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Disruptive manufacturing

The effects of 3D printing

Content

A 3D printing primer

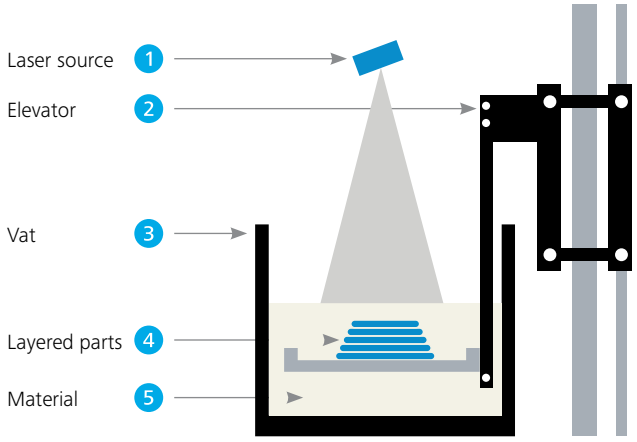
Understanding 3D printing

Additive manufacturing, or 3D printing as it's often called, is a manufacturing process that has been developing steadily since 1984. Founded by Charles Hull, the process allows three-dimensional objects to be printed from digital data.

When three-dimensional designs are created using specific software applications, like AutoCAD, digital data can be sent to a 3D printer. The output is a three-dimensional object, which is printed in sequential layers using different materials. Figure 1, below, depicts the way in which 3D printing works.

Figure 1 – How 3D Printing Works (Source: T. Rowe Price[1])

3D printers work like inkjet printers. Instead of ink, 3D printers deposit the desired material in successive layers to create a physical object from a digital file.



1 A laser source sends a laser beam to solidify the material.

2 The elevator raises and lowers the platform to help lay the layers.

3 The vat contains the material used to create the 3D object.

4 The 3D object is created as parts are layered on top of each other.

5 Advanced 3D printers use one or more materials, including plastic, resin, titanium, polymers and even gold and silver.

Due to the inimitable manufacturing processes of 3D printing, people now have the ability to innovate products from the inside out. The process cannot be mimicked using traditional manufacturing methods, since 3D printing is an additive process. This means that individuals and businesses alike can create internal skeletal structures and unique shapes within an object.

History of 3D printing

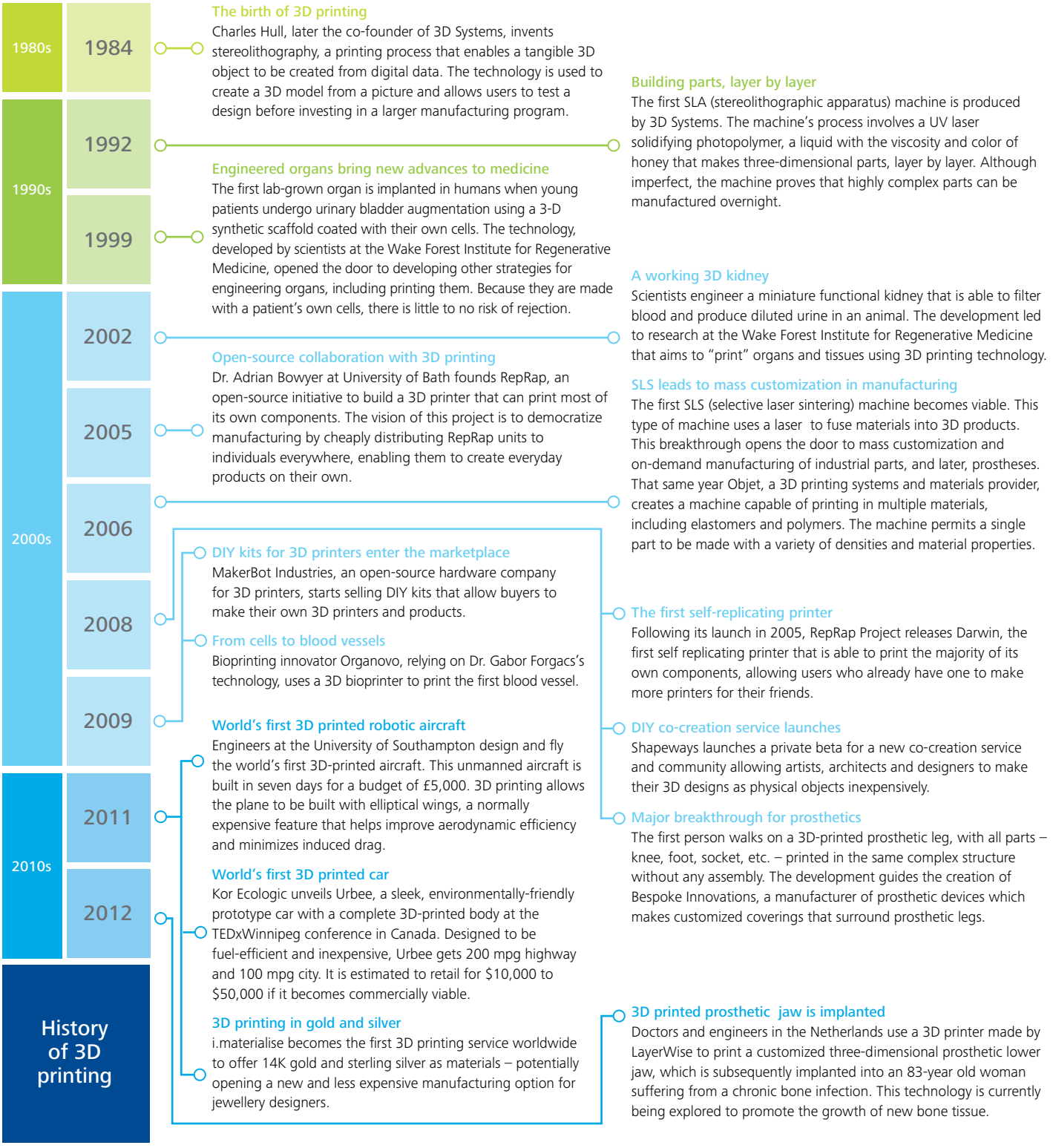
As 3D printing evolved significantly over the past 20 years, so too have the innovations that resulted from developments in the technology.

