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Rapid Growth and Development of 3D Printing

Natish Chalotra[1], Amitpal Singh[2]
Department of Computer Science and Engineering
Guru Nanak Dev University, Regional Campus, Gurdaspur, Punjab, India
natishchalotra@gmail.com [1], apsohal@yahoo.com [2]

Abstract:
3D printing also known as Additive manufacturing has been revolutionized the world, from now to next hundred years, economists, hobbyist and innovators said this 'third industrial revolution' but I said this '3D revolution'. This technology is now used for construction and production of every material, viz. from needle to ships to satellite; from human, tissue to organ replacement. This article is to provide an overview of the rapid growth and development of 3-D printing in various fields, its current potential use, and its limitations. Practical considerations concerning, adaptability of 3D prints for a variety of applications are explored, as are prospective future developments concerning this technology.

Keywords: 3D printing, manufacturing, defense, aerospace, healthcare.

I. INTRODUCTION

3D printing also known as Additive manufacturing (3D printing) is manufacturing technology that creates objects by addition of layers rather than subtraction. 3D printing is now commercially available to individuals, corporate departments, hospitals, schools and small businesses. Now it gives the flexibility of make parts, tools and appliances by using different type of materials. Now you can download a digital 3D model of an object and using a computer simply create a new object by just click on "print," you can watch making of 3D object. 3D printing is a new reality not a science fiction now. [1]

3D printing is evolving instantly, by all of practical examples in myriad industries including aerospace, automotive defense and healthcare. Now, 3D printing used to construct structures that cannot be produced using all other technology. [1]

3D printing technologies were developed nearly 30 years ago, but this decade, 3D printer has seen a rapid development in tools, applications and techniques in both commercial and consumer side.

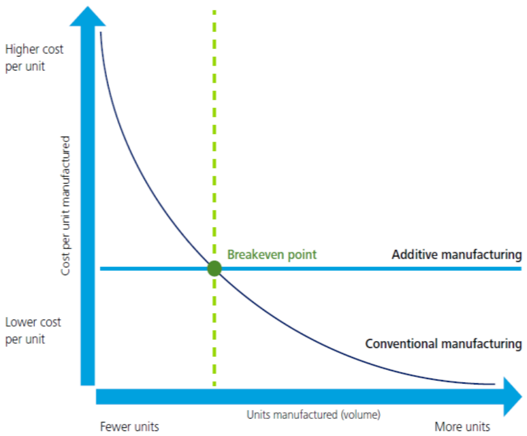

Figure 1. Breakeven analysis comparing conventional and additive manufacturing processes
Source: Mark Cotteleer and Jim Joyce, 3D opportunity: Additive manufacturing paths to performance, innovation, and growth, Deloitte University Press, http://dupress.com/articles/dr14-3d-opportunity/, accessed March 17, 2015.

The cost per unit price of additive manufacturing is dropping, making 3D printing increasingly developed with respect to conventional manufacturing due to differences in costs. Although costs for 3D printing is higher than that for conventional manufacturing, but effort is made to reduce up-front investment that often makes total cost of 3D printing less for small production runs (see figure 1). [2]

So, 3D printing a important technology for small production firms, as material cost of printing design such as solid block is less and also requires less time and material. The production is transferred from physical world to the digital world through open source designs provided by the company(shapeways, thingsverse, sculpto). Now engineers can design complex, intricate, crystal structure and upload for review on the company site for review. Also now, manufacturers can produce lightweight and stronger parts that help reducing overall cost of production because it require less assembly time, thus increasing the value of product. [2]

3D printing has historically used plastics such as ABS and PLA, but newer machines can print with the combinations of materials. 3D printing use polymers, maple wood, bronze, iron, or ceramic are now available at the client level, which allow designers to create objects with characteristics of material used. For example, MarkForged experimenting in printing PLA objects infused with carbon fiber, fiberglass, or Kevlar, which results3D-printed objects with load wearing capacity because it has higher strength-to-weight ratios than aluminum and other hard materials.[3] Christian von Koenigsegg manufacturer of the Swedish supercar has discussed the utility of this technology in high-performance, low-volume applications. Company named GE make titanium jet engine turbine blades. Also construction firms from china print five-story cement apartment buildings in Suzhou Industrial Park. 3D printers seamlessly used in electronics industry by using embed electronics with combining conductive and structural materials in the same device and print intricate electronic circuitry within an object during production. 3D printing also used in medicine, recreating human organs using a mix of alginate and human stem cells, printing custom hip replacements that facilitate bone growth. [3]

In other words, 3D printing development in the next phase within manufacturing companies will provide imminent manifest realm. Stratasys has a direction connection to some of this work that is carried out in various industries. NASA in November 2014 a Jet Propulsion Laboratory installed parts 3D printed by Stratasys onto one of its satellites bound for outer space. Airbus is using Stratasys' production-grade printers to print flight parts for its new A350 XWB airplane; the first one of these planes delivered in December 2014 had more than 1,000 3D-printed parts installed in it. In his SDM's report Allison wrote "Within 10 years, every commercial airplane will have 3D printed parts on it". Bartel said "If you wanted to print a full airplane wing, you could theoretically do it".

Worldwide market for 3D printing services and products grew to $4.1 billion in 2014, and expected to grow by $8.0 by 2020, according to the Wohlers Report. And more growth is expected in coming years. [3]

II. Survey That Describe The Requirement Of 3D Printing

It is incredibly exciting to create and build own design with 3D printing technology. Now, commercial aircraft also uses 3D printer to produce its parts. Within 10 years, every commercial airplane will have 3D printed parts on it. That is not just 3D printing technology apply across multiple industries medical, defense, energy, automotive, etc. At Stratasys 3D printing is revolutionizing the changing way of manufacturing the product. [4]

3D printing's has an imminent impact on various industries. This is the survey of serious, professional users of 3D printing, many of them working for companies with over $50M in revenue. Various Questions asked during the survey are; how will they use 3D printing over the next three years? What do they see as the greatest benefits of and hurdles to 3D printing adoption? What is the business value? How will product development evolve? Who will invest in owning the technology and what role will service providers play?

The rapid changing industry needs argue a 3D printing industry research report is almost futile because the findings will quickly need updating once completed. While the data may only be accurate for a short period of time, it's the insights we can glean from them that hold the greatest value. With this research project, Stratasys Direct Manufacturing set out to uncover the common themes among companies who are on the spectrum of larger-scale adoption and integration of 3D printing into their manufacturing process. The most interested discovering how they will do it and their latent needs. What do they see as barriers to getting there, and what resources and support will they need along the way? Sharing this information with the industry to help advance adoption and help manufacturers maximize the business benefits of 3D printing. [4]

The findings indicate what equipment, materials, applications, services and business benefits are capturing the attention of 3D printing's most committed users, and where their companies will invest. Respondents expect their companies to expand their use of 3D printing – most will increase in-house capabilities to meet the demand, yet many also express the need for a partner that will not only augment their internal manufacturing capacity, but also guide them through the expansion of internal capabilities, providing technical support and design consulting. 3D printing's greatest value is not as a technology, but as an enabler to derive greater business value.

If your company is a committed user of 3D printing, these findings will provide assurance that you are headed down a similar path of your peers and face many of the same challenges to adoption. Using 3D printing to made products may just be emerging as a competitive advantage today, but companies that don't initiate investment soon will quickly be at a considerable disadvantage. [4]

*Note: The terms additive manufacturing (3D printing) and 3D printing were used interchangeably in this study.

