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Organisations of the Future

Brief 3: How will distributed manufacturing affect people's lives?

Distributed manufacturing, increasingly known as additive manufacturing, has the potential to take us all by surprise. It is a process in which machines build physical objects bottom-up, by adding layer to layer – hence the term additive manufacturing.

A Ci briefing paper for stars'09

Introduction

This briefing paper is one of three written specially for the next-generation international leaders taking part in **stars**'09. The papers were designed as input to a structured workshop process, to stimulate thinking on emerging issues that will impact organisations in future. The topics have been selected as examples of developments in the fields of environment/resources, politics/economics and technology.

The 2009 papers address:

1. Micro/local power generation
2. Transnational crime
3. Distributed manufacturing

Each theme is presented in the same way:

- The story so far
- What will influence the next 20 years?
- What might be the implications?

The papers are based on a review of literature and fresh interviews with selected experts, further edited to include outputs from the symposium itself. They are not designed to make precise projections, but to identify the factors that will influence developments in these fields.

Participants are welcome to use this **stars** briefing paper in their own organisations, with or without support from Ci.

About stars

The Stein am Rhein Symposium (**stars**) is a platform for "Leaders of the Next Generation" in business, science, politics and culture. **stars** creates an inspiring network and finds answers to the question "What makes a good future leader?"

www.the-stars.ch

About Ci

The Career Innovation Company (Ci) is a catalyst organisation, working with some of the world's best-known employers. Ci uses fresh research insights, collaborative events and high-impact online career and leadership tools to help them increase business agility and gain recognition as inspiring places to work.

www.careerinnovation.com

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How will distributed manufacturing affect people's lives?

Distributed manufacturing, increasingly known as additive manufacturing, has the potential to take us all by surprise. It is a process in which machines build physical objects bottom-up, by adding layer to layer – hence the term *additive* manufacturing.

Traditionally lathes, drills and other 'subtractive' tools have removed material from – say – blocks of metal, perhaps as the first step in creating a mold. The mold has then been used to make a series of identical parts, which are joined to others produced in a comparable way.

By contrast, distributed manufacturing relies on an additive principle. It lays down material in layers. These layers may be metal-, polymer- or ceramic-based, or composites. Various methods can be used.

You can unwind a plastic filament or metal wire, for example, push it through an extrusion nozzle, heat the nozzle to melt the material, use a numerically controlled mechanism to move the nozzle in horizontal or vertical directions (following your computer-aided design), and add layer after layer to make objects of different shapes.

Or you can deposit powder layer by layer. On to each layer, an ink jet sprays a colored resin, creating a shape similar to that produced by an ink-jet printer on a piece of paper. The resin glues together the powder it touches. The process is repeated layer on layer. When finished, the unglued powder is blown away to reveal the completed object.

These processes don't waste material and don't need a mold. You can go straight from a computer-aided design (CAD) to making the object, saving time and money.

The story so far

Over the past 20 years, hundreds of different types of machine – 'fabricators' – have been developed to do additive processing. What began as means of building prototypes have now become processes for creating a wide range of finished objects.

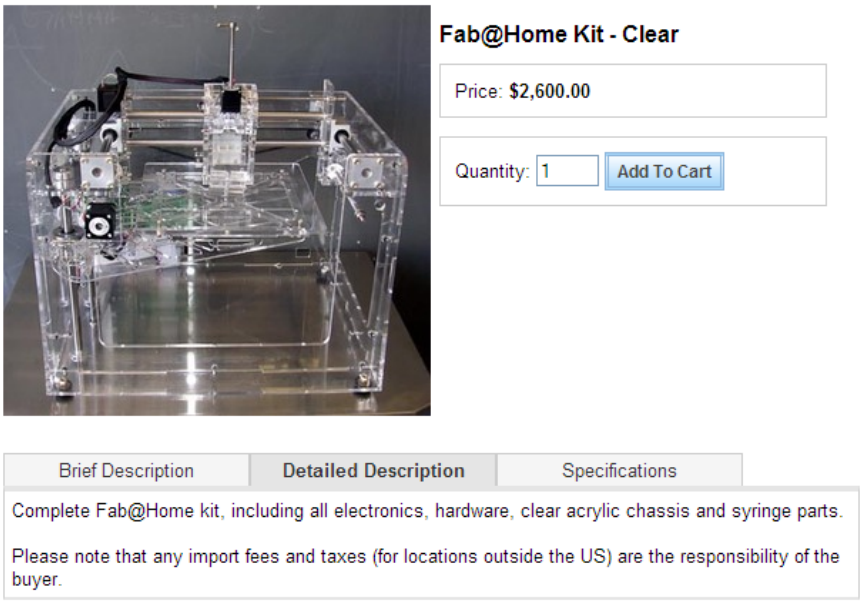
Additive manufacturing is used in a growing number of industries, such as automobile manufacture and aerospace.

