# The adoption of 3D printing

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**Three-dimensional (3D) printing is not a new technology. It has been present since the 1980s, but has only been available to the consumer market in the last two years. Many people have viewed 3D printing, which is a form of additive manufacturing, as a disruptive innovation, because it allows consumers to manufacture their own products.**

According to Sung-Won (2013), it is one of the seven most disruptive innovations. Hyman (2011) states that the technology is among the top 10 technologies that will transform the next decade. It is viewed as disruptive for both manufacturing and service. However, some researchers question how disruptive it is really going to be.

Exploratory collaborative research conducted at the Graduate School of Technology Management (GSTM) aimed to investigate 3D printing and its emerging markets.

## Methods for 3D printing

The most common form of additive manufacturing is 3D printing (Budmen and Rotolo, 2013), although the two terms are sometimes used interchangeably. Additive manufacturing is the process of building an object in many layers (Barnatt, 2013). Due to the combination of design software and the absence of a mould, it has made manufacturing a possibility for virtually anyone. One of the reasons why 3D printing is often considered a disruptive technology is that it does not require specific manufacturing skills.

There are a few different technologies for 3D printing. The first is fused deposition modelling (FDM), which is a material extrusion process similar to the process used in a two-dimensional (2D) inkjet printer. A company called Stratasys invented FDM and has trademarked the term. Subsequently, other companies refer to this technology as plastic jet printing (PJP), fused filament modelling (FFM), fused filament fabrication (FFF), the fused deposition method or simply thermoplastic extrusion (Barnatt, 2013). During this process, the printing material, usually a special type of plastic that comes on a spool, is heated and led through the printer head. It is then spread on the printing surface. Additional layers are put on top of each other, similar to repeatedly printing the same letter on the same spot, so that the ink layer becomes thicker and a noticeable three-dimensional structure appears. Aside from plastic, this technique can also be used for metals, wood, concrete and even chocolate. One disadvantage of FDM technology is that it can be slow. There is also a possibility that products may warp or shrink as a result of the cooling process.

The second method of 3D printing is stereolithography. According to Barnatt (2013), stereolithography is a 3D printing technology that builds objects in layers using a stereolithographic apparatus (SLA). This process involves a container with a chemical liquid. A printing bed is positioned near the top of the container so that there is only a thin layer of liquid on top of it. This layer is then exposed to light, typically a laser, which solidifies it. The printing bed is then lowered a tiny fraction so that another thin layer of the liquid is formed on the newly created layer, and the process is repeated.

An alternative to stereolithography is digital light processing (DLP). With this technology, a DLP projector is used to selectively solidify a polymer liquid (Barnatt, 2013). Another alternative is two-photon polymerisation (2PP). This nanophotonic 3D printing method is very similar to stereolithography, but works on a very small scale. An advantage of SLA is that the products are smoother. However, it is a more expensive technology and requires the handling of chemicals.

The third method of 3D printing is selective laser sintering (SLS). SLS is a powder bed fusion 3D printing technology that uses a laser to selectively sinter together the granules of successive layers of powder (Barnatt, 2013). There are some similarities to the SLA process, but instead of a liquid, it uses powder. Thus, a thin layer of powder lies on top of a building surface. A laser traces the shape of the object and the build platform is slightly lowered. A new thin layer of powder is placed on top of it and the process is repeated.

A fourth, quite different method of 3D printing is laminated object manufacture (LOM). LOM builds objects in layers by sticking together laser-cut sheets of paper, plastic or metal foil. In the LOM process, a feed mechanism advances a thin sheet of material onto the build platform. The material either has an adhesive backing or at this stage has adhesive applied. A roller (sometimes heated) then passes over the sheet to press it into place. A laser finally cuts the outline of an object layer into the sheet, and the build platform lowers just a little. The process is then repeated until all object layers have been created (Barnatt, 2013).

