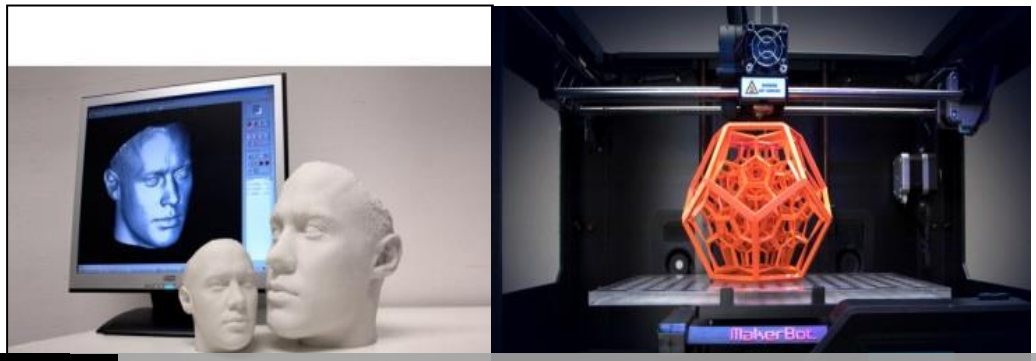
Fall 2013



ETM 532 – TECHNOLOGY FORECASTING

THE FUTURE OF 3D PRINTING FOR THE CONSUMER HOUSEHOLD

By

Aparna Balasubramanian
Curt Edmondson
Kruti Narvekar

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Abstract

3D Printing is the 2013 *cause celebre* as the popular press predicts that this technology can displace the current Chinese manufacturing economy and also allow consumers to "print" our dinners [1], [2]. This spike in popularity is also reflected that over 70% of consumer grade "e-books" concerning 3D Printing were published in 2013. But, like many technologies, there is a question whether the current rush towards 3D printing in the consumer market will result in a "false start", such as with tablet computing during the 1980's and 1990's, or if this precedes an a predictable adoption curve [3].

This purpose of this paper is to try and forecast the adoption rate of "consumer grade" 3D printers for use in a typical United States household. Several assumptions are made. The first assumption is made that the consumer will treat the 3D printer as a "durable good". The second assumption is that the consumer's purchasing limit will be $1000. The third assumption is that the cost of consumables will be less than the equivalent cost of the product when purchased.

Introduction

3D printing (aka Additive *Manufacturing*) is a technique of making a three-dimensional solid part/object of virtually any shape from a digital model as shown in Figure 1.

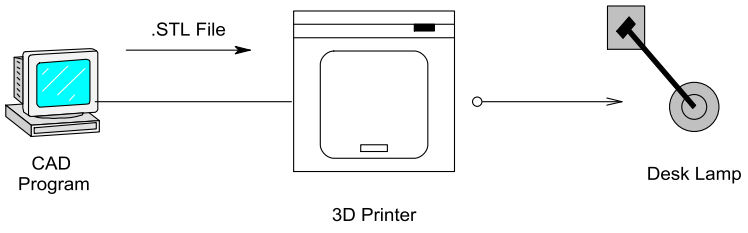

Figure 1

The fundamental components of 3D printing are: a computer system to create or render the computer file for the 3D part, the 3D printer, and the feedstock that is used to create the 3D part. Each of these three components play an important role in creating the 3D part and ultimately acceptance by the consumer.

Technology Process

The first step in the process of creating a 3D printed part involves the creation of a computer file that represents the shape of a target device into a computer file. The standard file format for this computer file is known as a ".STL" file, (STL is a file extension identifier for STereoLithography.) Computer programs that create the .STL file format include: Autodesk Inventor, Catia, Google Sketchup, IronCAD. McNeel Rhino, Pro Engineer, Solid Edge, SolidWorks, and UGS NX [4]. Other technologies involve 3D scanners that create STL files directly from imaged 3D parts. After the STL file is created, it is transferred to the 3D printer.

