3D printing

Thought Leadership

Atos

The aim of this White Paper is to analyze the impact that new 3D printing technologies will have in the current product life cycle as well as the new opportunities and challenges it will bring to the processes and the supply chain.

Our ambition is to help horizontal IT professionals as well as manufacturers and retailers understand how 3D printing could impact their current business.

Contents

About the Authors

This White Paper was developed by the members of the Atos Scientific Community:
Lidia Hernández Álvarez (Editor in Chief), Paul Albada Jelgersma, Francisco José Ruiz Jiménez, Will Hyams, Vincent Couteau.

And special thanks to José Esteban Lauzan for his review.

Introduction

Impact

In the coming years 3D printing technologies will be, in most cases, an alternative to current manufacturing processes. The democratization of the production assets has arrived to our lives. Are we witnessing a new industrial revolution? Maybe not but it will be a real revolution in the way products are created and delivered. This phenomenon is already happening and its challenges as well as its opportunities are what we want to afford in this White Paper.

At the same time, depending on the nature of the product and the industry, 3D printing effects will be different. Very specialized and technical demanding products such as human knee prosthesis or aeronautic parts will be impacted mainly in the design and production stages as the distribution and selling should remain as they are today. Mass production items such as electronic components or decorative items will have the focus in the selling and distribution chapters as is in these kinds of products where these stages are turned upside down. Maintenance is applicable to both mass and specialized objects.

Definition

In 2014 3D printing is a hard term to define. Officially it is just one of the many new and upcoming manufacturing techniques and is used as a synonym for rapid manufacturing, digital manufacturing, direct digital manufacturing, rapid prototyping, desktop manufacturing, freeform fabrication or 'fabbing'.

Each one of these terms has a distinct meaning but they are all competing for our attention to become the official term to describe any process whereby the information in a digital file describing an object virtually (such as an STL or CAD file) is used to rapidly make a real object, usually by one single machine and usually in limited production runs.

More precise definitions define 3D printing as an additive manufacturing technique that deposits material layer by layer using a 'print'-head similar to that of an inkjet printer. The head moves along the X and Y axis and the object being printed moves up and down on the Z axis, gradually creating a layered 3D shape as it does so[1].

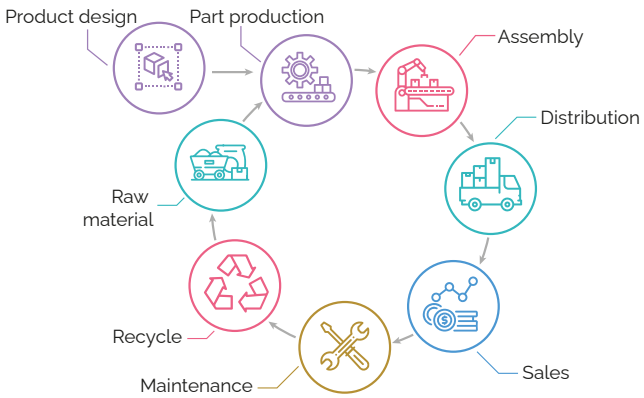
Similar definitions are provided on sites such as Wikipedia, where the concept of additive manufacturing is also explained: "Additive manufacturing or 3D printing is a process of making a three-dimensional solid object of virtually any shape from a digital model. 3D printing is achieved using an additive process, where successive layers of material are laid down in different shapes. 3D printing is considered distinct from traditional manufacturing techniques, which mostly rely on the removal of material by methods such as cutting or drilling (subtractive processes)".

1 See the publication on the Shapeways website (Tuesday, July 15. 2008) that gives a good explanation and definition: http://www.shapeways.com/blog/archives/39-3d-printing.-a-definition-and-links.html