When new markets emerge, people often make incorrect predictions about the industry disruptions that will ensue. Ken Olsen's prediction is a case in point. In 1977, Olsen, the founder of Digital Equipment Corporation, said, "There is no reason for any individual to have a computer in his home." Although many people bought into this fallacy, Olsen failed to realize what computers would become, rather than what they were at the time. Two years before Olsen's erroneous prediction, an underground movement began in Silicon Valley where a community gathered to discuss the ways in which computers would change the world. Much like the time when the Homebrew Computer Club was founded in 1975, society is now at a period where a new technological disruption is being born: 3D printing.

As shown below, Figure 2 provides a brief illustration of the industry advancements that have occurred as a result of 3D printing. The examples cited pertain to the automotive, manufacturing, aviation, medical, do-it-yourself and jewelry industries. As such, the possibilities for 3D printing are diverse, dynamic and disruptive, and many industries will continue to produce new innovations each year as the technology becomes more efficient and effective.

Much like the time when the Homebrew Computer Club was founded in 1975, society is now at a period where a new technological disruption is being born: 3D printing.

Figure 2 – History of 3D Printing (Source: T. Rowe Price[1])



Applications of 3D printing

Because 3D printing allows users to develop and revise products rapidly before undertaking the costly processes associated with traditional manufacturing, the applications for the technology are vast.

As 3D printing becomes more accessible on a global scale, consumers have begun to innovate across a diverse range of industries. As a result, the process of additive manufacturing is beginning to create industry disruptions, causing new businesses to emerge and stagnant, yet well-established, businesses to fail. Navigating this disruption and embracing this new technology requires strategic foresight to profit and prosper over the next 10-20 years. The question is, "How many businesses will be ready?"

More specifically, the process of 3D printing spans many industries, including automotive, manufacturing, aviation and medical. Although the capabilities of 3D printers improve exponentially each year, a diverse range of materials can already be printed through these devices. These include urethane, metal, human tissue and even food products. As shown below, Figure 3 illustrates the global opportunities arising for 3D printing across many different industries.