Next, the process involves the 3D printer placing successive deposition of layers of material that is laid down in different shapes. Other traditional machining techniques include subtractive process of removal of material by methods such as cutting or drilling, but 3D printing is an additive process. For most part they work like inkjet printers. This additive process is done by "cutting" the virtual object in 2D slices and printing the real object slice by slice. Slices are printed by stacking one on top of the other and since each slice has a given thickness, the final object gets volume slice by slice.

Trends in 3D printing technology and applications

History and Emergence of 3D printing

The inception of 3D printing can be traced back to 1986 when Charles Hull, later the co-founder of 3D Systems (a public 3D printer company), invented stereo-lithography, a printing process that enables a tangible 3D object to be created from digital data [5]. The technology is used to create a 3D model from a picture and allows users to test a design before investing in a

larger manufacturing program. In 1984, adaptations and advances on the inkjet concept morphed the technology from printing with ink to printing with materials. In the decades since, 3D printing has been an emerging technology and a variety of applications of 3D printing technology have been developed across several industries.

The different processes used for 3D printing include Selective Laser Melting /Direct metal laser sintering/Fused deposition modeling/Stereo Lithography/Laminated object manufacturing. The earlier process of printing was called rapid prototyping for many years. This involved designing an object as CAD (computerized aided design) file by an engineer and pass this file to create the real object. This technology used plastics and metals to build the prototypes. However, the end products were not sturdy and without structural integrity, so it was just for engineers to create a product in CAD and see what it looked like in real life.

The whole emergence happened when 3D Systems came up with nanocomposites, different blends of plastics, and different blends of powdered metals. They were then able to create a part that, if you held it in your hand, you'd think it was steel. You can throw it down on the ground against cement, and it looks and acts just like steel. This radical change helped make very, very robust materials that can literally be used as a machine part, rather than just a prototype of a part. This transformed the industry from just being about rapid prototyping, something that's only an R & D function—to becoming a manufacturing strategy.

Scope and Applications

At the outset, 3-D Printing will impact every industry in some way. One major implication is that the part and goods can be printed close to their point of purchase causing more goods to be manufactured and available. With more locally produced goods, the outsourcing of manufacturing to other countries, will decrease, allowing for more jobs in the United States. Thus, even if the production cost is higher, it will be fairly inexpensive in future due to less shipping costs.

As this brings out the creative excitement among consumers, it could cause issues for some manufacturers who are affected by this disruptive technology. The supply chain management may be eliminated eventually since there won't be a need any longer.

There has been a major impact on the medical industry where customization is necessary due to the diversity among patients and the requirements. 3D printing has paved the way to print out millions of hearing aids from scans of the ear canals. These prints earlier came from 3D molds but now with the advances in biocompatible plastics, they are printed directly and do not have any side-effects on patients skin.

Other industries that are being impacted by this disruption range from aerospace, heavy industry, consumer goods, retail and fashion accessories and automotive to name a few.

Challenges in 3D Printing

In the next several years, 3D printing will continue expanding into industrial, manufacturing and engineering segments. Despite of lot of advantages, current 3D printing technology does not provide all the necessary functionality to penetrate the consumer market. The ability of 3D Printers to replicate consumer products is strongly dependent on the acceptance of the generated product by the consumer. For example, a consumer may readily accept a 3D printed replacement dowel that is used as a replacement part in a lamp, but, the same consumer may reject a 3D printed saucer due to the roughness of the finish.

There are several challenges in the path of 3D printing. These challenges can be broken down under two different categories; Technological challenges and Social challenges

Technological Challenges

The major technological challenges in 3D printing are limitations in material currently used, accuracy in printing objects, quality of the printed objects, efficiency of the available 3D printers to print objects and ease of use of the 3D printers.

Material

The most obvious challenge for 3D printing from a consumer stand-point is that the dominant feedstock is plastic. Typical objects are made from combination of materials that involve a combination of plastics, metals, and sometimes organic materials (typically wood). It is this hybridized fabrication that presents a challenge to consumer acceptance.