## Consumer market

The 3D consumer printing industry is in an early, turbulent stage of development. In some ways, it resembles the early home computer market where several technology-oriented hobbyists were building their own home computers. Some of these entrepreneurs were successful in launching their computers, such as the ZX Spectrum and the Commodore 64, into the market, and numerous clones were also produced. It is believed that more than 250 companies make personal 3D printers and a few generated revenues of $1 million or more within a year of the printer's launch (Wohlers Associates, 2013).

One of the most recent introductions comes from Dremel. In September 2014, this tool-manufacturing company introduced its 3D Idea Builder (Mearian, 2014). Some companies, such as MakerBot, even have their own retail stores. Several other companies have aligned themselves with chains, such as Home Depot or Staples, where their printers are now being sold.

The main characteristics of 3D consumer printers include the build volume, print speed and print accuracy. As can be seen from Table 1, the printers are still expensive and typically only allow the manufacture of small products.

## Industrial market

In contrast to the 3D consumer printer segment, fewer companies operate in the industrial market. In 2013, 34 manufacturers around the world produced and sold industrial 3D printing systems (Wohlers Associates, 2013). In 2013, while growing by 26.4% compared to 2012, an estimated 9 832 machines were sold for an average price of US$90 370, while the cumulative figure is 66 702 units (Wohlers Associates, 2013). The market share of industrial manufacturers is mainly held by two companies: the US-based 3D Systems and Stratasys (see Figure 1).

## Market development

Figure 2 illustrates the number of units sold in the industrial market during the last two decades. The annual sales of industrial systems in 2015 are expected to exceed 15 000 units, which means that the industry will exceed $21 billion by 2020 (Wohlers Associates, 2013). However, it is not clear how this relates to consumer 3D printers, because many personal 3D printers are non-traditional and difficult to track.

This study used bibliometrics to investigate worldwide 3D printing trends. The Google Scholar database was analysed and cumulative trends of the 3D printing growth associated with the industrial and consumer market is shown in Figure 3. First, it can be seen that the cumulative trends of 3D printing technology seem to be different for industrial and consumer applications. For example, it should be evident from Figure 3 that the cumulative industrial trend is 2 800 units, as opposed to 600 units for the consumer trend in 2010. This seems to disprove the implication that fewer companies operate in the industrial market compared to the consumer market. However, one should remember that this bibliometrical analysis could imply that more activities have been associated with industrial markets and the development of 3D printing technology than for the ensuing consumer markets during the same times of development.