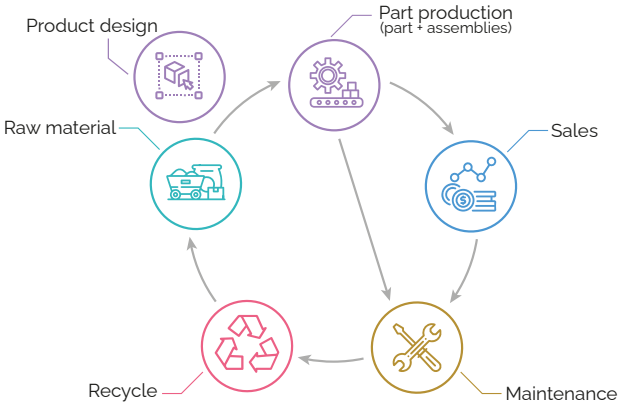
New opportunities

3D printing as a technology has been in existence in some form for about 30 years but the change occurring today is the increasing affordability of 3D printers and materials[2] with the increasing attention of very creative and entrepreneurial people. Although still in its infancy, some critics are openly hailing the rise of the 3D printer as destructive a change as the emergence of the Internet. This paper looks at why 3D printing could be such a disruptive and transformational technology.

The possibilities of 3D printing technologies are almost as limitless to the imagination; if anything is available in a digital form you can print it. 3D printing is likely to be used for different situations: the home user, the onsite 'just-in-time' business, super-custom bespoke businesses and streamlining in existing manufacturing. These strengths are translated into different opportunities depending on the market or field they are exploiting.



Picture 1-1 : Current supply chain



Picture 1-2 : Additive manufacturing supply chain

2 See the prospects of patent expiring in the next months:
http://3dprintingindustry.com/2013/12/29/many-3d-printing-patents-expiring-soon-heres-round-overview/

These are some of the fields where 3D printing is already in production stage

Market	Use case	For more information...
Home 3D printing	At the time of writing, the 'MakerBot Replicator 2' 3D printer is available to buy for $2,199 given that fact, maybe the future of children's toy market could easily become the purchase of designs from the internet which are then immediately printed out on the 3D printer. Another example of this reality is Jay Leno, the US talk show host, who has been printing unavailable-to-buy parts for his classic car collection for some years now from bespoke designs.	Here you can find some information about the penetration and the potential users: http://www. businessinsider.com/credit-suisse-on-3d-printing-2014-1 And in the link http://www.3ders.org/articles/20120514-jay-leno-uses-3d-scanner-and-3d-printer-to-replaceold-car-parts.html you will find Jay Leno's 3D rapid prototyping story.
On-site just-in-time (JIT) industry	For 3D printing not possible at home (or through choice), consumers will come to expect outlets to be able to print objects for them on an on-demand JIT basis. Where currently designs for custom products are measured, quoted and then sent off to be created at the factory returning days or weeks later, 3D printing opens up the possibility of having the factory in the outlet and fulfilling the order straight away. This possibility can be true for many examples within our everyday lives, but also in more extreme or unusual environments such as 3D printing in hospitals or even space stations.	Even though it is only an idea, you can find the information about the rationale for 3D printing on the Moon: http://sservi.nasa.gov/articles/building-a-lunarbase-with-3d-printing/ Auchan (Groupe Auchan SA) has already begun printing objects for their customers: http://www.smart-talk.eu/en/francais-auchan-metlimpression-3d-a-disposition-de-ses-clients/
Super-custom bespoke utilities	There are firms which 3D print from bespoke designs created by the consumer. One such company is London-based Makielab which allows consumers to design their own individual toy dolls which are then 3D printed. At the moment 3D printing design software is in its infancy and it too will need to evolve so that consumers are able to easily manipulate the software to create designs that they can print themselves.	More information in case you want to create your own doll: http://makie.me/
Healthcare	The mix between 3D scanning and 3D printing is bringing new opportunities to the prosthetics world; we are now able to produce adhoc hip, limbs or dental implants that perfectly adapt to the individuals physical appearance.	There is a good video on printing dental prosthetics on the Stratasys website. http://www.stratasys.com/industries/dental and an additional video on printing prosthetics for amputees on the Singularity weblog. http: //www. singularityweblog.com/bespokeinnovations-3d-printed-prosthetics-if-lizards-can-growtails-humans-should-print-limbs/
Aerospace	This industry with low latency requirements and where the manufacturing of components involves a lot of machined parts where a lot of raw material is lost, is a clear candidate to adopt additive manufacturing technologies. Also to improve performance by new and complex geometries (avoiding manufacturing constraints). This is something current manufacturers have already noticed.	Here is a link to a story of how Airbus is using 3D printers and high grade metal airplane parts (18-10-2011): http://www.3ders.org/Blog Posts/20111118-printingairbus-a380-parts.html
Manufacturing	Bespoke mass customization is the possibility of producing rather long series (thousands) of items; highly customized at the cost of traditional mass production objects.	Some companies are already moving to this business model. This is a report from October 2013 showing the background to mass customization in 3D printing: http://smartechpublishing.com/reports/low-volumemanufacturing-mass-customization-markets-for-the-3dprinting-ind