Further, an inability to print electronic circuits where these electronic circuits are integrated with the plastic or metal structures is a major limitation [6]. As a result, consumer products that consist only of plastic There is an open question as whether material substitutions will be acceptable to the consumer as the only feedstock material for 3D printing. This may be overcome as other devices that are experimenting with other materials. [7].

Accuracy

Accuracy is the ability to get within an accepted level of precision of the place where you actually intend to be. Accuracy is the property that more closely determines accurate geometries and dimensions. Precision is the ability for the printer to reproduce the same movements again and again identically between layers or even between prints. The more repeatable the tool-path is in real space, the more precise it can be said to be. [8].

There are also quality limitations with the current printers as they relate to consumer acceptance. Current printers operate with a .2mm step height, a step height that still discernible roughness to tough. At this step height does not have the quality needed for consumer parts [9]. To achieve consumer acceptance of smoothness, post-processing of parts is required, which involves either physical sanding of the parts and/or the application of smoothing chemicals (i.e. acetone). [10]. Consumers are unlikely to invest time into the post-processing of parts.

Quality

Will the quality of the goods be acceptable to the Consumer? The current printers, have a .2mm step height do not have the quality needed for consumer parts [10]. Many companies offer a ‘smooth’ surface finish, but often neglect to add the suffix ‘for 3D printing’. You can also

post-process parts, but this generally involves labour and/or chemicals like acetone (really nasty stuff) and loses detail and tolerance on parts [10].

Will a material substitution be acceptable to the Consumer? The answer is No as Plastic is the dominant source material, but, new devices are experimenting with other materials [7] .

Ease of Use

Consumers expect printers to be highly easy to use. They should be easy to assemble, more user-friendly and reliable. This is not in the case of 3D printers. Current printers are not at all easy to assemble as well as not easy to use. The level of knowledge and understanding about print bed, temperature control of extruder is quiet an obstacle to a new user. Knowledge and skills of using like CAD products is essential for 3D printing which again acts as an obstacle to users. The learning curve in using a 3D printing is too steep and some improvements need to be made in this area.

Organizational Challenges

Apart from major technical challenges, the other socio-economic challenges and risks need to be understood and addressed as 3D printers get mass acceptance.

Cost

While a lot of cheap 3D printers, and 'tinkertoys' can be bought for around the $100-$500 range, these offer limited capabilities and are only of use to the occasional enthusiast and entrepreneur, and not truly useful to the commercial end-user. More reliable 3D printers that truly offer multi-material print capabilities and give a true edge to the end-user are in the range of few 1000s of dollars. For the industrial segment, the prices for 3D printers for rapid prototyping extend well into $100,000 and beyond, and for full-scale systems with ability for high-volume manufacturing; these can be as high as $1M [11]. For the end-user customer who needs an affordable and yet versatile and useful 3D printer, this cost has to come down to a few 100s of dollars for the market to truly take-off. It is expected that the cost and capability of 3D printers are likely to follow similar exponential trends (like the famous Moore's law that states that the number of transistors on a PC chip doubles every 18 months) that were

observed in the PC industry from 1990-present [12]. Stratasys expects to have a sub-$500 3D printer for consumers by as early as holiday 2014, but others expect that this might not happen until late 2015 or 2016 [13]. Thus, conservatively speaking, one could expect that by 2016, the consumer demand for 3D printers would take-off assuming this price point.

Social Challenges

Social Implications

3D printers in a way democratize the manufacturing process, and give more control and customization capability to the end-user. However, it is not without some social costs. The impact on the blue-collar jobs is likely to be high with assembly lines and the manual labor involved in them transplanted by automated machines that can produce a whole part end-to-end in a single step without needing any human intervention. While this could result in a loss of jobs in the manufacturing sector, it will lead to a gain in the knowledge sector where the aspects of designing of parts, and testing of these for structural rigidity. This may or may not be an easy transition as this involves massive re-training of existing labor force, and might lead to heavy movement of capital and investment, and will lead to movement of capital to the West from the East [14].