Figure 3 – Global opportunities: 3D printing (Source: Forbes[2])

		Target user		
		Consumer	Small to mid-sized business	Corporations
Printer readiness	In need of further R&D		• Organ Replacement, $30B	• Furniture, $20B • Consumer electronics, $289B
	Nearing commercial use	• US Prepared food, $23B	• Bicycles, $6B • Guns and ammo, $11B • Global apparel, $1T	• Life sciences R&D, $148B • Home building and improvement, $678B • Power tools, $22B
	In use	• Craft and hobby, $30B • Animation and gaming, $122B	• Medical prosthetics, $17.5B • Retail hardware, $22B • US Auto parts stores, $40B • Toys, $80B	• Industrial R&D (for Prototyping), $23B • Aircraft and defense R&D, $9B

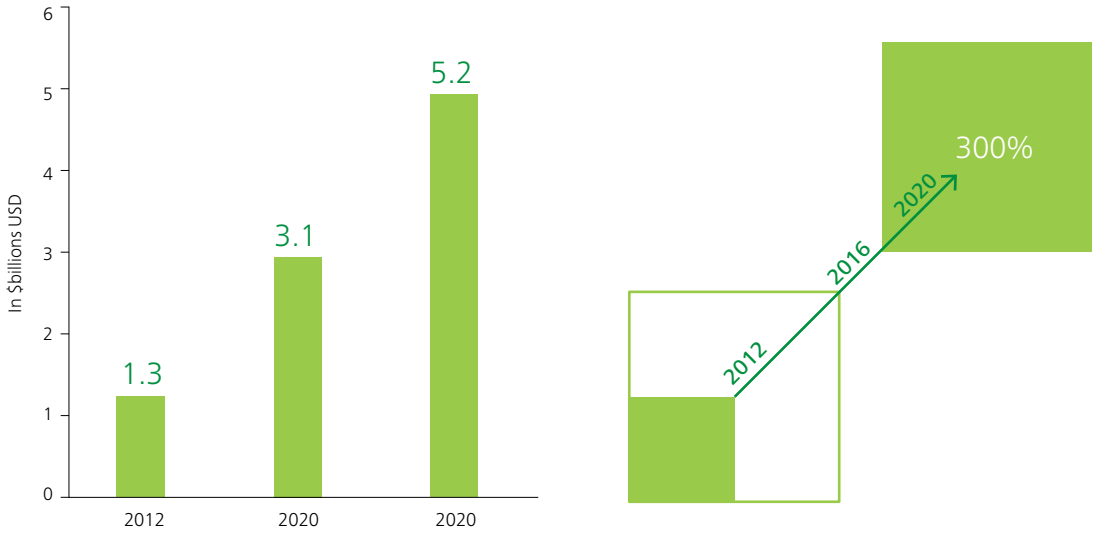
Beyond these examples, 3D printing is being used within the aerospace industry to create products for space exploration; NASA is printing parts for its J-2X and RS-25 rocket engines that will power the Space Launch System (SLS), set to launch in 2017. 3D printing is also being embraced within the life sciences industry: 3D Systems: Bespoke Products, a company that produces 3D printed prosthetics, is printing custom-made prosthetic parts to fit the individual needs of each user. Medical research labs are even experimenting with printing human organs and tissue. To date, scientific discoveries allowed these innovations to occur successfully, although they have not been implemented at a commercial level.

Industry growth

Since the mid-1980s, 3D printing has changed drastically. As the Consumer Electronics Association noted, "Sales of 3D printers will approach $5 billion in 2017, up from $1.7 billion in 2011, as demand expands for everything from consumer applications to markets such as automotive, aerospace, industrial and healthcare."[3]

As Figure 4 shows, 3D printing is forecasted to grow by 300% from 2012 to 2020. As stated by the website On 3D Printing, "The 3D printing industry is expected to change nearly every industry it touches, completely disrupting the traditional manufacturing process. As a result, the projected value of the industry is expected to explode in the near future."[4]

Figure 4 – Growth of 3D printing: 2012 to 2020 (Source: On 3D Printing[4])