III Survey Methodology: How Survey Is Conducted

Data Collection:

Survey administrator: SMS Research Advisors

Methodology: Online

Timeframe: April 10 to May 1, 2015

Survey length: 36 questions

Sponsor: Stratasys was NOT identified as the study sponsor, so as not to bias results

Database: Industry list of approx. 40,000 email addresses aggregated from multiple sources

Completed interviews: 700

All statistically significant results are reported at the 95% confidence level

Statistical accuracy: +/-3.8%

Qualified Respondent:

- Currently uses or is considering additive manufacturing in the next 3 years.
- Has some role in either the selection or management of manufacturing service providers.
- Uses or foresees using (within the next 3 years) at least one additive or traditional manufacturing process.

PROFILE OF SURVEY RESPONDANTS:

Survey's respondents are serious users of 3D printer. Respondents are one of the 700 executives, engineers, designers and project managers who already using 3D printing in their industry processes or plan to do so in the next three years, making this one of the most valuable industry surveys of professional 3D printing users.

40% of participants were employed by companies with over $50M in revenue in 2014, as noted in Figure A. Many of them are decision-makers in the selection of 3D printing services and processes for their companies. Industries represented include consumer products, medical, aerospace and automotive, among others.

Some of survey findings are from The Wohlers Report, the 3D printing industry's comprehensive and undisputed source of trends, analysis and forecasts. Though different in their scope and scale, these two reports serving a similar purpose: to further advance the knowledge, resources and expertise available within the 3D printing sector. By delivering knowledge to the greater industry community, this accelerate adoption and influence public perspective of resources, expertise, designers and those in production.

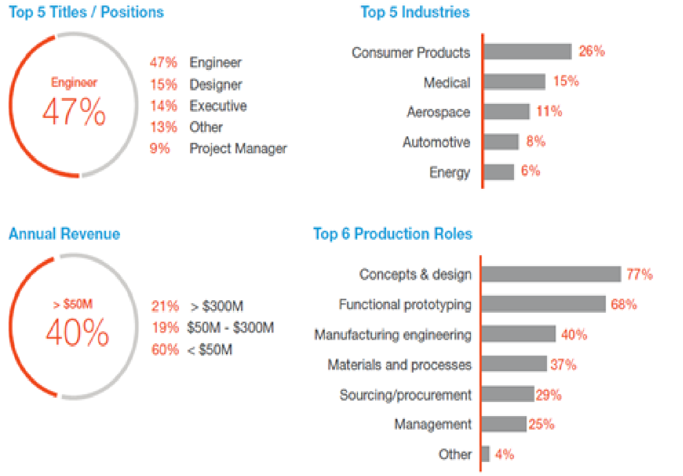

Figure A. Survey respondents ranged from engineers and designers to executives and project managers,
40% of who work for companies with more than $50 million in revenue. They serve in a variety of production roles and work across a number of industries.

CURRENT STATE OF 3D PRINTING: BENEFITS:

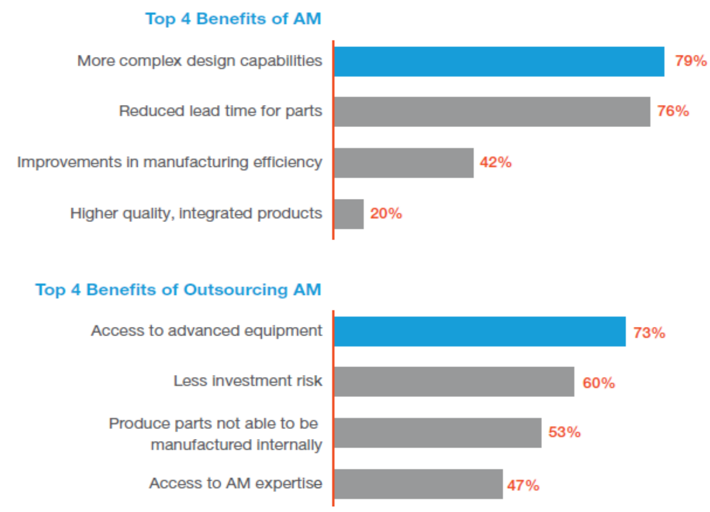

Figure B. Respondents were asked what they perceive to be the top 3 benefits of both 3D printing in general and outsourcing 3D printing. The 4 most popular responses are highlighted here.

The most significant benefits of using 3D printing are addressed there. The most common responses were: improvements in manufacturing efficiency (42%) reduced lead time for parts (76%) more complex design capabilities (79%).
What they believe to be the top benefits of outsourcing 3D printing is also addresses in this bar graph. The most common responses were: access to 3D printing expertise (47%) produce parts not able to be manufactured internally (53%) less investment risk (60%) access to advanced equipment and materials (73%).
The responses validate that 3D printing users find the benefits essential to product development and manufacturing because the process creates complex parts in a way that increases industry efficiency and gets them to market faster. Regardless of whether companies own 3D printing machines, respondents indicated outsourcing part production is valued as a way to minimize risk and compensate for resources or expertise that doesn't exist internally.
The manufacturing industry must change the conversation from emphasizing 3D printing's technical benefits to its overall business value.

CHALLENGES:

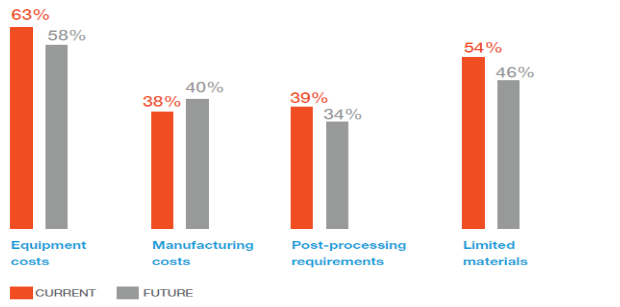

Figure C. Respondents were asked what they perceive as the top challenges their company faces in using 3D printing now and will face in the future. The 4 most common responses are shown in this graph.

An analysis of the current state of 3D printing would not be complete without being realistic about the challenges to implementation. We asked respondents to weigh in.
As noted in Figure C, two of the top four challenges are financially-based, indicating that cost remains a notable barrier to implementation.
In order to overcome these challenges, Stratasys Direct Manufacturing believes the industry must change the conversation from emphasizing 3D printing's technical benefits to its overall business value.

ATTITUDES:

25% / 45%	If the benefits of AM were better understood by our company, I believe we would be doing more of it.
32% / 49%	I do not believe my company is fully leveraging the advantages of AM today.
40% / 7%	We are now doing more AM in-house that we used to outsource in the past.
40% / 28%	We have already started to rethink product design to fully leverage the design capabilities of AM.
50% / 61%	I believe that manufacturing service providers will play an increasingly important role in the future of manufacturing.

USING AM CONSIDERING AM

Figure D. The attitudes of respondents towards 3D printing varied based on whether they currently use 3D printing or plan to use 3D printing in the next 3 years.

Some survey questions were developed specifically to allow us to compare and analyze the difference in attitudes held by decision-makers and influencers whose companies are currently using 3D printing against those that are considering, using 3D printing within the next three years. Our hypothesis was the attitudes would vary depending upon where companies are along the spectrum of adopting 3D printing, which the findings proved to be true. Here are the most interesting differences between the two groups:

- Businesses currently using 3D printing are more likely to say they have started to rethink product design to fully leverage the design capabilities of 3D printing than those who are considering 3D printing.
- When compared to those already using 3D printing, people who are considering 3D printing are more likely to believe manufacturing service providers will play an increasingly important role in the future of manufacturing.

- Other significant attitudinal differences are highlighted in Figure D.