Safety

The most important requirement for adoption of 3D printing by consumers is safety. Till now 3D printing is mostly used in industrial environments and the prototypes generated do not leave the lab. Thus the safety issues are not yet experienced by consumers. If 3D printers are to be used by consumers then the materials used such as polymers and chemicals must be child-safe and home-safe. Inks used must be non-hazardous and disposable as standard household waste [15].

Another aspect of safety in 3D printing today is printing harmful objects like guns, explosives which can be a serious threat to the society. People have started printing guns with plastic. If 3D printers have to enter the consumer market then this particular safety threat

would be a huge challenge. It would be a huge challenge to control the manufacturing of guns and then the inappropriate use of those printed guns.

Intellectual Property/Copyright Issues

Intellectual Property is a broad group of intangible rights that are provided to incentivize the efforts of "creators" [16]. The theory is that a person or company will not seek to create unless that creation provides a return on their creative investment. Creators cite to the "tragedy of the commons", which serves to disincentive communal creations [17]. There are critics of this philosophy, stating that people will create independent of expected rewards. But, the current paradigm is that creators, and the companies that employ them, expect financial rewards for their works.

A hidden cost that is imposed by 3D printing is the step in creating or scanning the design into the CAD system. A typical consumer will not want to "create" designs for the products that they would like to have manufactured. Mass consumer adoption of 3D printing will require that a system be established where designs can be easily "downloaded" from the internet as shown in Figure 2. Much like the "iTunes" store that allows the immediate downloading of a song based on search criteria, consumers will want a similar interface for designs. This type of interface is evolving in the 3D community, for example, with the 3D Content Central internet site. But online directories will create conflicts with existing owners of patent, trademark/trade dress, and copyrights.

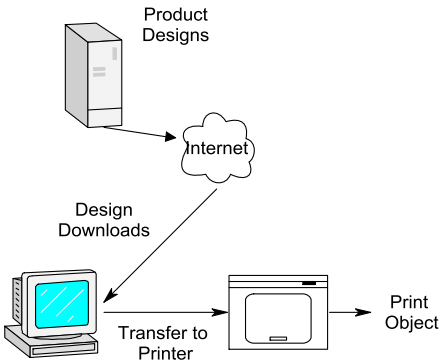

Figure 2

This point is illustrated by analyzing the creation and marketing of the “Alfredo” coffee mug as shown in Figure 3 [18].

Figure 3

For example, the process of designing, producing, and marketing the “Alfredo Coffee Cup” in a traditional manner involves several steps that implicate various aspects of intellectual property. First, the designer conceives of a new cup design, this followed by an interactive process of the designer refining the cup design, once the design is finalized, the product is sent mass production, and then marketed as shown in Figure 4.

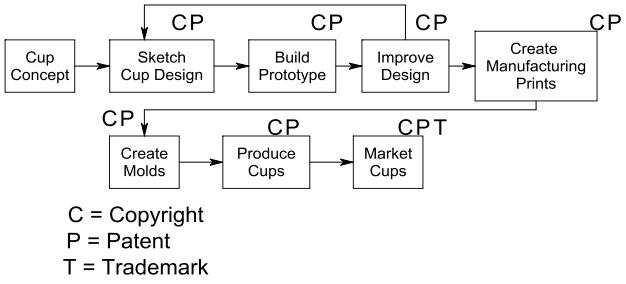

Figure 4

One of the challenges of the internet age is how to prevent the unlawful infringement of intellectual property rights by the consumer. Owners of copyrights are all too aware that the internet has created an easy platform for the infringement by the downloading of music,

movies, and books can be readily infringed [19]. Owners of the intellectual property rights related to consumer products will seek to delay the integration of the internet with litigation in three primary areas: patent litigation, copyright litigation, and trademark/trade dress litigation.