Direct Write technology, for instance, employs tiny pressure-driven nozzle heads to deposit a variety of materials on to an existing structure. Antennae can be 'written' on to the outside of an aircraft,

reducing weight and drag. Methods for embedding electrical circuits within structures are being developed.

At The Wake Forest Institute for Regenerative Medicine, standard ink-jet printer heads have sprayed layer upon layer of mouse heart cells to form a functioning two-chamber mouse heart.[1] The team is exploring how to employ a similar process in human heart surgery.

The falling cost of fabricators (additive machines) has brought this technology closer to consumers. Fab@Home encourages individuals to shop around for parts to make their own machines, using an online design. Or if they prefer, they can buy a kit.[2]



Acknowledgement: Fab@Home

Online competitions encourage users to improve on the designs and share their improvements. Schools in particular are getting involved. Fabricators now start for as low as US$3000.[3]

The Centre for Bits and Atoms at MIT has rolled out around 30 Fab Labs (Fabrication Laboratories) in 10 countries, most in North America and Europe. They are equipped with small mills, laser cutters and other equipment that anyone can use to make a fabricating machine.

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1 This was showcased on the American television program *60 Minutes*. Wyatt Andrews, "Medicine's Cutting Edge: Re-Growing Organs," *60 Minutes*, 23 March 2008 http://www.cbsnews.com/stories/2008/03/22/sunday/main3960219.shtml.

2 http://fabathome.org/wiki/index.php?title=Main_Page.

3 http://www.nextfabstore.com/servlet/Categories?category=Fab%40Home.

Fab Labs have allowed an Indian businessman to build a fabricator that creates a device showing whether you are being sold watered-down milk. A Norwegian shepherd built GPS tracking tags for his sheep.[4] Small Fab Labs can be installed for as little as US$20,000.[5]

The Dutch company Shapeways offers web-enabled templates within which consumers can design a range of products, from lights to napkin rings. Users email these designs to Shapeways, which sends them to additive manufacturing suppliers. The finished product is shipped to the consumer.

Individuals are also encouraged to design objects without using a pre-existing template. Shapeways then works with suppliers to see if the object can be manufactured on an additive basis. Shapeways has an online store where consumers can buy and sell fabricated products.[6]

Kenji Kondo of NextFab claims that 'thousands' of fabricated objects, from furniture to jewelry, are now being sold by a growing number of small companies. There will come a time when we won't remember a world before fabricators.[7]

Manufacturing is beginning to shift from subtractive to additive technology and from centralized to distributed location.

What will influence the next 20 years?

The potential market, appropriate business models and ways of jumping the current barriers will drive additive manufacturing forward. By the 2020s, our lives may be revolutionized.

Market opportunities

The long-term potential market for additive manufacturing is huge. As more and more industries see the possible applications, vast amounts of research and investment will drive additive technology to new heights.

In healthcare, for example, additive manufacturing will increasingly allow a sectional image of part of the body to be accurately reproduced as a physical model in a matter of hours.

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4 *Wired*, "The Dream Factory," September 2005 http://www.wired.com/wired/archive/13.09/fablab.html.

5 This is an average of various estimates available.

6 Peter Weijmarshausen, 'Enabling Consumer Production Through Rapid Manufacturing', paper to Rapid Manufacturing International Conference, Loughborough University, 8-9 July, 2009.

7 Interview with Kenji Kondo of NextFab, 3 April 2009. http://www.nextfabstore.com

As is already starting to happen, these models will offer surgeons better understanding of complex anatomical details, help determine implant size and type, and enable 'hands on' surgical planning and rehearsal.