Embracing 3D printing: A new medium for innovation

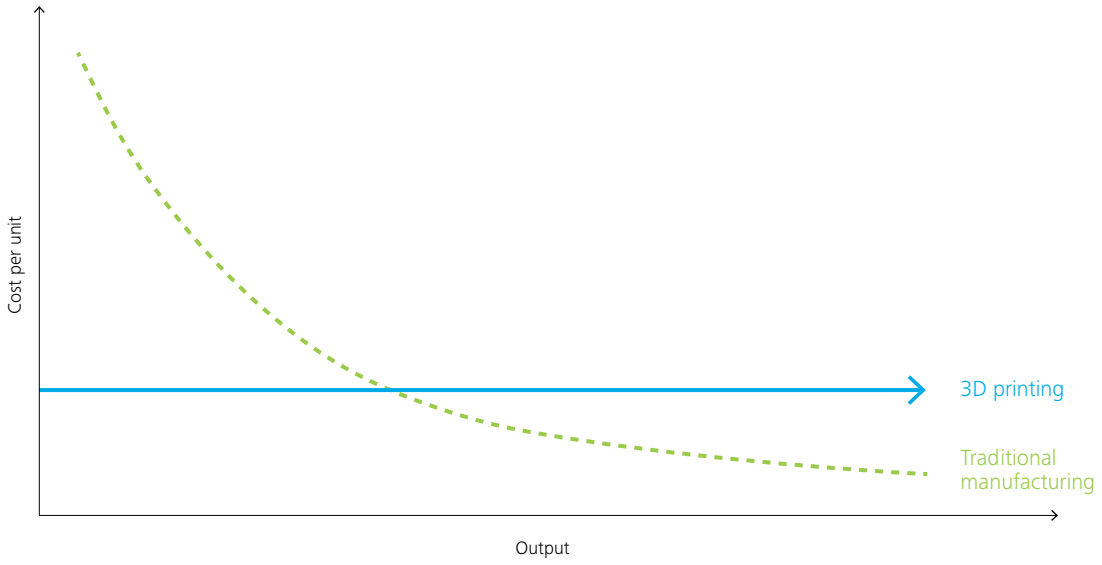
Benefits and challenges of traditional manufacturing

When new technologies emerge, the decline of industries is never rapid, nor is it immediate.

In the North American manufacturing industry, global competition has increased and industry growth has fallen for many years. The United States, once the manufacturing centre of the world, now supports fewer manufacturers than it once did. The irony is that economic growth requires innovation, and innovation cannot occur without embracing technologically-advanced manufacturing capabilities. That's why it's integral for manufacturers, and companies across many industries, to develop 3D printing capabilities to innovate continuously.

Yet, traditional manufacturing still holds an important place in the business world. Once products are developed, it is challenging for 3D printers to match the economies of scale available through traditional manufacturing. Figure 5 below illustrates a comparison of the costs of producing goods through traditional manufacturing methods vs. 3D printing. The main advantage of 3D printing is that a low number of goods can be produced at an inexpensive cost, as compared to traditional manufacturing, which typically requires higher volumes to lower costs. However, as those economies of scale come into play, traditional manufacturing can be more beneficial for producing larger quantities of products.

Figure 5 – Production volumes versus costs: Traditional manufacturing versus 3D printing



Benefits and challenges of 3D printing

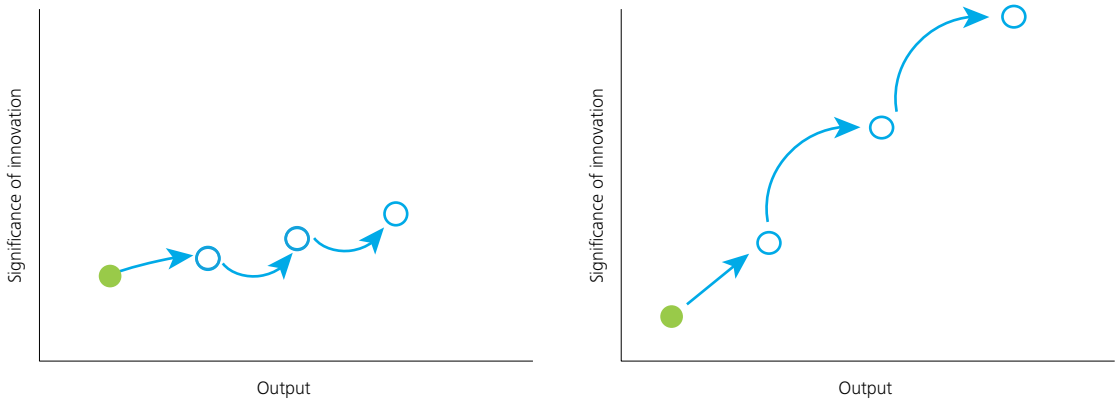
Although there are many benefits to 3D printing, there are also challenges associated with using the technology, as compared to traditional manufacturing.

These benefits and challenges arise in relation to the uses and applications 3D printing offers for consumers and businesses across many industries. These include rapid prototyping, rapid manufacturing, mass customization and mass production, amongst others.