To determine the future risk of patent litigation an analysis of the United States Patent and Trademark Database (USPTO) was performed using keyword searching on the term "3D Printing". This keyword search was applied to the abstract and in the claims portions of the patent. The hypothesis is that the claimed invention is likely to use this search term as an indicator of the scope of the claimed technology. The results from this search show that for printed US patents that the term "3D Printing" in the *Abstract* returned 13 US patents, and in the *Claims* returned 18 US patents. Further, the same search on the patent application database returned 20 published applications in the *Abstract* search and 50 published applications in the *Claims* search. The results indicate that future risk of regarding claims of patent infringement appear to be relatively low in view of the current volume of patent litigation.

The future risk of copyright infringement for 3D printing is much greater. Copyright infringement involves the replication of non-functional elements in an expressive work of authorship. The cost of obtaining copyright registration is relatively low ($ 35.00) in view of potential statutory penalties (up to $ 150,000.00). The Napster decision, *A&M Records, Inc. v. Napster, Inc.*, 239 F.3d 1004 (2001), created the template for copyright holders to imposed contributory infringement liability when they knowingly allow infringing materials on their websites. Passage of the DCMA (17 USC 512) mitigates this risk somewhat, but has not mitigated the aggressive acts of "Copyright Trolls". Copyright Trolls have imposed significant legal costs on individuals who have downloaded music and films. It is likely that copyrights will be used to prevent or disrupt consumers from downloading 3D designs from the internet.

The greatest risk to 3D printing and the distribution of 3D Designs on the internet will come from the enforcement of trade dress rights. Trade dress is the non-functional physical detail and design of a product or its packaging, which indicates or identifies the product's source and distinguishes it from the products of others. Trade dress is identified by color schemes, textures, sizes, designs, shapes, and placements of words, graphics, and decorations

on a product or its packaging. Since the trade dress rights can accrue without the need for a rights owner to seek registration, a claim of infringement can be made simply by alleging that the trade dress rights exist. This claim will impose significant legal costs on the users of 3D printers.

Therefore, distribution of designs to be used by consumers with 3D printers will be delayed by uncertainty of claims that can be made by the holders of intellectual property rights. This risk can be mitigated by manufacturers creating sites with designs that have clear intellectual property title for the designs provided. Alternately, Congress can create safe harbor legislation, like the DMCA, that reduces the risk of inadvertent infringement. But until risks are mitigate, the widespread adoption of 3D printers by consumers may be slowed due to the potential legal risk.

Vision and future of 3D printing

This paper would be incomplete without a look at the current state of different companies engaged in production of the 3D printers. As with any industrial segment, there is a lot of competition in this area too, and it is interesting to see the dominance of this technology shape the future.

Current Market Analysis

Due to the explosive nature of growth of sales of 3D printers, there have been rapid mergers and acquisitions happening in the 3D printing world. Currently, while the market share is highly fragmented, companies are rapidly engaging in R&D to compete for the gold-share of the patents in this field [20], and the winner is likely to dominate this field for years to come. A total of 16 companies operate in Europe, 7 in China, and 5 in the US, and 2 in Japan manufacture and sell 3D printers. Currently, the big players in this area are Stratasys, 3D Systems, ExOne, Arcam, and Voxeljet. In terms of patents, 3D systems is the leader, and Stratasys is a close second, and they each have their niches in terms of materials that they use for printing, and their share in the printing services. ExOne and Arcam are leaders in very-large industrial scale printers, and count many automobile makers and industrial giants among their

customers [11]. Apart from these players, the traditional technological giants and conglomerates such as HP, and GE are anticipated to enter the market either by buying smaller companies or by tie-ups with one of the above manufacturers. A worldwide sale of 3D printers is estimated at nearly $2B, and is expected to grow at a CAGR of 23% until 2020, wherein the market is estimated at more than $10B [21]. Meanwhile, the growth in the design-to-manufacture value chain is estimated to grow from $30B to $50B in the same timeframe, or a CAGR of 11% [12]. US leads in the number of 3D printers installed at 38% of world-wide capacity, and Japan, Germany, and China follow with 8-9% capacity each.