Market	Use case	For more information...
Arts	3D printing allows anyone and especially artists to create almost everything. There are two main trends: create new sculptures (creating art using 3D printer) and recreate a piece of art at home.	Some art examples are here: http://www.joshharker.com and here: http://www.ufunk.net/en/artistes/eric-van-straaten/ (pictures can contain some mild nudity) Home printing of art is shown in a video on this site: http://www.kpbs.org/news/2013/jul/09/printing-arthome-3d-printer/ and you can hear an explanation when you follow this link from October 2013: http://www.npr.org/blogs/alltechconsidered/2013/10/11/231450884/3-d-printing-a-masterwork-foryour-living-room
Retail	3D printing could really change the Retail industry, by providing new distribution channels or basic items, for example the Nokia bumper for mobiles printing, to be able to print your own replacement.	These new distribution channels are explained by Scott Dunhame in a blog posting from August 2013: http://3dprintingindustry.com/2013/08/16/theexpanding-retail-3d-printing-channel-and-other-factorsaffecting-the-future-growth-of-personal-3d-printing/ If you want to try for yourself, the graphics file is available for download, with instructions, here: http://developer.nokia.com/community/wiki/3D_print_a_shell_for_your_Nokia_Phone
Energy	In energy market we should consider two possible approaches, how 3D printing supports energy production and how 3D printing allows saving Energy.	An article of February 2013 shows how solar cell components can be 3D printed and bring added value: http://www.theguardian.com/environment/blog/2013/feb/22/3d-printing-solar-energy-industry In this October 2013 publication, scientists shows how 3D printing will reduce material and thus energy cost: http://www.eurekalert.org/pub_releases/2013-10/mtu-3pt100313.php
Food	3D printing could really change food creation and distribution, one example is its usage in inaccessible places as Space, but also for traditional usage.	Visit this website to see how and why NASA is planning to use this http://www.nasa.gov/directorates/spacetech/home/ feature_3d_food_prt.htm Print lunch: http://www.computerworld.com/s/article/9242517/Hungry_Let_s_print_lunch Or printing your dinner: www.nytimes.com/2013/09/22/opinion/sunday/dinneris-printed.html?_r=0

Table 1 1: Market opportunities examples

Parts and assemblies design

Once we have had a glance at the opportunities additive technologies will bring, it is clear that these are transformational technologies with potential to change the supply chain as we understand it today, at least in certain industries. A phenomenon similar to the information democratization we went through in past decades with Internet adoption could be just around the corner, as we embrace the new 3D printing philosophy.

Parts and assemblies design

Michelangelo said «Every block of stone has a statue inside it and it is the task of the sculptor to discover it.»

The initial step in the creative process involves the conception of the piece. The role of the creator, the sculptor, is based on the vision of the piece and its physical creation. However, technology has meant a huge change to the creative process, the sculptor has changed the chisel for the mouse, and physical creation has become an industrial process.

3D printing extends the current concept of creation and enables people to create objects, from conception and design to the physical creation. In the current era, Michelangelo would not have to look at the block of stone. "Moses" would come to life from nothing, and would be modeled in a virtual environment, changed and repeated endlessly, modifying its gesture or position. Sadly we could guess that this new sculpture would neither answer when it was asked to speak.

The evolution of technology and computer aided design (CAD) have helped streamline the creation process and enable new tools like prototyping or creating new components from 3D scanning[3]. The new creation techniques have changed the meaning of the WYSIWYG concept: "What You See Is What You Get" (and What You Touch).