	Benefits of 3D printing	Challenges of 3D printing
Rapid prototyping	• Single items can be produced inexpensively without incurring the mold and tooling costs of traditional manufacturing	• Entry-level 3D printers produce goods that are often inferior to those produced using traditional methods
Reduced lead times	• Lead times can be reduced as a result of being able to produce goods relatively quickly	• N/A
Rapid innovation	• New innovations can be created and revised quickly since 3D printing is an iterative process	• N/A
Rapid manufacturing	• Just-in-time inventory can be easily managed and created	• Depending on the type of printer, it can be slow to produce large volumes of products
Reduced overhead	• Overhead required to invest in inventory, and warehouse it, is reduced since items can be printed as needed. Traditional manufacturing methods typically require larger volumes of inventory to be produced and warehoused at one time	• N/A
Mass customization	• Products can be customized for a single purpose or created in small and economical production runs (see Appendix A for a business model created around this concept)	• Limited materials can be printed through 3D printers for commercial production
Mass production	• Unique products that can't be made using traditional manufacturing methods can be produced for mass production	• While traditional manufacturing can produce extremely large products, such as pipelines for transporting natural resources, most 3D printers cannot
Use of unique materials	• Materials, such as human tissue, can be printed through 3D printers	• N/A
Economies of scale	• N/A	• The cost of producing large volumes of some products can be high using 3D printers

Figure 6 below depicts the differing nature of innovation as it tends to apply to traditional manufacturing versus 3D printing. Specifically, traditional manufacturing often results in evolutionary innovation, while 3D printing can result in revolutionary innovation.

Figure 6 – Innovation through traditional manufacturing, as compared to innovation through 3D printing



Evolutionary innovation (Leads to stagnation)

Revolutionary innovation
(Leads to growth and competitive advantage)

Evolutionary innovation is incremental and frequent in nature. It occurs when a new product, service, process, or experience is created to improve on the attributes of the existing offerings in the market. Innovations which are evolutionary result in new attributes to be created, whereby customers expect these attributes to be developed eventually within the market.

Revolutionary innovation is radical and less frequent in nature. It occurs when a new and unexpected product, service, process, or experience is created within the market. Revolutionary innovation does not typically affect existing markets, since the innovation being offered in the market is completely new to customers.

Cost of using 3D printing to produce a product

The cost of producing large volumes of goods through 3D printing is not always economical.

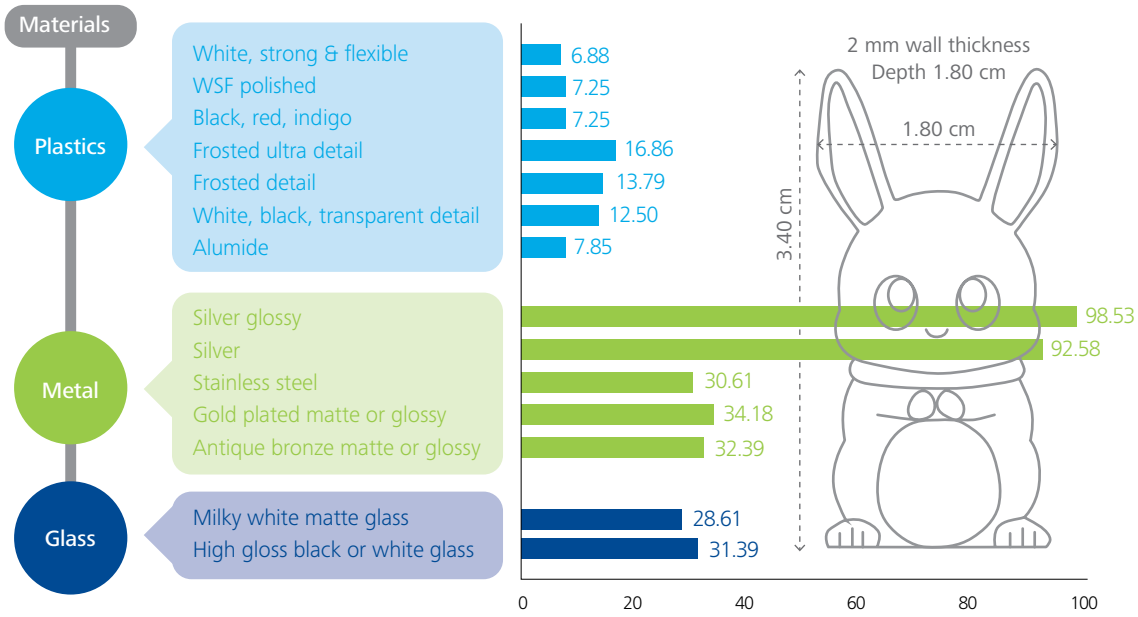
However, depending on the materials used to print an object, it can be inexpensive to produce low volumes of goods when economies of scale are not required. For example, Figure 7 illustrates the cost to produce a toy bunny using different materials through a 3D printer.