The 3D printer market is at an inflection point, and the sales are expected to double in 2014, and 2015 timeframe. The advances in the 3D printing ecosystem encompassing design tools, scanners, materials and the printers themselves are likely to reduce the cost and complexity of creating 3D printed items. Thus, the expansion of 3D printing to other areas such as architecture, defense, and medical products is almost inevitable. The areas that are most impacted by 3D printing will be the consumer products, industrial and manufacturing sectors, and medium impact is expected for construction, energy, medical, governmental, telecommunication, transport, and utilities. Industries that are in services sector such as financial services and insurance are likely to be least impacted. [22]

Expected Future Trends

Several niche areas are also likely to be impacted by 3D printing, and some exotic areas such as in food engineering are likely to create marginal or no impact due to the fact that in printing food, there is no concept of cooking, but only a concept of assembling the ingredients microscopically to give an appearance of food using the particles of the cooked ingredients. [23]Yet, it could thrive in a niche market such as in space research organizations such as NASA, where there would be a need to print food in outer space.

The impact of the open source community in creating and maintaining a repository of 3d designs for various user components is adding to the growth and adoption of 3D printers in the mainstream [24]. Also, software by Google Sketchup [25] allows users to view, create and

edit 3D designs and store them on the cloud. Interesting there are ideas such as self-replicating 3D printers [24] also available in the market today! Other non-opensource websites also allow users to create their own designs, and for a price, print and ship their designs too. Thingiverse[26] which is part of Makerbot, which was recently acquired by Stratasys, one of the world's leading manufacturer of 3D printers has more than 130k users registered on its website with more than 100k downloadable designs that are ready for 3D printing. It is entirely plausible that within a span of few years 3D printing services would be as common as regular photo-printing and Gartner [22] expects that at least 20% of global retailers would be selling 3D printers in their brick-and-mortar retail stores and/or in their online portals.

In areas such as in aerospace, GE aviation expects that it would be making greater than 100,000 parts using additive manufacturing techniques. Also, it is expected that these have the potential to reduce the weight of a single aircraft by more than 1000 lbs [12].

Going forward, it can be expected that various applications that are currently in the research stage or in the low-volume production, would reach commercial grade and result in additional adoption of 3D printing as an inevitable option in the respective areas. One such example is in tissue engineering; where in 3D printers are used for creating tissues used in regenerative medicine. These tissues are ever so close to the natural tissue, and easier to integrate with the host tissue, and opens up a promising area in medicine and cosmetics [27]. Another niche area is in the fashion industry and the accessories industry, wherein the emphasis is not the high-volume manufacturing, but very low volume, with high degrees of customization. This is one area that has recently warmed up to the 3D printing world, and many designers are starting to show-case especially 3D printed apparel and accessories [28].

Scenario Analysis

Lot of speculation is made about the future of 3D printing. Will it enter the consumer market? Will every person have a 3D printer at home? What will be the price? Will it be easy to use? Will the objects printed have a good quality? What laws will be defined for Intellectual property and copyright issues? There are many questions that are not answered today.

In this paper we have used the method of Scenario Analysis [29] to predict the possible future of 3D printing considering all the challenges it is facing today. The beginning of the analysis is assumed to be today and the analysis is done for the next 10 years.

As per the steps in Scenario Analysis, the first step was to find out the influencing factors that would impact the future of 3D printing. As of today the challenges faced by 3D printing are the most influential factors that would block or pave the way for success for the 3D printing industry.

The following table states the influencing factors that impact the development of 3D printing [30]. Those factors are divided into categories similar to those of the challenges; Technical and Social/Organizational factors and additionally the direction of the influence is clarified.