PREPARATIONS FOR THE FUTURE:

We wanted to know what steps companies are taking to prepare for transferring from traditional manufacturing to 3D printing in the future. The top responses, presented in Figure E, are shared by companies who are already using 3D printing today as well as those who are planning on using 3D printing in the future.

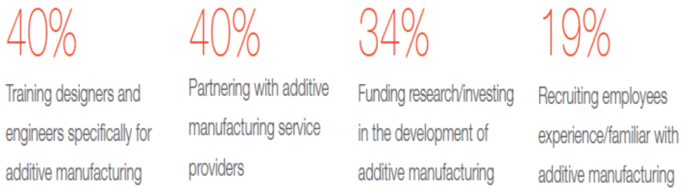

FIGURE E. Companies are taking a number of steps to prepare for an increase in their 3D printing output.

The most common steps taken include: partnering with 3D printing service providers (40%) and training designers and engineers specifically for 3D printing (40%). Based on these responses, it's clear companies have been focusing on shoring up gaps in internal expertise. Companies are investing in the future by training employees specifically for 3D printing and encouraging professional development through educational classes and seminars. Partnering with a service provider not only gives users access to equipment and materials they may not have experience with, but also consultative expertise.

FUTURE STATE OF 3D printing: ISSUES OF GREATEST FUTURE IMPACT

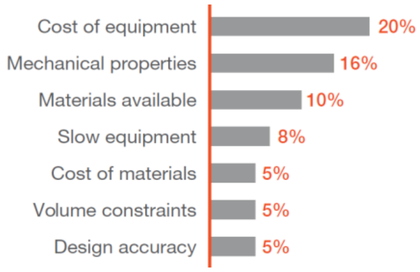

FIGURE F. Respondents were asked what one issue they feel will have the greatest impact on the 3D printing market. Interestingly, no one issue stands out significantly more than another.

We asked respondents what issues they see as having the greatest impact on the 3D printing market. As you can see, responses range from cost of equipment and mechanical properties to materials available and design accuracy. Interestingly, employee training and education did not come up high on the list. This may be because, per the findings on Preparations for the Future, some respondents said they've already invested in training designers and engineers specifically for 3D printing, and recruiting employees who are experienced or familiar with 3D printing.

Among the top 7 responses (Figure F), no one issue stands out more than another. We believe this indicates users are looking to industry thought leaders – 3D printing companies, analysts and members of the media – to tell them what issues will impact them most, so they can focus their efforts on those one or two issues.

SCALING CAPABILITIES & THE ROLE OF THE SERVICE PROVIDER:

According to The Wohlers Report 2015, use of 3D printing services grew nearly 40% from 2013 to 2014. With this survey, we were interested in learning how companies intend to expand their use of 3D printing in the future – will they acquire and expand internal capabilities, rely on an external partner, or both?

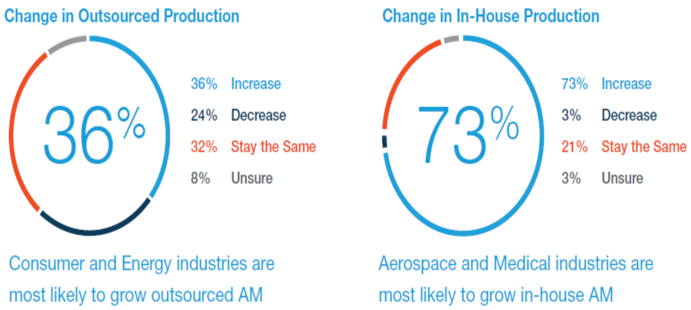

FIGURE G. We asked respondents whether they expect their company's in-house 3D printing production to increase, decrease or stay the same over the next 3 years. We asked the same question relative to their company's outsourced 3D printing production.

It stands to reason that in-house 3D printing capabilities are expected to grow as more companies invest in equipment, specifically those in the aerospace and medical industries. Nearly half of those who already have in-house equipment use it for the vast majority of their total 3D printing needs.

The majority of respondents said that regardless of their company's in-house 3D printing capabilities, they believe there will always be value in partnering with a 3D printing service provider to augment internal capabilities.

Companies are choosing to outsource 3D printing projects not because they have to, but because they want to. Respondents are especially attracted to outsourcing technologies that require more post processing, particularly Direct Metal Laser Sintering and Laser Sintering. Not only does outsourcing help companies meet production shortfalls, but service providers may have experience with a company's application type and may be better suited to help them realize 3D printing's full potential. The interest in ongoing access to expertise, spanning across the entire spectrum of product development and technology adoption, helps explain why respondents expressed interest in working with service providers even after they've purchased 3D printing equipment.

The majority of respondents – both current and future users over the next 3 years – strongly believe that more end-use parts will be designed specifically for 3D printing in the future.

APPLICATIONS:

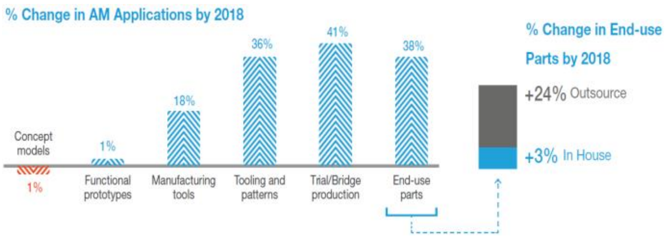

FIGURE H. This chart shows anticipated growth in 3D printing by application type over the next 3 years. Aerospace and Automotive are expected to grow the most in production of end-use parts.

By 2018, 3D printing can expect growth spurts in tooling, stability in early stages of product development trial and end-use production applications. Respondent’s investments in 3D printing and designing specifically for 3D printing have helped expand their use of the technology for end-use part production.

Aerospace and automotive industries will expand their end-use part production the most. This is not surprising because these industries were among the first to explore end-use part production and, therefore, are further along in validating designs and materials to fit application needs.

A higher percentage of new end-use part production will be outsourced to service providers rather than done in-house. Survey results show there will be a 24% increase in end-use parts produced via outsourced 3D printing by 2018 (Figure H), indicating respondents believe 3D printing service providers have the expertise, materials and/or processes to meet their company’s 3D printing endues part production needs better than their own internal capabilities. This augmented support helps those who are new to end-use production with 3D printing navigate uncharted territory.

MATERIALS

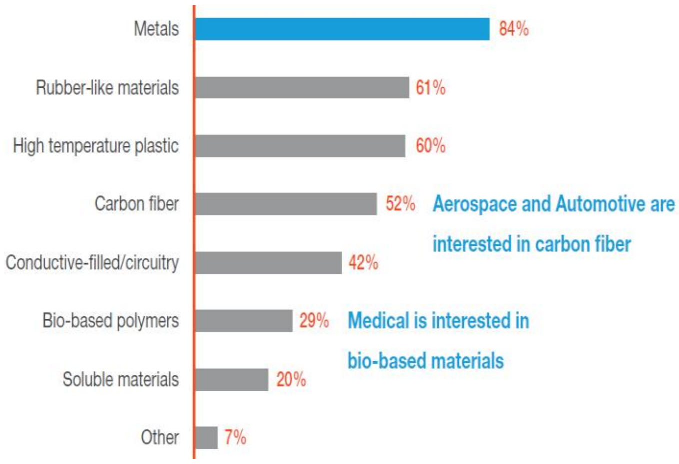

FIGURE I. Respondents were asked which materials they’d like to see further developed for 3D printing in the future. Metals are the clear leader.

We asked respondents what materials they would like to see further developed for 3D printing. Future material interests and needs are focused on properties.