The traditional 3D design tools have also become tools for creating objects to be printed. This new functionality has a direct impact on the design process, on the one hand it provides additional flexibility by prototyping objects[4], and on the other hand it adds capabilities for stress engineering for the analysis of strength and resistance of the created objects. The tools that assist the creation of objects for 3D printing are some of the traditional ones, like Autodesk 3ds Max, Catia, SolidWorks or SketchUp[5]. In order to communicate with the 3D printer, the standard format has been traditionally STL (Stereo Lithography) files, however at this moment there is a new standard file, AMF (Additive Manufacturing File) that in addition to geometric elements, includes specific properties of the physical object such as color, texture or materials.

A fundamental aspect of design and 3D printing is that it eliminates certain barriers for creating pieces which could be considered impossible[6], the ability to eliminate joints that could reduce resistance to the object and which can be printed now as a whole, without current limitations of shapes, sizes or angles. This point is particularly important because there are restrictions in both the manufacturing processes and the tools used to create the objects. 3D design is a key area in the supply chain, 3D printing opens a new dimension to this model, removing barriers and enabling new ways of working.

Technologies and raw materials

There are different 3D printing technologies that provide plenty of possibilities in terms of speed, materials, resolution and accessibility. Nowadays almost everybody might have a 3D printer at home although for certain applications, the requirements in terms of equipment and conditioning are very restrictive.

Describing the different technologies is out of the scope of this White Paper and can be easily accessed in different sources[7] but it is interesting to highlight the strong link between the technology and the nature of the raw materials that can be used. Currently the main efforts are not only focused in the research of new technologies but also in materials and processes analyses[8] in order to increase the materials catalogue and the equipment accuracy and productivity.

Of course nowadays it is possible to print 3D objects out of thermoplastics or edible materials[9] and even in the near future we could attend to human organs synthesis[10] but the challenges in the pure manufacturing ecosystem (which is where this chapter is focusing) are leading to create high tech, high quality and high capabilities parts for high demand applications such as aerospace, automotive and biomedicine. Steel, aluminum and even titanium are now under development and will change most of the manufacturing present processes.

3 Makerbot is planning new technology to make 3D scanning very easy as can be seen on their website (March 2013) http://www.geek.com/articles/gadgets/makerbot-digitizer-plans-to-make-3d-scanning-as-easy-as-3dprinting-20130310/

4 For an explanation of what Rapid Prototyping is please visit http://en.wikipedia.org/wiki/3D_printing#Rapid_prototyping

5 An overview of available software and pricing can be found here: http://3dprinterhub.com/3d-printer-software

6 See this TED talk for some examples: http://www.houstonforesight.org/?p=1108

7 A good overview of all technologies is here: http://en.wikipedia.org/wiki/3D_printing#Additive_processes

8 On this web page you will find the EU announcement of a €2M study into knowledge-based engineering system (KBE) that can estimate functional properties of 3D parts automatically and in short time: http://cordis. europa.eu/projects/rcn/94835_en.html

9 For an example see this January 2011 article of CNN: http://money.cnn.com/2011/01/24/technology/3D_food_printer/index.htm

10 For an example of printing a kidney, see this 2011 TED talk: http://www.ted.com/talks/anthony_atala_printing_a_human_kidney.html

Production and pre-production stages

The word "product" can mean anything from golf tees to very complex assemblies with millions of parts such as an airplane. In this section we will focus on parts production (3D printing allows replacement of several traditionally assembled parts with just one part) leaving behind another manufacturing steps that are out of the scope of this White Paper.

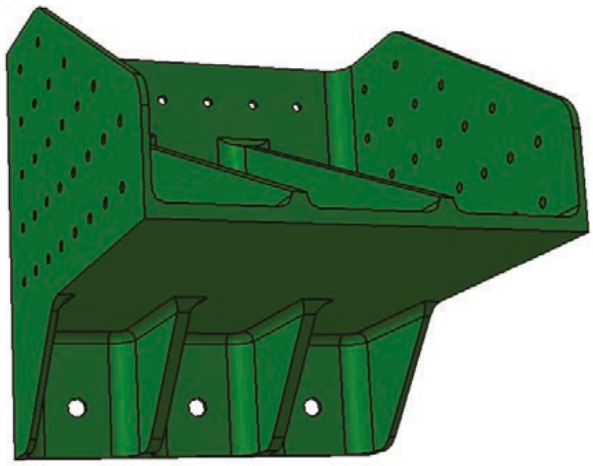
3D printing technologies can be used anywhere throughout the product production cycle, from pre-production (i.e. prototyping) to full-scale production, depending on several factors such as the product manufacturing steps or the product manufacturing time versus the production demand.