Figure 7 – What does a 3D printed bunny cost? (Source: Shapeways[6])

What does a 3D printed bunny cost?

What does Bowie the Bunny cost in different materials available at Shapeways?

*Bowie the Bunny is from BAROBA's shop at Shapeways and has been used to calculate cost estimates ($USD) or printing Bowie in different materials. These estimates are based on printing Bowie using the following dimensions: 1.80 cm (W), 1.80 cm (D), 3.40 cm (H), and 2.0 mm wall thickness.



Unforeseen disruption: A case of rapid innovation

Chris Anderson, former editor-in-chief of Wired Magazine, is a perfect example of a consumer who embraced 3D printing to create new innovations.

In 2009, Anderson began experimenting with 3D printing to produce unmanned aerial vehicles (UAVs). As he innovated continuously, his products became popular with UAV enthusiasts. In 2012, Anderson left Wired to work full-time on his venture, 3D Robotics. Currently, the venture-backed enterprise is a multi-million dollar company and is growing significantly each year.

Already, 3D Robotics has more than 70 employees across three offices in San Diego (engineering), Berkeley (business and sales) and Tijuana (manufacturing). It is the commercial sponsor of the DIY Drones community and the exclusive manufacturing partner of the Pixhawk UAV research team at the renowned Swiss Federal Institute of Technology in Zurich.[5]

This example is particularly notable given its capacity to disrupt larger organizations that could have been developing products in the UAV space. Boeing, Standard Aero and even NASA all come to mind as potential UAV competitors. Yet, it took Anderson's home-based start-up to introduce these UAV product innovations to the market by embracing 3D printing.

Needless to say, Anderson is not alone. As other individuals and entrepreneurial businesses begin to embrace 3D printing, countless industries will be subjected to potentially serious, and unanticipated, disruption.

As other individuals and entrepreneurial businesses begin to embrace 3D printing, countless industries will be subjected to potentially serious and unanticipated disruption.

Establishing a 3D printing initiative: Creating value through innovation

Adopting a 3D printing framework

Before businesses can capitalize on these emerging opportunities for innovation, they need a framework for success.

Since 3D printing is still foreign to many businesses, it can be difficult to align all the elements required for program success, such as strategy and operations, human capital, technology and financial advisory. To avoid missteps, it is important to adopt a well-thought out 3D printing framework. The framework below includes five key steps:

3D printing – Strategic framework

Establish the initiative

- How can 3D printing directly affect our company or industry?
- What are the future implications for industry disruption?
- How can we establish 3D printing within our organization?

Invest in technology

- What technology (hardware and software) is required to set up a 3D printing initiative?
- How much should we spend on technology, based on our size and capabilities?
- Where can we source the technology?

Create a network

- What key partnerships should we establish to ensure 3D printing success?
- Are there any public sector grants or benefits we can access?
- Who are the key stakeholders in the 3D printing industry?
- Do we need to change any of our governance controls to protect our intellectual property?

Change the organization

- What key skills and abilities do we need to start and run a 3D printing initiative?
- Do we need to change our organizational structure?
- Do we need to create new business units?
- Who are the key stakeholders expected to manage our initiative and help create value for the organization?
- What new jobs and roles must we create to manage the initiative?

Implement the innovation

- How will we take 3D printing innovations to market?
- If we need to scale up, should we produce products through 3D printing or traditional manufacturing?
- Are the innovations new products for an existing market or a new market?
- How do these products fit within our existing product range?
- Who is the target market and how will we present this product to the market?

Future implications of 3D printing: Industry outlook moving forward

Industry outlook

3D printing will potentially have a greater impact on the world over the next 20 years than all of the innovations from the industrial revolution combined.

3D printing has developed significantly over the past 30 years and now allows consumers and businesses to conduct rapid prototyping and even produce individual items at a profit. A new industrial revolution is coming as commercial 3D printers become smaller and more portable. As the costs for 3D printers decreased drastically in recent years, the technology has become accessible to businesses across many industries. Commercial printers, which once cost $10,000 to $20,000, now cost between $2,000 and $5,000. This price decline is making high-end 3D printers accessible to the mass market. As a result, general consumers are using 3D printers to create unique items from the comfort of their own homes. In fact, consumers are even creating new innovations without financial, technological or human capital support from large organizations.

In the future, 3D printing will have a wide range of applications extending from healthcare to construction and beyond. In healthcare, for instance, 3D printing represents a truly disruptive force, particularly as costs rise and resources for transplant surgery remain scarce. Once bio-printing or the 3D printing of human organs and tissue becomes commercially viable, patients will have access to single organs, printed using the size and organic structure they need. As surgical lead times and healthcare costs drop, these innovations will be important for both emerging and developed economies.