Decidedly, metals are most highly-coveted across all industries, with 84% of respondents interested in seeing more metal material developments (Figure I). Rubber-like materials and high-temperature plastics are in high demand for future use as well. Past these top 3 materials, property needs are very industry-specific. For example, respondents in aerospace and automotive sectors are more interested than other industries in carbon fiber, while respondents in the medical industry are more interested in bio-based materials.

There’s a perception that metals are more highly sought-after in the aerospace sector than other industries, but this survey indicated the demand is equal across all sectors.

Stratasys Direct Manufacturing believes materials development will lead to new 3D printing applications and solutions, giving companies opportunities to expand into new markets and multiply product lines. Thanks to their increased strength, durability and other beneficial properties, these materials will create – and already are creating – parts that are indistinguishable from conventional manufacturing methods materials and engineers, developers and manufacturers will progressively rely upon them. Additive metal use is expected to nearly double over the next 3 years.

PROCESSES:

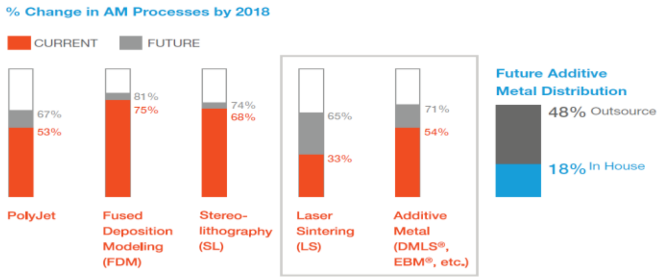

FIGURE J. Here you see current vs. anticipated future usage of several 3D printing processes among respondent companies.

Respondents were asked to describe their companies’ current and future usage of several 3D printing processes, including photopolymer, thermoplastic and additive metal processes. The chart in Figure J depicts both current and future usage of each process, making it easy to see that Laser Sintering and additive metal processes are prime for future growth. In fact, additive metal use is expected to nearly double over the next 3 years.

The market is more likely to turn to service providers for access to additive metal technologies rather than buy equipment and build the required team and skills. It can be difficult to implement these processes in-house since they’re messy, can require additional equipment (like CNC machines) and necessitate a team for post-processing. They can also be expensive for one-off parts, depending on the geometry.

Stratasys Direct Manufacturing is seeing the greatest interest in additive metals in the medical, oil & gas, and aerospace industries.

So what do the survey’s findings reveal about the future of 3D printing for serious, professional users? They confirm that growth over the next three years will largely come in end-use production, with an emphasis in metals. These two trends combine to drive the third trend: a demand for expertise and know-how. Companies need help identifying new additive applications to determine the technology that can best fulfill those needs. For end-use part production, they need support in optimizing 3D printing processes to bring cost down, while fully leveraging 3D printing’s benefits and its business value.

It won’t surprise you to hear that Stratasys believes the future is bright for 3D printing and manufacturing service providers—a view realized in its acquisitions of Solid Concepts and Harvest Technologies to combine with its parts business, RedEye, in 2014 and form Stratasys Direct Manufacturing. It’s an exciting time to be in this challenging and rewarding industry. While the future holds incredible potential, I like to remind people that expanded adoption of 3D printing for end-use parts does not happen in the blink of an eye—it happens one application at a time. It’s our job to take customers’ amazing new ideas for products and technologies and champion them into real applications, one-by-one, by identifying ways additive can bring them to life faster and easier. While it doesn’t happen overnight, it’s something Stratasys Direct Manufacturing is uniquely and exceptionally good at. We get to know each part and project at a level that transcends the customer’s company or industry needs, allowing us to create unique solutions using a variety of

tools. It's also not a shock that additive metal is the future of manufacturing services because the market has long yearned for a method to create complex metal parts. Service support is necessary because, as one of the newer additive technologies, additive metal still needs evaluation and qualification. Partners with experience and know-how will be sought-after. At Stratasys Direct Manufacturing, remain focused on growth and research in additive metal technologies and supporting processes.
One of the questions about the 3D printing industry that I hear often in the press and within the investor community is: When will end-use part production go beyond the early adopters and become "mainstream"? No survey can tell us whether we've reached the inflection point; only time will tell. But make no mistake: 3D printing is here and now. We're building real production parts in every field you can think of, across a wide range of applications today. For any manufacturers out there that haven't started using 3D printing, they better start looking at it now, or they'll fall behind and it will be difficult to catch up.
The last thought I'll offer is that today 3D printing is still perceived as a technology solution, but the future of 3D printing is as a business solution. Stratasys Direct Manufacturing and Stratasys are committed to evolving the conversation because technology is a tool that enables innovation, not defines it.
For any manufacturers out there that haven't started using 3D printing, they better start looking at it now, or they'll fall behind and it will be difficult to catch up. [4]

III THE RISE OF 3D PRINTERS

AM will bring in time to bloom and confront the incumbents. Today's modern barriers such as materials charge, quality, quantity limitations and throughput thing will require to be overcome. As amply, trade and financial barriers such as retooling a full industry and redesigning service strategies, processes and roles will prefer to be addressed. (See Figure 2.)
AM is providing a proclamation for synergy that is accelerating deviation and disturbance in the material reality, barely as the Internet fostered synergy, divergence and eruption in the digital world formerly adoption occurs virtually faster than all imagines possible.
Experiments on AM were carried out from 1960s, it was mid 1980s Charles Hull (founder of 3D Systems inc.) and Scott Crump (founder of Stratasys) developed a range of technologies related to AM. Basically, their work was based on additive processes where solid objects created layer by layer.
That is why this process is well known as additive manufacturing (AM). The term AM has been broadly adopted by the industry and mass media to refer to any AM technologies. For simplicity this report uses the term "AM" instead of ''Additive manufacturing (AM)'' interchangeably to describe the creation of physical objects, layer by layer.
AM already provides significant value for low volume product. Development cost and time can be cut by eliminating the need for tooling used in factory manufacturing. One can use wide variety of materials for 3D printing; designers can create complex structure of a product for optimal effect. Wastage of raw material reduced in comparison with traditional subtractive processes, which can leave up to 90 percent of the raw material on the factory floor. Fused Deposition Modeling (FDM) method reduced the cost of manufacturing from \$10,000 to \$600, and build time from 4 weeks to 24 hours, and weight of the physical object by 70-90 percent. [5]

Figure 2: Advantages and areas of further development.
Source: CSC

AM started with plastics, but today there is outstanding range of printable materials that includes polymers, ceramics, food, glass, metals and even human tissue. These printers generally work in one of two ways: a material (e.g., various plastics) is melted and extruded through a nozzle onto the build area, where the material solidifies and builds the object up layer by layer; or a bed of powdered material (e.g., plastic, various metals) is laid down, layer by layer, and selectively fused solid. Usually some post-production work is required, such as cleaning the excess powder, or dissolving support structures in a solution or baking to achieve strength or hardness. Industrialists, researchers, organizations and hobbyists have modified methods to broaden the range of possibilities to create object. For example, at University of Exeter 3D printer is modified to print chocolate. [7] Cornell University, working with the French Culinary Institute in New York, took the idea further by creating a range of 3D-printed food items such as miniature space shuttles made of ground scallops and cheese. [8]

These principles have even been applied to biological substances, opening the door to research on a range of health applications:

- Washington State University has developed a bone-like material that provides support for new bone to grow. [9]
- Researchers from the University of Glasgow have developed a system that creates organic compounds and inorganic clusters, which they believe could have long-term potential for creating customized medicines.[10]
- Organovo has created a range of human tissue using human cells as material and has even printed a human vein. [11]
- Work underway to use living cells to 3D print organs needed for transplants.