Parts production

As we already know, addictive manufacturing where successive layers of material are laid down in different shapes is in contrast to subtractive technologies that imply material removal (drilling, milling, laser cutting, etc.). It is true that one of the cheapest and typical manufacturing processes is the injection molding; it is fast and cheap and with a high raw material utilization ratio (it is not a subtractive technology). Injection molding is widely used for mass production where there is no customization at all, as molds are usually very expensive and the parts obtained often need additional operations. Nowadays there are applications where there is no point in using 3D printing but this list is reducing fast and 3D printing appears as a feasible manufacturing option for certain industries and applications.

Let's illustrate the importance of this fact in the following example, showing how an additive process could reduce costs in a part production with respect to traditional subtractive processes. This is the case of a channel fitting made of Titanium (Ti-6Al-4V) used to allocate bolts and rivets joining two different sub-assemblies in an airplane (high mechanical demand and very short series).

Nowadays 3D printing technologies are not able to satisfy high demand industries such as automotive (high production ratio, low cost per item, high physical properties, etc.) but it is a feasible concept, from a production point of view, in other industries where the physical properties are not key (i.e. entertainment) or where the items per months are low (i.e. aerospace and healthcare); in fact in 2012, 28.3 percent of the $2.2 billion global 3D printing market was tied to the production of parts for final products rather than prototypes[11]. In the following chapters we will analyze both prototyping and production stage applications.



Picture 3 1: Example part

11 A good analysis by Bloomberg in May 2013 is available here:
http://www.bloomberg.com/news/2013-05-14/how-3-d-printing-could-disrupt-the-economy-of-the-future.html

In order to manufacture the channel fitting; we should first buy the raw material. In this case the most suitable supply is a 1x1 m and 60 mm thick plate. The production begins with the 3D file that is translated into PLC commands and introduced in a modern numerical control machine, the raw material will go through at least three different manufacturing stations for cutting, milling and drilling; and in all of them, most of the material of the initial plate will be removed and lost. A finishing treatment could be also necessary.

Picture 3 2: Subtractive Manufacturing simplified process example

The 3D printing process could be summarized the following steps: the raw material (powder) is stored in a container in the very printing machine and the 3D printing process produces an almost finished part according to the 3D file that has been translated into an STL file.

Picture 3 3: Additive manufacturing simplified process example

Once the preliminary part has been printed, an additional finishing stage could be necessary. Though the printer resolution is sufficient for many applications, depending on the final requirements of the part, printing a slightly oversized version of the desired object and then removing material with a higher-resolution subtractive process can achieve greater precision. By means of 3D printing equipment it is also possible to provide different kinds of treatments such as coating or even local thermal treatments for metallic materials that increase the physical properties of the finished part. For some materials a stress release cycle could still be necessary.

As a result of this process we have saved more than 65% of a very expensive material such as titanium when manufacturing our fitting and have reduced the number of manufacturing stages.

Parts prototyping

Nowadays, prototyping is one of the main applications of 3D printing technologies as it is a rather cheap way of producing a short series for parts whose tooling requires a high investment; molding or stamping tools are clear examples of these expensive manufacturing means. The creation of the tooling itself is also a clear candidate for 3D printing technologies as, most of the time, only one or two pieces are necessary and 3D printing is the ideal technology for complex shapes manufacturing. The additional advantage is that it is possible to adjust specifications and create new iterations cheaply and quickly.