In order to benefit from the applications and opportunities of 3D printing moving forward, companies in virtually every industry must be fast, flexible and capable to understand the implications that 3D printing will have on the nature of their businesses. Failing to do so will lead to a potential loss of market share, due to increased competition from new companies that create market changing, disruptive innovations. And competition won't stop there. As more and more individual consumers gain the ability to engineer and produce their own goods, and 3D printing becomes a more efficient and cost-effective way to produce goods, there will be an opportunity for individuals to create new innovations, disrupt industries, and potentially generate new sources of wealth. As long as the technology is accessible, new businesses will continue to emerge.

Although traditional manufacturing will likely still hold a place in the competitive landscape in the years to come, the next 10 to 20 years promise to reveal a rapid increase in the innovations made possible by 3D printing. To fully capitalize on these opportunities, governments may choose to make 3D printing widely accessible within free public service locations, such as schools and libraries. For its part, the private sector will want to continue working towards embracing this technology as a platform to create new businesses, business models, products and services that push society forward by spurring the creation of new sources of global wealth.

In the future, 3D printing will have a wide range of applications extending from healthcare to construction and beyond.

Appendix A – Case study: Digital dentistry

Invisalign: Creating a new business model through 3D printing

In FY12, Invisalign generated over $500M in revenue globally, all from a single product created from a 3D printer.

3D Systems was already a leader in the rapid manufacturing of end-use parts when they were approached by a start-up company with a novel idea. The concept was to use digital scanning and 3D printing to dramatically change the way teeth were straightened for adults and older teens. This company believed that personal orthodontic treatment devices manufactured using the latest, digital technology could eliminate the reliance on metal or ceramic brackets and wires, significantly reducing the aesthetic, discomfort and other limitations associated with braces.

That company, Align Technology, was founded in 1997 and received FDA clearance for their invention, the Invisalign System®, in 1998. 3D Systems worked closely with Align every step of the way to develop this customized solution, installing and servicing a fleet of SLA 3D printers with the necessary consumable materials and service.

Source: Digital Dentistry[7]

Now, in a factory-like setting, 3D Systems technology produces 50-60K units daily, positioning Invisalign Systems® as the marketplace leader and changing the way people look at orthodontic procedures. Align Technology was a very early adopter of 3D printing for mass customization and they continue to iterate on their concept, extending their reach and helping both dentists and patients find something to smile about.

Appendix B – Sources

Endnotes

1. **Timeline of 3D printing**
   http://individual.troweprice.com/staticFiles/Retail/Shared/PDFs/3D_Printing_Infographic_FINAL.pdf
2. **How HP Could Reinvent 3D Printing…and Itself**
   http://www.forbes.com/sites/stevefaktor/2012/10/15/how-hp-could-reinvent-3d-printing-and-itself/
3. **Sales of 3D Printers to Reach $5 Billion by 2017**
   http://wirthconsulting.org/2012/10/16/sales-of-3d-printers-to-reach-5-billion-by-2017/
4. **3D Printing Growth**
   http://on3dprinting.com/2012/11/01/3d-printing-industry-growth-forbes-incorrectly-says-52b-by-2020/
5. **DIY Drones**
   http://diydrones.com/profiles/blogs/3d-printed-uav-models
6. **What does a 3D printed bunny cost?**
   www.shapeways.com
7. **Digital Dentistry**
   http://www.aligntech.com/Pages/Solutions.aspx