Using Bio-Additive Manufacturing (BAM), one company is researching how to extract bladder cells from the patient, multiply them in the laboratory, and use 3-D printing to combine these cells with a bio-compatible polymer to form a new bladder. Once implanted, the polymer would gradually be replaced by self-generated cells.[8]

'Developments in BAM will enable progress from the manufacture of cell-integrated products towards the future goal of manufacturing advanced living parts and/or bio-functional living systems.'[9]

A growing number of manufacturers will see advantages in additive processes, such as:

- Reduced tooling costs. Shoe company, Converse, cut its tooling costs by nearly 60% between 2006 and 2008 by using Z Corporation's 3-D printers.[10]

Acknowledgement: Z Corporation

- Cost savings from less waste of materials, especially exotic metals. In some aerospace processes, you can end up with a product weighing as little as 30 kg from a billet weighing 180 kg. Recycling the scrap can be expensive. Additive manufacturing replaces this subtractive approach.[11]

- Cost savings from locating some types of manufacturing nearer to the consumer. In particular, if climate change policies add carbon costs to shipping costs, supply-chain economics could shift significantly. With fabricators being scaled up so that they become economic for larger and larger batches, production closer to the end consumer will become viable.

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8 Interview with Dr Phil Reeves, 8 July 2009.

9 David L Bourell, Ming C. Leu & David W. Rosen (eds), *Roadmap for Additive Manufacturing. Identifying the Future of Freeform Processing,* Texas: University of Texas, 2009, p. 24.

10 Z Corporation webcast featuring Converse Digital Product Creation Manager Bryan Cioffi on 5 May 2009 https://zcorpevents.webex.com/zcorpevents/lsr.php?AT=pb&SP=EC&rID=1327332&rKey=F589A4329B7CF853.

11 Jeffrey Allen, 'Possibilities for Powder Based Manufacturing at Rolls-Royce', paper to Rapid Manufacturing International Conference, Loughborough University, 8-9 July, 2009.

- Cost savings from reducing inventory (stock) to zero. Distributed manufacturing will have the same effect as printing books on demand.

- Time savings. Additive manufacturing is faster than traditional processes. If its product was easily copied by competitors, a company might manufacture small batches, improve the product, and then quickly run off another batch to stay ahead of the competition.

- Customization. Even now, additive processes are being used to manufacture some of the customized parts of commercial aircraft. Experts believe it will become economic for additive technology to produce steadily longer production runs, enabling mass production to be combined with greater customization.[12]

There will be growing demand among consumers – in particular:

- Hobby-ists. Chess pieces and action men can be fabricated using 3-D printing. Players of the online game World of Warcraft can buy models of their personally designed W o W character. This market is set to expand considerably.

- Gifts. UK market research has found that there is little demand for personalized products for oneself, but significant demand for customized gifts or items shared with other people.[13] Christmas tree angels can be fabricated with the face of each family member.

- Those who like brands. Many brands help the buyer to fit in with a particular group. At present, customization that helps you stand out weakens this effect. But in future, might some brands enable all their owners to personalize the product to some extent? This is beginning to happen with some furniture and fittings. One of the brand values would be the ability to personalize.

- Entrepreneurs. In time, enterprising hobby-ists will buy a fabricator to supply products to others who share their hobby, earning an income in the process. Others will produce jewelry and the like for sale through online markets.

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12 This was a major theme of a symposium held in 2008. See David L Bourell, Ming C. Leu & David W. Rosen (eds), *Roadmap for Additive Manufacturing. Identifying the Future of Freeform Processing,* Texas: University of Texas, 2009.

13 Interview at Rapid Manufacturing International Conference, Loughborough University, 8-9 July, 2009.

Business models

A key driver will be the development of business models that make co-production, using fabricators, attractive to consumers. There are several possibilities.

The gym model (fixed-cost membership allowing use of shared facilities).[14] Individuals might use equipment in a fabrication laboratory (like MIT's Fab Labs) to build hardware that will fabricate objects they had designed at home, or for pupils to use in schools or for architects, say, to use in the office.

The service-bureau model. You might design your object at home, and then visit your local service centre where the item will have been 'printed' out.

Acknowledgement: Z Corporation

In 2006 Google bought SketchUp, a program that allows users without any specialist knowledge to design a 3-D object of their choice. Might Google (or another firm) link up with a bricks-and-mortar company to bring fabricating centres to the high street?

There have been reports 'that select name brand copy centers may be installing 3D fabricators soon.'[15]

A leasing model. Fab@Home, for example, features a chocolate bar maker[16]. As prices fall, might a firm like Cadbury's lease such a fabricator to consumers, with a tied-in supply of materials?[17] Restaurants and perhaps eventually households would be able to produce a range of chocolate objects.