Distribution

Digitalization is an uncomfortable process. In the case of 3D printing there are a lot of similarities to what has happened in the music business. No more CD's, LP's or singles (remember those?) to manufacture, distribute, stock and sell. Nowadays we have a platforms or ecosystems (iTunes or Spotify) that have many reusable components (cloud computing, MP3 players or smart phones) in which the large variations of products can be brought to live.

If there is any location in the product life cycle that will be affected by 3D printing, the area of mass distribution will be affected the most. Using basic building blocks in metals, porcelain or plastic (and in the future various bio-matter) all the different products from cars to jewelry and from dresses to lawnmower spare parts could be created at the location where it is needed.

Digital Distribution effects

It is inevitable that the digitalization and parameterization of objects will lead to various positive and negative effects, of which the most visible will be the easy distribution, availability and access to the core of the product. You only need the base material and the printer to bring the product from the digital world into the physical. This ease of access will possibly increase the democratization of ownership. At the same time it will spark customization and support our desire for more individualism, because that can be easily achieved through manipulation of the digital source.

Next to these individual effects, the larger impact will follow in the areas of commercial transport, warehousing and distribution of raw goods. And finally it will allow a new type of retailer to emerge; most likely tailored to bring together communities of designers[12] and local production facilities, even allowing for the smallest shops to deliver the most elaborate products.

In the true sense of the word, the wait is over; low cost distribution and local shops with access to selling millions of products in thousands of variations will significantly change the relationship between manufacturer and customer.

An overview of differences

Traditional supply chain	3D printing supply chain
Products are mass produced in low cost locations	Customized production that is location independent
Goods are pushed in the markets, leading to stress in the distribution and sales process	Goods are created based on customer pull
Long lead times from design to manufacturing to delivery	More information in case you want to create your own doll: http://makie.me/
High transport cost	Low transport cost
Large carbon footprint	Low carbon footprint

Table 4-1: Supply chain differences between traditional and 3D printing supply chain

Sales

Being able to tailor 'the product' to the exact specifications of the customer is a great influencer in the commercial process. Customers who previously could not be served because of size, preference or other product specifications that would not fit their needs can now be added to the target group. And this change in scope for your product comes without the additional cost of having to hold stocks of materials and pre-produced material. Potentially this ranges from customers who want to have a house on the Moon to customers who have a significantly different left and right shoe size. Both in small and large items you can now truthfully say that every possible variation can be delivered.

And although these variations in specifications are now also possible to create and sell – they are still considered 'specialized' products and only sold in special shops or through manual manufacturing processes. The significant change is that the customization will become a mainstream aspect of the sales process.

Most commercial processes use pricing as a method to influence their target market and the sales volume. High pricing is related to the uniqueness of the object that is being sold or the perceived value to the customer. Low pricing is related to high volume and standardization. And while there is no discussion that products produced by 3D printers are still more expensive in comparison to mass-produced items, it is expected that production cost will go down significantly. As a result the price factor will no longer be an aspect to regulate your sales.

In addition to the previous paragraph, through rapid prototyping in 3D, the sales people have "something concrete and convincing to show customers even before the product comes to market, confirming its appeal and generating interest and pre-sales" (quote from 3dmaker. co.nz.).

12 See for example http://www.shapeways.com/

Maintenance

As well as creating items 3D printing can be used to fix them. This has real benefits where parts may not be available from the manufacturer and in many instances today items which are broken in one small way but are otherwise working often have to be disposed of and a whole new item purchased to replace it.

Examples today include a dial on a washing machine which broke off and the manufacturer of the machine not offering a part for replacement. Before 3D printing, the owner of the washing machine had a straight choice: try to fashion a replacement by hand from non-original materials, or dispose of the machine and buy a whole new unit. The cost of the plastic dial would be just cents and other far more costly parts would be thrown out. As well as financial advantages, the sustainability benefits of repairing items with 3D printing are clear. Provided the part designs are available, replacements can be printed for all sorts of breakages which today are considered to mean the end-of-life for the product. On a higher level, the same benefits would apply to industry.