3D PRINTING AT WORK:

Today AM new products is used for largest commercial application, estimated to be 70 percent of the AM market are made from this technology.[12] So, this process, save significant time and money when bringing new products to market.

AM, also known as digital manufacturing provide 3D open designs on website and one can easily download and prints its design, as we discuss this in introduction. Now, specialized high-precision surgical systems used by a U.S.-based AM service, GPI.

AM is broadly used in many areas for both rapid prototyping and direct digital manufacturing. Following are examples from defense, aerospace, automotive and healthcare.

3D PRINTING IN DEFENCE:

Imagine in war zone a technician sending an email along with a digital scan copy of an unserviceable part of an armored fighting vehicle which then gets printed at the nearest available 3D printer and delivered to him in no time. At larger scale, the need of carrying and maintaining large inventories in a battle zone can be done away with 3D printing. 3D printing bringing revolutionary change in the ways by which supply chains and logistics are maintained in defense forces.

Components used in defense forces must be strong, durable and reliable, as failure can put lives at risk such as mount for camera gun sights on the M1 Abrams tank and Bradley fighting vehicles need to be strong. Due to this, high precision components are mounted on the external body of the tanks, where they must survive incredibly harsh shock, vibration and environmental conditions. A leading defense system design and development Company EOIR Technology, is able to manufacture mounts strong enough for use on the tanks using a 3D printer. In the future, through the help of digital design, it may be possible for the military to print replacement parts on battlefield instead of relying on limited spares or the supply chain. For example, Sheppard Air Force Base in Texas facilitate Trainer Development Flight (TDF) is using 3D printing to develop training aids for the Air Force and other U.S. Department of Defense branches.[13]

Using 3D printing has enabled the government to save over \$3.8 million from 2004-2009, provide improved and timely training in areas including avionics, medical readiness weapons systems and telecommunications systems. Student interns working on a U.S. Army research project created and flew a 6.5-foot-wingspan plane (a UAV) made of 3D–printed parts to help study the feasibility of using such planes. [14]

Defense forces use 3D printing for the creation of topographical models to provide better intelligence. HAL has developed a strategic business unit (SBU) to focus on the unmanned aerial vehicle (UAV) market, which in India alone has the potential to be worth \$2 billion.

This technology, if adopted by Indian defense forces, will have a broad effect on the long supply chains being maintained, thus reducing the cost of its maintenance substantially. Components which are critical to functioning of any vehicle or combat equipment can be identified by each of the three services and by placing the 3D printers along with raw material and digital designs at key locations, these components can be churned out as and when needed. This will help the exchequer in saving the money required for maintenance of storage space, shelf life and manpower needed to maintain the long supply chains.

3D printing is not limited to private sector companies. Government organizations such as Defence Research Development Organization (DRDO) and Indian Space Research Organization (ISRO) are also using 3D printing technology to streamline manufacturing processes.

3D PRINTING IN AEROSPACE:

Like many industries, aerospace is has a lot more use of 3D printing to improve the performance of assets, consolidating components, reducing maintenance requirements and saving fuel costs with lighter parts.

Now AM is used by Boeing, for printed 22,000 components that are used in a variety of aircraft.[15] For example; Boeing produce environmental control ducting (ECD) for its new 787 aircraft which previously created only up to 20 parts using other industry techniques due to its complex internal structure. Using AM Boeing produces ECD as one piece which reduces inventory, maintenance times and does not require assembly and improves inspection.[16] As parts produced weigh less, so the overall aircraft's operating weight decreases, resulting in fuel savings. Annually, American Airlines, for every pound of weight removed from its aircraft, company saves more than 11,000 gallons of fuel.[17] Boeing, as well as other aerospace giants GE and the European Aeronautic Defense and Space group (EADS), maker of the Airbus, are conducting further research to optimize parts such as wing brackets. (See Figure 3.) Ferra Engineering, an Australian aerospace contractor (that supplies Boeing and Airbus), has a contract to 3D print large two-meter-long titanium parts for the F-35 joint strike fighter, reducing machining time and materials waste.[18] Boeing even envisions AM an entire airplane wing in the future.[19]

Another benefit is the use of AM manufacturing is to address supply chain issues. Components mass produced in one part of the world can take weeks to arrive at an assembly factory.

But AM components on site eliminate shipping time, reduce friction in the supply chain and reduce inventory levels at the factory. An extreme example of a long supply chain is space exploration. Imagine if it were possible to print products, tools or replacement parts on the International Space Station or even on Mars. That is exactly what groups like Made in Space and

Lunar Buildings are investigating. Both organizations are developing tools, processes and systems for directly manufacturing in space, avoiding the costly and decade-long planning cycles required to send a rocket into space with the necessary replacement parts and tools. Made in Space has a contract with NASA and is currently conducting zero gravity tests, with plans to trial AM on the International Space Station. This would allow astronauts to print tools and parts in space exactly when needed. [20] (See Figure 9.)
Looking ahead, NASA is exploring AM as a service (3DPaaS) for rapid pre-prototype work. AM, makes it easier to capture the imagination of the mission concepts. We can see what others are imagining." Engineers could use 3DPaaS to rapidly obtain peer reviews, additional design concepts and approval to prototype. Initial prototyping and iterations would be done using low-cost, fast-turnaround open source CAD tools and 3D printers. As we already discussed about open source, open design approach.
Now, NASA's next space exploration vehicle (rover) includes about 70 3D–printed parts; NASA engineers also 3D print prototypes to test parts before production. [21]

3D PRINTING IN AUTOMOTIVE:

Automotive manufacturers have been using AM for designing the entire gear box as a whole. For example, Urbee, billed as the world's first printed two passenger car created by KOR EcoLogic. Not all parts are 3D–printed — just the shell of this hybrid prototype car — though interior components are planned to be 3D printed. [22] (See Figure 11.) Urbee, which could be in low-volume production by 2014, [23] has planted the seed for AM of large-scale car components. In the near future, 3D printer creates unique car styles, designs and shapes to appear.
Also Materialise created the world's first race car using a AM technique called mammoth stereolithography (SL) largely with AM competed on the track in the Formula Student 2012 challenge in July 2012. Mammoth SL is designed for printing large objects and has a build area of over 6.5 feet (two meters). [22]
Also engineers at BMW have 3D printer to create ergonomic, lighter versions of their assembly tools to increase worker productivity. By improving the design, workers are carrying 2.9 pounds (1.3 kilograms) less and have improved handling and balance. As BMW engineer Günter Schmid says, "This may not seem like much, but when a worker uses the tool hundreds of times in a shift, it makes a big difference."[23]
Also company uses 3D printer for creating car interiors, showing front and back with all the attachment points as part of its presentation. Pictures may tell a thousand words, but touch and feel make it real.
Tata Motors is currently using AM to manufacture cosmetic trim parts such as dashboards, as well as some major underhood (engine) parts, especially those which require a lot of optimisation and multiple iterations before they get it right. In 2009, the company acquired a machine that enabled AM of large parts.
Local Motors at the International Manufacturing Technology Show (IMTS), a car was 3D printed live. Local Motors Strati, based on a contest-winning design by Michele Anoe, took 44 hours to print, another day to CNC mill the body to its final shape, and two more days to assemble additional components. [24]
The Strati combines new community driven, micro manufacturing business models with new AM technology to re-imagine the nature and process of auto manufacturing. Local Motors in summer 2015 will put the results into practice, opening a combination micro-manufacturing facility and retail outlet dedicated to designing, printing, and selling Strati. Also plan to print even large, complex, and heavily regulated products.
AM also deceases the product complexity took the car from 20,000 parts to 40, [25] as to design complexity; complex geometries can be printed just as easily as a solid block.

