prints her collections on Stratasys and Materialise machines.

Figure 12 – Stratasys printed cape and skirt from a 2013 collection by Iris van Herpen

The technology allows to combine both hard and soft elements within the same print. According to van Herpen, "it is only a matter of time before we see the clothing we wear produced with this technology."

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