As well as these consumer-focused approaches, manufacturers may have to change their approaches. In 15 years time, might Oxford's BMW mini plant become a generic factory, allowing consumers to choose their brand? Moves in this direction are

[14] Interview with Michael Angst of E-Line Ventures on 10 April 2009.

[15] David L Bourell, Ming C. Leu & David W. Rosen (eds), *Roadmap for Additive Manufacturing. Identifying the Future of Freeform Processing,* Texas: University of Texas, 2009, p. 45.

[16] http://www.fabathome.org

[17] Interview with Peter von Stackelberg of Alfred State College (State University of New York College of Technology) on 9 April 2009.

already seen in joint ventures such as Toyota Peugot Citroen Automobile in the Czech Republic[18].

Overcoming obstacles

For these models to be viable, a number of barriers will need to be overcome.

Cost is clearly one. Fabricators are not yet affordable for most households or businesses. But companies are working hard to bring the cost down. In April, a new kit to assemble a simple 3-D printer went on sale in the US for under $1000.[19]

When the industry reaches a certain maturity, a company like Hewlett Packard is likely to enter the market with a low cost machine, doing for 'personal fabrication' what Microsoft did for personal computing.

Usability will be important. Most design software currently requires users to be familiar with CAD. But software is being developed that is easier to use and limits design errors.

For example, if you personalize a pen, the software would prevent you changing the inner core (where the ink goes) and so making the pen unusable.

Such developments will enable consumers to redesign products within constraints set by the original designer, thereby protecting the reputation of the brand.

Intellectual Property Rights have been a problem. Thousands of patents deter new entrants and force imitators to make modifications in ways that reduce performance or increase complexity.

'However, the [additive manufacturing] industry is on the cusp of a new set of opportunities, as many of the original process patents are expiring. This will open up new opportunities for competition and process improvement.'[20] The spread of open-source approaches is having a similar effect.

Technological limitations include the disadvantage of being able to use only one material at a time, the quality of finish on some objects

[18] http://www.tpca.cz/en/about-us

[19] http://www.wired.com/gadgetlab/2009/08/makerbot/

[20] David L Bourell, Ming C. Leu & David W. Rosen (eds), *Roadmap for Additive Manufacturing. Identifying the Future of Freeform Processing,* Texas: University of Texas, 2009, p. 16.

and – in the case of manufacturing – the cost effectiveness of only small runs.

As the industry develops, more money will be ploughed into R & D to reduce these constraints.

What might be the implications?

A step-change in customization lies ahead. Neil Gershenfeld of MIT believes that personal fabrication will encourage enhanced creativity and widespread innovation. Products will be so personalized that they will appeal to a "market of one."[21] Society will take another step toward an 'it-must-fit-me' world.

Consumers will become producers – 'prosumers'. Peter Weijmarshausen of Shapeways has described 3 democratizations – of communications (from the telegraph to the mobile phone), of information (from mainframe computers to PCs and PDAs) and of production.

The latter will comprise a shift from industry-scale manufacture to personal, digital fabrication – a new form of D-I-Y. Could this development be bigger than the internet, he wonders.[22]

The production of spare parts will be transformed. Building on an emerging trend, spare parts that have gone out of mass production will be replaced using additive techniques.

Will new businesses specializing in spare parts be established close to customers? Instead of shipping the part from half way across the world, it would be sourced from much nearer home, saving time and transport costs.

Ships may be able to manufacture spare parts and carry out running repairs while at sea. They would dock for shorter periods, cutting costs.

Within healthcare, hospitals will establish facilities to produce custom-made body parts. Certain hospitals may develop specialisms that serve regional markets.

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[21] Neil Gershenfeld quoted in Jeffrey M. O'Brien, "A factory of one's own," *Fortune*, 7 November 2006. http://money.cnn.com/magazines/fortune/fortune_archive/2006/11/13/8393124/index.htm.

[22] Peter Weijmarshausen, 'Enabling Consumer Production Through Rapid Manufacturing', paper to Rapid Manufacturing International Conference, Loughborough University, 8-9 July, 2009.

Some supply chains will change radically. If it becomes economic to bring production closer to the consumer, what will supply chains look like? Could off-shoring be reversed as some types of manufacturing return to North America and Europe? Some hobbyists are already calling their 3-D printers, 'having China on your desktop'.[23]

[23] http://www.wired.com/gadgetlab/2009/08/makerbot/