Expensive plant machinery when needing repair may not only save on cost but also on the time to repair if there was a 3D printer on site which could produce new parts much faster than waiting for the shipping of the part from the manufacturer. Other industrial machinery which may operate in dangerous environments, be hard to access or be made from much more bespoke designs could also benefit from 3D printed repairs. Wind turbines for example, operate in a dangerous environment and often are affected by strikes from objects such as birds which can damage them. With 3D printing for repair, wind turbines can have the amage cavity measured, the 3D design created and a new piece of wind turbine can be printed which perfectly fits the hole made by the object which struck it. Rep-Air project (research project intended to improve the airplanes maintenance by “manufacturing” spare parts where and when needed) is also an example of the importance of having a customized part in the right place at the right time.

Other considerations

There are other aspects that surround the supply chain that should also be taken into account and that have not been directly addressed in the previous chapters.

Footprint effects

Recent research has shown a significant change in energy demand and carbon emissions when using 3D printing:

"To quantify the environmental impact of distributed manufacturing using 3D printers, a life cycle analysis was performed on three plastic products. The embodied energy and emissions from conventional large-scale production in lowlabor cost countries and shipping are compared to experimental measurements on a RepRap with and without solar photovoltaic (PV) power fabricating products with acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA). The results indicate that the cumulative energy demand of manufacturing polymer products can be reduced by 41-64% (55-74% with PV) and concomitant emission reductions using distributed manufacturing with existing low-cost open-source 3D printers when using <25% fill PLA"[13].

Copyright and DRM

3D printing has sharply evolved on the technology side. This steep and rapid technology move raises questions on how legal issues raised can be handled. Current regulation may be unable to solve such issues and hence legislation changes may be needed in the future. The most pressing legal issues faced by 3D printing are:

- In a distributed production environment, copyright and design holders may face difficulties enforcing their IPR against a collective ecosystem of individuals engaged in printing. Copyrights may apply on designs (on top of legal design rights) or on the computer code of printable files.
- IPR positioning in 3D printing itself, especially through patenting, shall most certainly be taken by both practicing and nonpracticing entities ('trolls') eager to use their patents defensively and/or offensively.
- Legal ethical considerations are often cited as barriers or limits to what could be considered printable without affecting the public good. The most common examples are printing of guns or human organs.
- The high "open source" impact on hardware and software applied for 3D printing may render direct enforcement of IPR more difficult, therefore the first legal claims to arise may be against those companies ("online repositories") providing platforms to users for sharing 3D designs and code.

Controversial

Even considering the advantages that could arise with 3D technology, there are many other considerations that should be taken into account when assessing its impact on the industry[14].

Maybe the most important one could be the expectations placed on the new technology[15], the idea that almost any object could be built with the desired shape and properties instantly in your own home. Throughout the paper many considerations and restrictions related to the strength of the materials, design constraints, costs, energy consumption and footprint effects or possible legal and ethical issues have been pointed out.

All these limitations are real and need to be addressed. 3D printing will not replace the industrial process as the printers did not replace the printing houses), but it will complement it. It will be used to produce some objects in a more dynamic and easy way and will be used in the phases of the supply chain in which it provides clear benefits (prototyping, design, etc.).

13 Source: Megan Kreiger and Joshua M. Pearce (2013). Environmental Life Cycle Analysis of Distributed 3-D Printing and Conventional Manufacturing of Polymer Products, ACS Sustainable Chemistry & Engineering, Just Accepted Manuscript. DOI: 10.1021/sc400093k [Open access] also at: http://www.appropedia.org/Environmental_life_cycle_analysis_of_distributed_3-D_printing_and_conventional_manufacturing_of_polymer_products

14 http://seekingalpha.com/article/1284331-how-will-3d-printing-impact-the-manufacturing-industry, March 2014

15 Nick Allen: http://gizmodo.com/why-3d-printing-is-overhyped-i-should-know-i-do-it-fo-508176750, March 2014

The future of 3D printing

In the next couple of years we will see three changes in the way additive printing will change from the niche activity it is now. These changes will mainly come from overcoming its current limitations: long processing time, limited materials to be used and size of the manufactured parts, as well as from the reduction of the raw materials and means of production.