Figure 4. Strati real image.

3D PRINTING IN HEALTHCARE:
Use of 3D printing is in the healthcare industry has the potential to save lives or improves them. 3D bio-printing in healthcare still has some years to go before mass adoption, but early developments to create tissue, organs, bones and prosthetic devices provide a glimpse of how lives may be improved.
Using a patient's own cultured cells or stem cells, the Wake Forest Institute for Regenerative Medicine has developed a 3D bio-printing technique for engineering tissue and organs. The ultimate goal is to help solve the shortage of donated organs available for transplant. Scientists are working on a variety of projects including ear, muscle and a long-term effort to print a human kidney. (See Figure 5.) The printer is designed to print organ and tissue structures using data from medical scans, such as CT or MRI. 3D bio-printer basic idea is to print living cells — and the biomaterials that hold cells together — into 3D shape. This organ or tissue structure would then be implanted into the body, where it would continue to develop. The kidney project is based on earlier work that used cells and biomaterials to engineer a "miniature" kidney that was able to produce a urine-like substance when implanted in a steer.
In addition, AM also has number of applications in making surgical tool too. For example, the Walter Reed Army Medical Center has created and successfully implanted over 60 titanium cranial plates.[44] In June 2011 the first 3D–printed jaw, also made of titanium, was successfully implanted in an 83-year-old woman by Dr. Jules Poukens of Hasselt University.[26] These implants perfectly match a patient's body and provide better fixation, which can reduce surgery time and infection.[27]

Figure 5. 3D bio-printer structures — kidney (top left), ear (top right) and finger — help address the organ shortage and need to repair if not replace damaged body parts.

Source: Wake Forest Institute for Regenerative Medicine

AM would enable those with limb loss to get exactly what they want for look, feel, size and weight, all for a fraction of the cost of a traditionally- made prosthetic. Bespoke Innovations, now owned by 3D Systems, uses AM to make custom coverings for artificial limbs and aims to 3D print the entire prosthesis in the future. For example are 3D-printed hearing aids that, though pricey, provide excellent sound quality due to their custom fit.

3D PRINTING AT HOME:

New generation of DIY manufacturers, have created by 3D printers. They use AM services online and have own low-cost 3D printers to create custom products that address their unmet needs.

Growing Services Market: 3D printers make it economical to create highly unique products that quench the rising thirst for personalization.

Whether it is a smart phone case personalized with your name (see Figure 14), an avatar from World of Warcraft or a self-designed robot toy, there are a range of services like Freshfiber, FigurePrints, My Robot Nation and Sculpteo at one's disposal. The consumer market is buzzing with affordable custom products, all available through the Internet using "as a service" techniques. Expect to see AM stores in a shopping mall near you soon!

A growing population of DIY designers is using these services to create and upload products and ideas to websites like Shapeways, a start-up "working to democratize creation by making production more accessible, personal, and inspiring."[28] (See Figure 15.)

Low-Cost Printing in Unexpected Places: In 2008-09 the AM market took a major turn with the availability of open source manufacturing kits priced under $1,000, including various derivatives of the RepRap open source project and the Cup-Cake CNC from MakerBot Industries. These devices ushered in a new group, hobbyists, who previously couldn't afford their own personal machines. And like all technologies, prices have continued to fall; for example, the Printrbot LC launched in 2012 for $549.50. The availability of low-cost 3D printers has spurred many to manufacture at home, bypassing numerous steps. (See Figure 16.)

What's more, with their roots in open source, many 3D printers are evolving rapidly and can now compete with some commercial printers. (See Figure 17.) For those that need higher quality products, a variety of online printing bureaus allow prints in different materials (metals, plastics and glass).

To get an idea of what these DIY manufacturers are printing, take a look at Thingiverse.com, a website with self created files for AM. Created by MakerBot Industries, the website has a large community of individuals who have shared over 25,000 models ranging from toys and gadgets to replacement parts.[29] All are available for downloading and printing by anyone. A few minutes searching on Thingiverse.com, one can able to download a any design, print it in 45 minutes.

It is important to note that homes, libraries, and schools have different quality requirements than factories. Consumers need to give finishing by hands or forgiving of faults in 3D-printed objects they have created themselves, as long as the object serves its required function.

3D PRINTING MADE MANUFACTURING EASY:

Until now, the creation of high-quality physical products or prototypes required very expensive machinery and investments in tooling and sophisticated CAD/CAM software. This posed a barrier, preventing many good ideas from ever being built (even to a prototype stage), as most people lacked the skills and financial resources to design, let alone manufacture or distribute, a product. In the last decade these traditional barriers have been stripped away. While AM is at the heart of the DIY production process, there have been developments in all elements of the DIY manufacturing lifecycle including free or low-cost 3D modeling and scanning tools (for design), sharing websites (for marketing and distribution), investment websites (for funding), and a new open design ethos (industry collaboration). Now these elements allow almost anyone to become a manufacturer or contribute to the manufacturing process.

Sophisticated Modeling Made Simple:

3D modeling and visualization play a crucial role in the early phases of product development. However, in the past, software was often expensive and required extremely powerful machines, making personal use impractical. Today this has changed. Now, most home PCs can run some of the world's most sophisticated software such as Creo 2.0 or SolidWorks. What's more, there are a number of free or low-cost modeling tools, such as 3DTin, SketchUp and Blender, that contain powerful design capabilities but are simple enough for anyone to use. For something even simpler, there is Tinkercad, which is free and let's people play with the basics of 3D modeling.

Bypassing the modeling effort altogether, a range of affordable 3D scanners enables physical objects to be digitized, modified (within limits) and reproduced directly by a 3D printer. Interestingly, several software products are blurring the distinction between scanning and modeling. By automating much of the 3D modeling experience, they allow almost anyone to rapidly generate sophisticated models. Check out Continuum Fashion[30] and FaceGen.[31] Both services — one for fashion, the other for facial modeling — hide the back-end 3D modeling effort from the individual, who simply wants the output. More recently, Autodesk launched a cloud service that allows people to create 3D models with a few swipes on their iPad or by uploading photos of an object from multiple angles. [32]

Another example of the democratization of design comes from 3D software house Digital Forming, which provides software that enables companies to share product design with their customers. The software lets consumers tweak dimensions of the desired product, whether it is the perfect lamp or a custom cuff link. Consumers can adjust shape, surface design, color and material (within limits). This closer relationship between consumer and manufacturer will spur a greater expectation for customization.

Although AM makes one think of the hardware and objects produced, a key part of the magic of AM is the software. Formlabs made software ease-of-use a cornerstone of its sophisticated 3D printer (discussed later). Elsewhere, a team of researchers has created software that examines the geometry of the CAD model and determines where to add joints, so elbows and knees get hinges, for example. [33] The software optimizes for full movement and no collisions with other joints or possible movements. AM then allows the whole model, including its joints and moving parts, to be materialized all at once. Sophisticated modeling made simple.

Share the Design, Ship the Design: After producing a product on a 3D printer, creators turn to marketing and distribution. Several years ago, if funding was scarce, the creator would initially manufacture and market a low volume of product for a specialist application. Over time, if the product was successful, further investment would be made so larger volumes could be marketed and distributed around the world. It was only at this point that the product could reach a broader customer base.

Now, thanks to online marketplaces like Thingiverse, Shapeways and Sculpteo, the marketing and distribution problem has been significantly reduced. As of August 2012, Shapeways had nearly 7,000 shops and over 160,000 members who had printed over one million products.[34] Shapeways enables designers to get paid for their products and also handles distribution, so products can be purchased and delivered anywhere in the world.