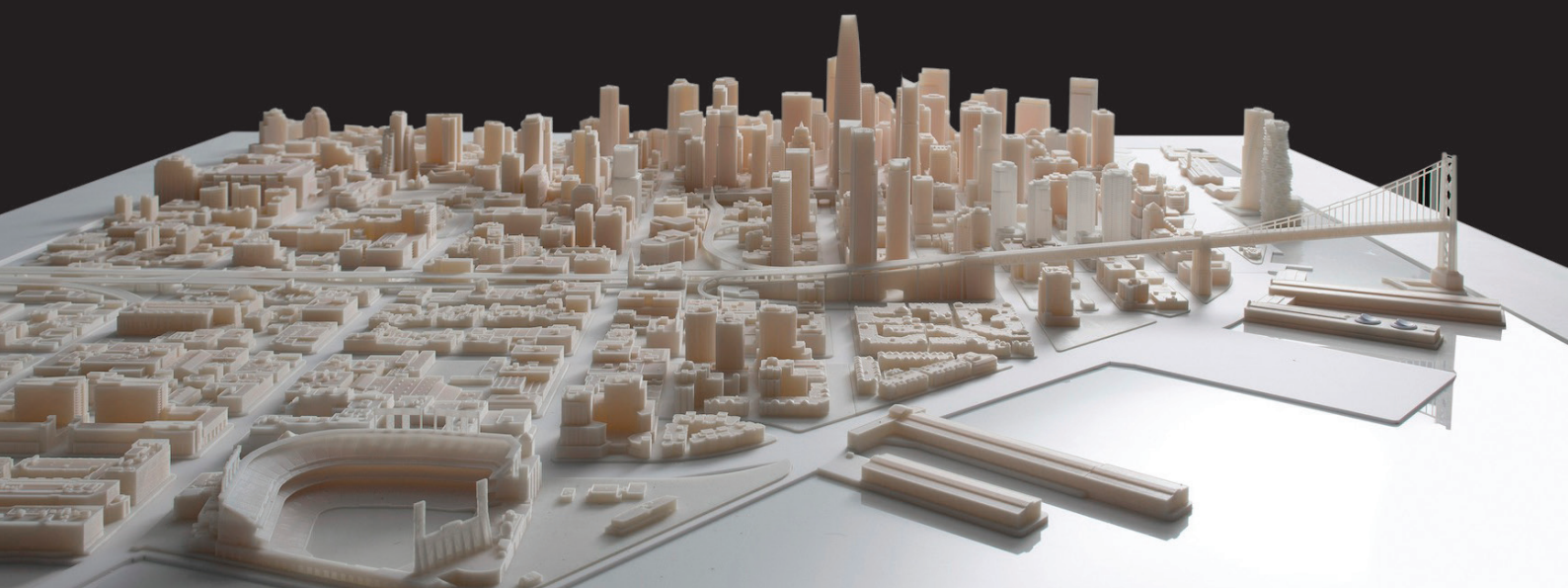
## Conclusion

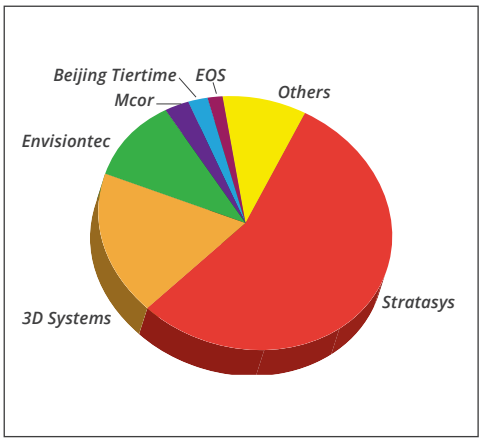
The evidence produced in this study seems to indicate four different methods for 3D printing technology. This research evidence supported the technical and advanced nature of 3D printing as an additive manufacturing approach.

→ *Table 1: Consumer 3D printer comparison*

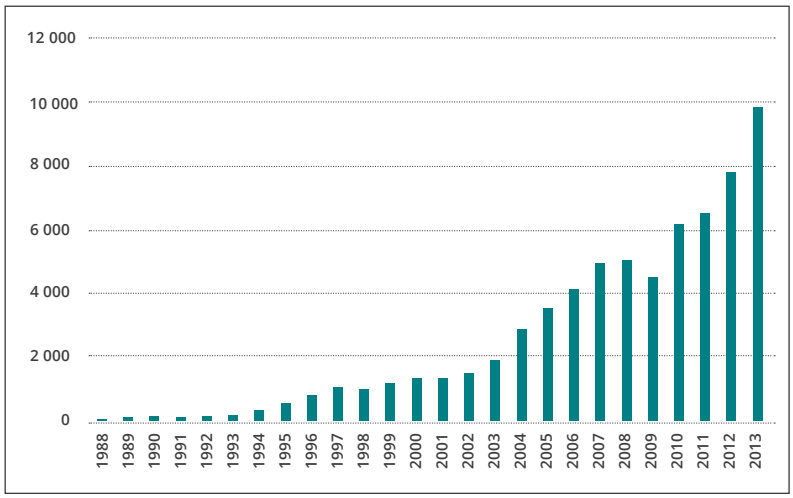
| Company | Build volume (inches) | Print speed (mm/sec) | Print accuracy (mm) | Price |
|---|---|---|---|---|
| Afinia H-Series | 5.5 x 5.5 x 5.3 | 3–30 | 0.4–0.15 | US$1 299 |
| Cube | 5.5 x 5.5 x 5.5 | 15 | 0.2 | US$1 299 |
| Felix | 10 x 8 x 9 | 10–200 | 0.05 | US$1 749 |
| LulzBot TAZ4 | 11.7 x 10.8 x 9.8 | 200 | 0.075 | US$2 194 |
| MakerBot Replicator 2X | 11.2 x 6 x 6.1 | 80–100 | 0.34–0.1 | US$2 799 |
| MakerBot Replicator Fifth Generation | 9.9 x 7.8 x 5.9 | Not available | 0.1 | US$2 899 |
| Orion Delta | 5 x 5 x 9 | 40–300 | 0.05 | US$1 499 |
| Printrbot Simple | 3.9 x 3.9 x 3.9 | 70 | 0.1 | US$349 |
| Printrbot Simple Metal | 6 x 6 x 6 | Not available | 0.1 | US$599 |
| Ultimaker 2 | 9 x 8.85 x 8 | 30–300 | 0.02 | US$2 499 |
| Ultimaker Original+ | 8.25 x 8.25 x 8 | 30–300 | 0.02 | US$1 599 |