Influencing Factors	**Positive Influence**	**Negative Influence**
Technical Factors		
Material	Variety of materials and Combination of different materials	Single material (eg. Plastic/Polymer)
Accuracy	Exact dimension and precision	Approximate dimension
Quality	Best print quality	Poor print quality
Ease of Use	Easy to use	Difficult to use
Speed	High speed	Low speed
Social/Organizational Factors		
Cost/Price	Low Cost/Price	High Cost/Price
Safety	Very safe; No hazardous effect on consumers	Not so safe; Potential hazardous effect on consumers
IP/Copyright Laws	In favor of printing objects at home	Not in favor of printing objects at home

Consumer Acceptance	High acceptance	Low acceptance

Table 1: Influencing factors and their impact on the future of 3D Printing

For this analysis, the key factors with the strongest influence from the consumer market's perspective are considered. The key factors are:

Material

The biggest challenge for 3D printing today is the material used. Today, 3D printers only manufacture products out of a single materials such as plastic, resin, ceramic, metals, etc.

For 3D printing to enter the consumer market, it should provide the flexibility to print an object with combining different materials. Multiple materials used in printing the objects would definitely act as the biggest selling point for 3D printers as the objects printed will be closer to real objects.

Quality

The 3D printed object will be expected to be as close to the real object. For this the quality of the printed object has to be the best. The material used for printing objects has to be of such a quality that will give the exact look and feel of the real object to the printed object. Thus quality is a very important factor in the success of 3D printing.

Speed

Today 3D printers made for personal use take around 2-3 hours to print an object. For consumers to use 3D printers like the other traditional printers, it is necessary for 3D printers to have a speed faster than what it has today.

Cost/Price of 3D printers

The price of the 3D printer is very essential for the consumer market success. If the price of the 3D printer available for consumers is very high, consumers would never go ahead and buy a 3D printer for their home. The price should be worth spending for a consumer to get any 3D printed object. The worth of printing an object would be expected to be more than actually buying that object.

Within this key factor the price of the material used for printing is also considered as the raw materials used will influence the price of printing an object.

IP/Copyright laws

3D printing makes it possible to create new kind of copies. Thus 3D printing will make it possible for consumers to copy products that are protected by IPR, enabling them to do so without paying anything to the rights holder. This is a major roadblock for 3D printing to enter the consumer market as the copyright holder of an object that is printed might not accept the printing of that object.

Now the trends of the key factors are combined and linked to scenarios. The different factors interact and thus strengthen or weaken each other. Three possible scenarios are presented here:

Best Case Scenario

Multiple materials used for printing, best quality of the printed object, faster speed, cheaper 3D printers, IP/Copyright laws in favor of consumers

In the best scenario domain, all the key factors are influencing the future and success positively. 3D printers are widely used by people and every home has a 3D printer. 3D printers are used in all possible applications such as printing food, clothes, toys, replacement parts, imaginative and creative designs, etc.

Materials used vary right from plastic to metals to mixture of human cells. Various combinations of materials is possible to print an object as equivalent to real objects having the same color, texture and feel like the real objects giving the utmost quality possible.

A 3D printer is cheaper than the conventional printers and is quiet faster than the conventional ink-jet printer.

A proper IP/Copyright law is in place and consumers don’t have to face legal issues for printing objects at home. People pay a minimal fee for printing objects at home yearly.

Trend Scenario

Most materials used for printing, not so good quality of the printed object, mediocre speed, Medium price of 3D printers, IP/Copyrights laws in the process of improvement

In the trend scenario some of the key factors influence the future and the success positively and some influence it negatively.

Many materials are used for printing objects and lot of combination of materials is also made possible but still there are some materials which do not print objects that's can be as equivalent to real objects. In the medical field, lot of organs are printed using 3D printers but the materials used is still not something that can be compared to actual human cells. The quality is good but not the best.

3D printers are available in a lower price but that depends on the quality of the object printed. Printing specialized objects requires special materials and these materials are still expensive making 3D printing still not affordable to consumers. A 3D printer is faster as compared to earlier versions but still consumers do have to wait for an object to be printed. Lot of research is taking place to reduce the amount of time taken to print an object.

As more and more people buying 3D printers, there are cases of copyright violations. Policy makers are in the process of changing the rules and regulations and putting a system in place to avoid all the IP/Copyright related issues.