AM is about shipping designs, continuing the evolution of the digitization of things. Being able to ship and print the design means that printing can be done on demand, whether through a service bureau, a company's own AM capability or even the end consumer. These innovative printing options will drive the next generation of distribution and pose major upheaval for traditional manufacturers, whose businesses revolve around shipping products, not designs.

Crowd-Funding: Although low-cost 3D printers and accessible CAD software lower barriers to entry for bringing new products to market, some capital is still required. This is where pioneering initiatives like Kickstarter come in. Kickstarter, a crowd-funding website for creative projects, allows anyone with a good idea to advertise for seed funding, usually provided by large numbers of small investors. The rewards for the investor are set by the entrepreneur and typically range from thank-you certificates for small donations to free copies of the product being sponsored. Most projects raise less than $10,000 though the highest funding to date for a single project was $10 million.

Formlabs, an MIT Media Lab spin-off, achieved its 30-day funding goal of $100,000 in less than three hours66 and reached over $1.5 million in one week. What's all the excitement about? Formlabs provides an affordable highresolution 3D printer (still in testing) for designers, engineers and serious hobbyists. The Form 1 printer uses stereolithography, the method used in high-end printers, thus bringing professional-quality printing to individuals. The democratization of manufacturing and the democratization of investing go hand-in-hand.

Open Design: "Open source" is best known as the term associated with freely-available software like Linux, Android and Apache. The philosophy behind open source is that information should be shared freely by a community of contributors, who work to improve the product and contribute their work back to the community for free use. The power of this philosophy is demonstrated by Wikipedia, which, through the contributions of millions of people, has become the premier reference encyclopedia in dozens of languages and is freely available, while its "closed" competitors (like Encyclopedia Britannica) have become obsolete.

Similarly, the term "open design" has come to be applied to the design of physical products, machines and components through public sharing and contribution. Low-cost 3D printers and availability of software for creating and sharing printable designs are enabling the necessary conditions for sharing designs of physical components. The concept of open design is starting to take off with products like VIA OpenBook (an open source laptop) and RepRap (an open source 3D printer). As well as fostering small-scale DIY product innovation by interested communities, open design can provide a framework for developing advanced technology projects that are beyond the resources of any single company or even country.

In 2011, the U.S. Defense Advanced Research Projects Agency (DARPA) turned to the public for inspiration to design a replacement for the iconic Humvee. DARPA issued the Experimental Crowd-derived Combat-support Vehicle (XC2V) Design Challenge, conducted in partnership with open design automobile manufacturer Local Motors.[35] In a stunning display of the power and enthusiasm of the open design community, Local Motors turned the winning design into a working prototype in just 14 weeks — about one-fifth the time of the automobile industry average.[35] (See Figure 6.)

Figure 6: This potential Humvee replacement was created by an open design community, which built a working prototype in just 14 weeks
Source: Local Motors.

3D PRINTING IN COMMERCIAL MANUFACTURING: While it is difficult to say with certainty how AM in its various forms (e.g., desktop, large-scale) will impact traditional manufacturing, emerging trends indicate that a fundamental paradigm shift has already started. As AM evolves, the new world of manufacturing looks like this:

- Time-to-market for products shrinks. This will be due, in part, to faster design and prototyping cycles as a result of AM, but also to the elimination of tooling and factory setup times for new products. Being “agile” will no longer be a competitive advantage but a basic necessity to stay in business.
- Products have superior capabilities. The barriers for manufacturing will be lowered, bringing new competitors with new ideas. At the same time, products incorporating 3D-printed components will exhibit superior features such as being smaller, lighter, stronger, less mechanically complex and easier to maintain. These products will hold distinct competitive advantage.
- Open design is here to stay. Communities of end users will increasingly be responsible for product designs, which will be available to anyone with the necessary skills and tools who wants to design and then manufacture. These open-design products will be superior to proprietary products. Manufacturers will compete on how well they implement the designs and their build quality, which will be mercilessly rated by end users on the Internet.
- Customization is the new normal. As innovative companies use AM and other rapid techniques to offer customization at no additional cost, consumers will come to expect customization as the norm. The per-unit manufacturing costs of small production runs (even batches of one) will approach those of long runs as technology barriers fall.
- The economics of off-shore change. The price advantage associated with mass production in low-cost regions will be challenged by 3D printers providing just-in-time manufacturing near the point of sale or point of assembly. Supply chains will be re-optimized to factor in the advantages of just-in-time, particularly for low-volume or highly specialized components. Conversely, designers will be able to minimize costs by using low-cost, high-volume components wherever possible, connected with specialized just-in- time components produced at the point of assembly.

Amidst this new world of manufacturing, traditional manufacturing processes must evolve or die. (See sidebar.) In a recent report, LEF researcher Simon Wardley noted that when an activity, in this case manufacturing, becomes a commodity, traditional practices must evolve to embrace the new, though highly disruptive, business processes. He states that the AM disruption “will almost certainly be led by new entrants whose practices will be radically different from those of existing players.”[36] Therefore, in preparing for this change, traditional manufacturers must keep abreast of evolving AM practices and be aware of their own internal barriers (e.g., culture, organization) that could prevent them from taking advantage of the change.

As more organizations and individuals become manufacturers, the lines between manufacturer and customer will blur. When there is a retailer in between, those lines will blur too. Manufacturing will move into retailing. Consumers and new entrants will move into manufacturing. Will traditional manufacturing be dead in 10 years? No, but it will look very different.

3D TECHNOLOGY ADVANCES AND FUTURE:

Like all technology, AM will continue to evolve. In addition to cost reductions (particularly in the consumer space) and eventual miniaturization, researchers are breaking new ground in terms of print size, material integration and speed. There are even systems being developed that combine the benefits of the traditional subtractive processes (e.g., CNC machining) with AM (additive processes). These hybrid approaches perform AM and machining at the same time, eliminating post-processing. For example, most metallic objects created by AM require human intervention for either finish-machining or polishing. However, a Japanese heavy machinery manufacturing company, Matsuura Machinery Corporation, has developed a system that combines AM (laser sintering technology) with high-speed milling that mills edges of the printed object in five-layer increments. [37]

These developments are creating new, unimagined solutions to existing problems, opening the door to new market entrants and paving the way for a constant stream of “world’s firsts.”

Researchers at the Vienna University of Technology have created 3D objects only microns in size using a technique called two-photon lithography. [38] The researchers’ breakthrough has been to speed the technique, making it more feasible for industry. Whereas printing speeds used to be measured in millimeters per second, they are now measured in meters per second. The race car in Figure 20, approximately 285 microns long (the average human hair is 40-120 microns in diameter), has 100 layers that were printed in four minutes.[39] While the structure is already miniscule, it is expected that printers will one day produce even smaller objects, opening new possibilities for innovation in areas such as medicine.

Breakthroughs in multi-material printing are enabling more complex products. The current leading multi-material 3D printer is the Objet Connex500, which allows up to 14 plastic like materials to be printed at the same time. This could be a rubber-like plastic or a more rigid ABS plastic. What is amazing is that the materials are all printed in one job run. Instead of being printed as separate components and attached one at a time, they are fused together simultaneously.[40] Multimaterial printing lets creators combine various properties in one model. One day a complete product or device could be printed as one, such as a mobile phone that includes plastic cover, metal, electronics and glass screen.