Source: www.makershed.com/pages/three-dimensional-printer-comparison






→ *Figure 1: The market share of industrial manufacturers (based on Wohlers Associates, 2013)*

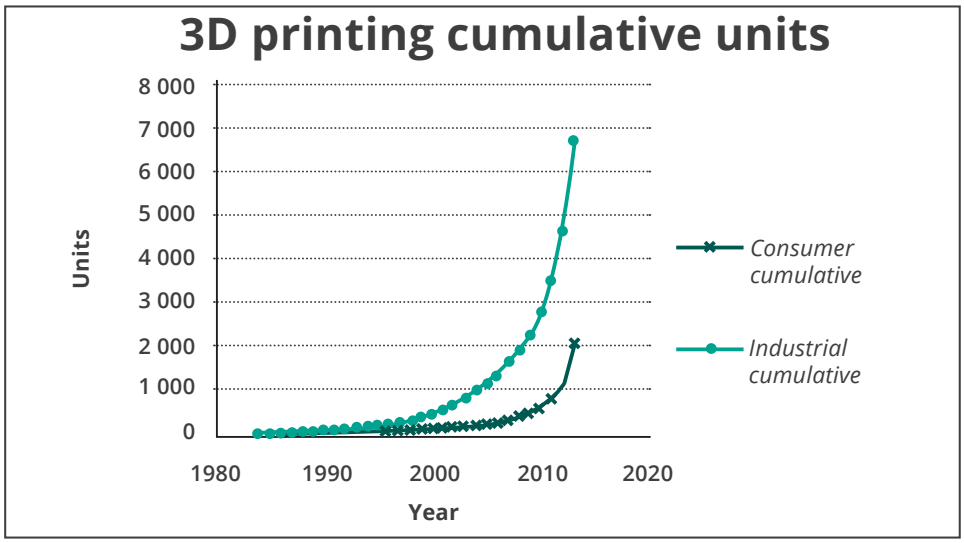



→ *Figure 2: Industrial machines sold per year (Wohlers Associates, 2013)*

Some initial company evidence gathered pointed to a difference in the industrial and consumer approaches to 3D printing.

A distinct difference was identified in the market growth patterns for industrial and consumer applications. In terms of 3D printing technology between 2002 and 2013, the ratio of consumer to industrial penetration has increased from 0.12 in 2002 to 0.42 in 2013. This points to a possible increased focus on consumer applications for 3D printing.

Further research may include the identification and analysis of additional case studies in the industrial and consumer application of 3D printing technology. Additional databases, such as patent sources, may be used to enhance the current 3D printing technology. System dynamics modelling may also be used to enhance the 3D printing market development analysis and possible technology trend forecasting.




→ *Figure 3: Bibliometric results for 3D printing technology diffusion in cumulative units.*

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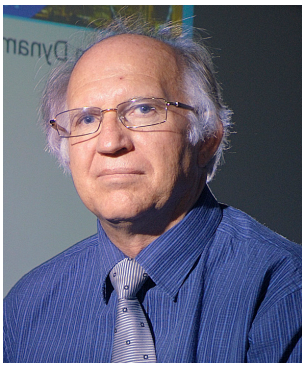

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