Bibliography

1. **The Top Ten Fastest-Growing Industries in America**
   http://business.time.com/2012/04/19/the-top-ten-fastest-growing-industries-in-america/slide/3d- printer-manufacturing/
2. **3D Printing is here – but the factory in every home isn't here yet!**
   http://www.deloitte.com/view/en_GX/global/industries/technology-media-telecommunications/tmt- predictions-2012/technology/ab173e14447a4310VgnVCM1000001a56f00aRCRD.htm
3. **NASA Plans for 3-D Printing Rocket Engine Parts Could Boost Larger Manufacturing Trend**
   http://www.scientificamerican.com/article.cfm?id=nasa-3-d-printing-sls-rocket-engine
4. **Mobile Apps Offer 3-D Printing Via the Cloud**
   http://blogs.scientificamerican.com/observations/2012/04/29/mobile-apps-offer-3-d-printing-via- the-cloud-video/
5. **Stratasys**
   http://www.stratasys.com/
6. **Technology, Media & Telecommunications Predictions 2012**
   http://insights.deloitte.ca/wp-content/uploads/2012/01/FINAL-Global-TMT-Predictions-2012-16264A_UL-Lo.pdf
7. **TED Talks: Anthony Atala: Printing a human kidney**
   http://www.ted.com/talks/anthony_atala_printing_a_human_kidney.html
8. **Lisa Harouni: A primer on 3D printing**
   http://www.ted.com/talks/lisa_harouni_a_primer_on_3d_printing.html
9. **United Kingdom: Deloitte Monday Briefing: Print Me A Bond Car**
   http://www.mondaq.com/x/207176/Economic+Analysis/Deloitte+Monday+Briefing+Print+Me+A+B ond+Car
10. **3D-printed consumer electronics just became a reality**
    http://www.extremetech.com/extreme/141669-3d-printed-consumer-electronics-just-became-a- reality
11. **The New Maker Rules: Big forces are reshaping the world of manufacturing**
    http://www.economist.com/news/business/21567127-big-forces-are-reshaping-world- manufacturing-new-maker-rules

12. **Carbomorph material enables 3D printed electronics, from any 3D printer**
http://www.core77.com/blog/materials/carbomorph_material_enables_3d-printed_electronics_from_any_3d_printer_23947.asp
13. **Liver troubles? Soon you might just print off a new one**
http://now.msn.com/liver-troubles-soon-you-might-just-print-off-a-new-one
14. **Dutch Architecture Firm Unveils Large Scale, Mobile 3D Printer to Print Architecture**
http://blogs.artinfo.com/objectlessons/2012/09/17/dutch-architecture-firm-unveils-large-scale- mobile-3d-printer-to-print-architecture-on-demand/
15. **You don't bring a 3D printer to a gun fight – yet**
http://news.cnet.com/8301-11386_3-57499326-76/you-dont-bring-a-3d-printer-to-a-gun-fight- yet/?part=pulse&subj=latest-news&tag=title&utm_medium=referral&utm_source=pulsenews
16. **Bre Pettis on The Disruptive Future of 3D Printing**
http://bigthink.com/amped/bre-pettis-on-the-disruptive-future-of-3d-printing
17. **"3D Printing: This Century's most disruptive innovation?" David F. Flanders, TEDxHamburg**
http://www.youtube.com/watch?v=ChKwIUhx_ic
18. **3D Printing Is Disruptive Technology With Political Ramifications**
http://ivn.us/2012/08/10/3d-printing-is-disruptive-technology-with-political-ramifications/
19. **Key Issues : 3D Printing: Bits to Atoms**
http://publicknowledge.org/issues/3d-printing
20. **It Will Be Awesome if They Don't Screw it Up: 3D Printing**
http://publicknowledge.org/it-will-be-awesome-if-they-dont-screw-it-up
21. **Atoms are the New Bits**
http://www.wired.com/video/atoms-are-the-new-bits/63270385001
22. **The 3D Printer Revolution**
http://www.wired.com/video/chris-anderson-the-3d-printer-revolution/1854142620001
23. **3D Printing Will Be Bigger Than the Web**
http://on3dprinting.com/2012/11/18/chris-anderson-3d-printing-will-be-bigger-than-the-web/
24. **Staples Announces In-Store 3-DPrinting Service**
http://www.wired.com/design/2012/11/staples-goes-3-d/
25. **New Industry Report on Additive Manufacturing and 3D Printing Unveiled**
http://wohlersassociates.com/press54.htm
26. **Makerspace**
http://makerspace.com/
27. **What's The Big Idea? Pentagon Agency Backs Student Tinkerers To Find Out**
http://www.npr.org/blogs/alltechconsidered/2012/11/19/165033117/whats-the-big-idea-pentagon- agency-backs-student-tinkerers-to-find-out
28. **Look Ma, I Made It Myself! 10 Amazing Things 3-D Printers Can Do Now**
http://www.wired.com/design/2012/04/10-things-3d-printers-can-do- now/?utm_source=Contextly&utm_medium=RelatedLinks&utm_campaign=Previous&pid=172&vi ewall=true
29. **3D printed organs aid surgeons**
http://www.engineering.com/3DPrinting/3DPrintingArticles/ArticleID/5575/3D-Printed-Organs-Aid- Surgeons.aspx
30. **Additive Manufacturing Market (2012 – 2017)**
http://www.marketsandmarkets.com/Market-Reports/additive-manufacturing-medical-devices- market-843.html

Notes

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