Although such a Star Trek-type replicator is still years from being mainstream, another device that is similar to the replicator for its recycling capabilities may be closer to reality. The Filabot is a desktop device that can recycle a range of plastics, including milk jugs and soda bottles, into spools of plastic filament for 3D printers.[41] (See Figure 7.) Funded and launched through Kickstarter, the Filabot has moved from concept to prototype in a matter of months and contains some 3D–printed parts itself. [42]

Figure 7. The Filabot lets people recycle plastic in a desktop environment to create their own plastic filament for a 3D printer. The Filabot extends the DIY of AM to the raw materials themselves.
Source: Google

Figure 8. The first 3D–printed bike, made from nylon and developed by the European Aerospace and Defence group, is strong enough to replace its steel and aluminum counterpart. The bike is a technology demonstrator that lays the groundwork for bike manufacturers to one day be able to 3D print a bike to fit the rider's exact size.
Source: Google

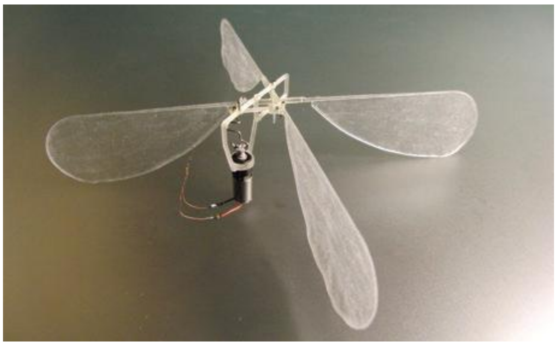

Figure 9: Researchers at Cornell University created the first artificial insect with 3D-printed wings that sustained untethered hovering.
Source: Google.

It is clear that traditional industry players will compete with new entrants offering alternative solutions previously not possible, thus disrupting markets. Consider Align Technology, which in 1999 introduced clear teeth aligners under the Invisalign brand that compete directly with wire dental braces. Costing slightly more than braces, the aligners incrementally shift teeth until they are straight, without the discomfort or look of wire braces. The aligners are made with 3D printers,[43] enabling the mass customization necessary to create cost-effective customized dental devices. In the past, creating such high-quality molds of individual mouths had not been economically feasible. This early use of AM enabled an industry first — invisible orthodontics — and injected competition into an otherwise staid market.

Expect to see a number of other industry firsts over the next few years. They will join a list that includes:

- the first fully printed shoe, created by a Dutch research institute, TNO Science and Industry, and concept design firm Sjors Bergmans Concept Design[44]
- the first printed bike, made from nylon and as strong as its steel and aluminum counterpart, developed by the European Aerospace and Defence group[45] (see Figure 8)
- the first printed plane (3.2-foot wingspan) that has actually taken flight, by engineers at the University of Southampton in the U.K.80
- the first artificial insect with 3D-printed wings that has sustained untethered hovering flight for 85 seconds, by researchers at Cornell University (see Figure 9)

3D PRINTING IS PLATFORM FOR INNOVATION:

Given the deep roots of traditional manufacturing and the challenges the nascent AM movement poses, will AM really disrupt the manufacturing industry? In short: yes. As The Economist reported, we may be on the verge of the third Industrial Revolution, and like all revolutions, the impacts run wide and deep. (See Figure 10.) The question for manufacturers anywhere in the supply chain is how they will need to change — not disappear — to adapt to AM.

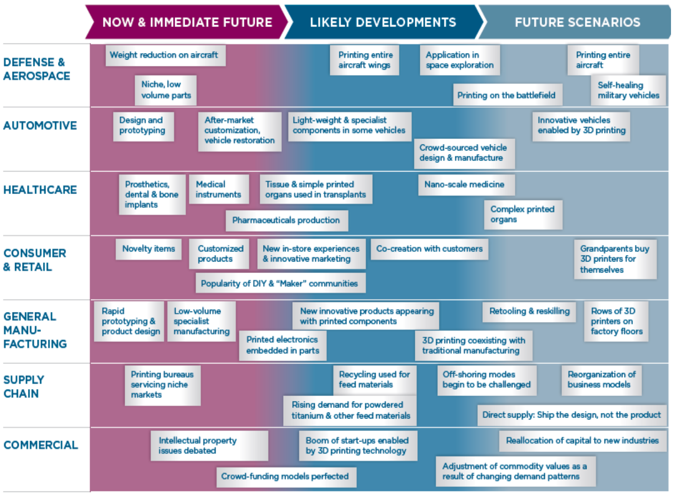

Figure 10. AM facts and future development.
Source: CSC

In the short term AM will not go head-to-head with traditional large-scale manufacturing but will increasingly be used for prototyping, tooling of traditionally manufactured items, and the direct manufacture of highly custom or technically complex low-volume items.

As the limits on object size and printing speed decrease and the price of printing materials falls, the economics of manufacturing will change dramatically in favor of AM. This is especially the case when considering the end-to-end cost of designing, manufacturing, assembling, transporting, distributing and operating a product.

People will increasingly use products that contain 3D– printed components (or are entirely 3D printed), from cars and airplanes to consumer electronic devices and kitchen appliances.

Because of the superior characteristics of 3D–printed products, these products will be more desirable. Startup manufacturers will flourish with new and innovative ideas, and they will have the means to rapidly scale up production with minimal capital investment. These startups, with their agility and incredibly short time-to-market, will be the competitors of tomorrow.

Anyone doubting the new sources of competition need only look at the capability of the hobbyists and open design community today. Without access to large factories, teams of industrial designers or big capital, communities can profitably sell 3D printers for as little as $600 and build prototype military vehicles in 14 weeks. These guys are already beating large-scale corporations hands down in niche areas.

For large-scale corporations that design and build things, AM is an opportunity for IT to forge new relationships with manufacturing and with those who need to visualize designs, like scientists and engineers. One example of this is part of a broader strategy by James Rinaldi, CIO of NASA Jet Propulsion Laboratory, to "change what 'IT' stood for from 'information technology' to 'innovate together.'[43]

Gabriel Rangel, solutions engineer in JPL's Office of the CIO, innovated together with the fabrication group at JPL to create its 3DPaaS model. The key innovation is the commercialization of AM, which lets many innovations flourish by using desktop AM in-house for pre-prototyping. Later, the printing of fewer, more expensive, more refined 3D designs can be automatically outsourced as a service. The result is that by partnering with scientists, engineers and the shop floor to re-think processes — aided by new design tools and 3D printers — the IT group has accelerated JPL's ability to print physical designs early in the product development cycle that can be shared, modified and re-printed, over and over, long before a prototype is built.

AM, is a digital technology, not just a manufacturing technology. With its open and democratic properties,

AM, sets the stage for innovation. It has lowered the barrier to entry for manufacturing, igniting the creativity of the masses. AM is creating new products and services, supporting greater levels of collaboration, and fostering disruptive market entrants. [43]

Manufacturers need to prepare for these disruptions and can begin by asking some key questions that challenge current assumptions. (See sidebar.) The changes surrounding AM are significant; we are only scratching the surface of what the ultimate impact will be. The glimpses of disruption seen today suggest wholesale change in the future. Customized, no-ship manufacturing will one day be as common as desktop printing. When that happens, and factories without factory floors are the norm, it will be hard to imagine how companies and consumers once lived without AM.

V CONCLUSION

After 100 years almost everything is printed by 3D printer, from needle to ships and outer space. 3D printing has a bright future, in printing many kinds of plastic and metal objects, in medicine, in the arts, and in outer space. Reprap community innovators now develop the machine that has cost no more than a few hundred dollars. 3D printers capable of outputting in colour and multiple materials also exist and will continue to improve to a point where functional products will be able to be output. As devices that will provide a solid bridge between cyberspace and the physical world -- and as an important manifestation of the Second Digital Revolution – that i give the name revolution. 3D printing is therefore likely to play some part in all of our futures.

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