Worst Case Scenario

Single material used for printing, low quality of the printed object, slower speed, expensive 3D printers, IP/Copyright laws not in favor of consumers

In the worst scenario all the key factors are influencing the future and success negatively. 3D printers are rarely used. 3D printing was one of the disruptive technologies that had lot of potential but faded away due to the challenges faced and could not improve further.

Lot of research was made on various materials and many companies introduced various materials that can be used for printing in the market. But as consumers started using the materials; many hazardous risks were identified. Handling of those materials is considered injurious to health and thereby recalled.

3D printers never got materials that would print the best quality objects. Object printed still look like fake ones or they are not up to the expectations.

It is too expensive to buy a 3D printer for home and those who bought them already are facing problems with performance. 3D printers are slow and require long hours to print objects. People prefer buying products rather than printing them at home.

People printing objects are sued by companies on the basis of copyright violation. There is no control on people printing copies of products and not compensating the copyright holders.

All these scenarios are hypothetic and the possibility of occurrence can only be estimated roughly. Especially the probability of the best and the worst scenarios happening is quiet low but there is a very high probability that a scenario somewhere between the bet and the worst will occur.

From the analysis, the trend scenario is the most probable scenario from our perspective and our literature review.

Discussion

3D printing is no doubt the technology for the future. It has lot of potential to make radical changes to the aspects of the way we live in. It is one of the latest disruptive technologies that will change our future.

There are lots of things that will be counted towards the success or future of 3D printing. Many challenges are yet to be overcome. As applications of the technology expand and prices drop, the most probable implication is that more use would be on the consumer level. Consumers would definitely want to produce good or products at home. This will also give them the flexibility of customizing the products according to their needs. But is that so beneficial? What about the risks of printing products at home?

In this paper we have discussed about the positive impact of 3D printing but there is surely a negative aspect of 3D printing too.

A study from the Illinois Institute of Technology has shown that some 3D printers can emit serious amounts of toxic nanoparticles [31]. These are particles which can hang in the air and be easily breathable, potentially poisoning you while you sleep, as long as you're printing stuff in your bedroom in the middle of the night. And once inhaled, these tiny plastic particles could not only deposit themselves in your lungs, but might even work their way up into your brain by way of your olfactory nerve. This can be very dangerous for human health.

Nowadays, a different use of 3D printing is printing plastic guns. The U.S senate has addressed some concerns on people printing plastic guns. The senate has extended the Undetectable Firearms Act [32] which was passed in year 1988 for another 10 years. The law, as extended, requires 3-D guns to have a metal strip that would make them visible to metal detectors. This law was passed for plastic guns having some sort of metal strip but today with immense research on the various combinations of materials used, guns can possibly be printed with metal in the near future. This will definitely pose a serious danger on all the people. It will be really interesting to see how the future unfolds for such issues with 3D printing.

Conclusion

3D Printing will definitely become more common in the coming years considering its various benefits and applications. The prices are expected to decrease during the next several years. Lot of research is happening on the materials used. Newer materials are introduced on a daily basis in the market which would definitely lead 3D printing towards success in not only the consumer market but also various other markets.

There are endless opportunities for 3D printing; be it in the medical field, the games and entertainment field, the fashion & retail field, defense & space field or just printing food for yourself. It definitely has the potential for helping to meet the needs of people throughout the world. Poor people in the developing world will find that clean drinking water, low cost energy

sources and other basic human needs will me met at much lower costs through 3D printing [33].

According to Gartner, in 2013, combined end-user spending on 3D printers will reach $412 million, up 43 percent from spending of $288 million in 2012 out of which the consumer segment will reach nearly $87 million. Further he predicts that in 2014, spending will increase 62 percent, reaching $669 million, with consumer spending of $133 million [22]. Gartner also predicts that seven of the 50 largest multinational retailers will carry 3D printers by 2015. We're already seeing the start of this today with Staples, UPS and Microsoft Stores all carrying 3D printers for consumers and enterprise.

If this trend continues, we will witness the penetration of 3D printers in the consumer market soon in the next couple of years.

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