In the non-industrial appliances arena, where neither mass production, nor high mechanical or thermal or other capabilities are targeted this is the foreseen evolution:

- First we will see that the printer itself will become much cheaper and smaller, and this applies to the printing material (the 'ink') as well. The result of this will be that the printer will become a household appliance, or at least an appliance that can be put in production in a neighborhood shop; very much like the copier or printing shop around the corner.
- `` Accessibility to these type of printers will fuel local crafts and on demand production of household 'things' or replacement parts. Additionally it will open the possibility of home-workers or individuals to become designers and create virtual marketplaces where designs can be traded.
- `` Finally it will open up the possibility that individuals will either take existing designs and amend them or build on top of them to improve or extend.

The impact of the materials to be processed could also be one of the key factors to reach success in 3D printing:

- `` It will probably take many more years – 5 to 10 maybe – for these types of printer to properly handle biological material; when that happens we will see the possibility to design and create food (that tastes good) or even body parts (Halloween will never again be the same). 3D printing of body parts using non-biological material is already available (bone structures, teeth and ears are being produced today), but more complex structures in various materials are still difficult to create now.
- Secondly we will see a change in the materials that can be used for 3D printing. Moving from plastic to aluminum and even harder materials providing high performance parts. This change will result in 3D printing becoming available for all possible economic markets and impact on all industries.
- `` Finally we will see a change that allows us to combine various materials. This will result in being able to create more complex end results, but also the possibility to create designs that will only create the final result when the printed result is brought into place. This '4D printing' capability allows for printed results that will take its final form when the right circumstances are there; for example you can print a component on land and it will only take final form under water.

Thirdly there will be a change in the way 3D printing will be used.

- `` Today its main area of use is in either the consumer space for on-demand printing of personal designs or in the industrial environment for prototyping. We however already see changes in the maintenance and field services industry. The US military have access to 3D printers in the field to manufacture spare parts on-demand and it is not difficult to imagine that field service engineers will have a small 3D printer in the back of their service truck to print a spare part when needed.
- `` Additive manufacturing technologies will also evolve not only improving productivity but also enabling the possibility of manufacturing one piece gigantic structures as can be seen here where Airbus envisions using 3D printers for planes[16].
- `` Finally we can envision that a large manufacturing company like General Electric or Siemens will sell, as part of their service contract, a 3D printer and the proper software and design to their customers to lower cost of maintenance and keeping stock of spare parts – their customers may even demand this type of service.

These are only a few ideas but additive manufacturing and its synergies with other technologies, such as 3D scanning, bring a new world of opportunities.

16 Airbus proposal about printing gigantic structures http://www.forbes.com/sites/parmyolson/2012/07/11/airbus-explores-a-future-where-planes-are-built-with-giant-3d-printers/

IT Opportunities

The opportunities that have been described all through this White Paper are almost always aligned with the manufacturing and retail markets, but in a digital world, where democratization of information and flexibility are the cornerstone of the whole argument, it seems easy to conclude that the impact in the IT business will be also of paramount importance. Some new businesses could arise from the main concerns that have been already highlighted, such as property rights. The corporate or even personal information protection might be assured by means of ecosystems where manufacturers or individuals could store their 3D layouts and authorized providers could print them out securely. A different approach to the same question could be afforded through App stores where users would pay for the data they are downloading.

In-house printing and design is not yet optimized as current CAD software is not affordable for non- specialized users (in terms of cost and knowledge) and cheap and easy to use design tools should be developed. 3D scanning and its link to the printer is also a functionality to be approached to the in-house printing ecosystem.

However, it's expected that Open Source will be a clear alternative for mass consumers17, Open Source software and hardware are being developed and spreading 3D Printing to the consumers ("prosumers"). Flexibility and agile manufacturing are concepts closely linked to 3D printing. It is clear that the ability to manufacture on demand is one of the main potentials which 3D printing brings but it won't be appropriately extended without a comprehensive approach. The new MES and PLM systems should evolve in order to take advantage of the new manufacturing means and connect not only the manufacturing process but also all the product life-cycle and supply chain. 3D printing and associated technologies are there and it is up to IT companies to make the most of them.

"The slow and patient work of refining and improving on existing technology will always be important. But what we need even more than the refinement of old ideas is the ability to develop new ideas and put them to work"

Henry Ford

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