NESTA Making Innovation Flourish

Personal Manufacturing

A numbered cookie cutter for a birthday party. A spare part for your car. A custom doll for your daughter. What if all these could be printed by you at home, based on downloaded designs? The near-future of personal manufacturing is easy to imagine, but this technology has the potential to change manufacturing, trade and entrepreneurship. Novels like Neal Stephenson's *The Diamond Age* and Cory Doctorow's *Makers* have envisioned possible futures where personal manufacturing dominates the culture. But what will the future really look like? Could personal manufacturing change 'physical' industries in the same way that open source has changed software, or access to cheap digital tools impacted on music, film-making or photography? What happens in a world where physical goods can be modified and distributed in the same way as information?

The event

For our event, 'Personal Manufacturing: the new look entrepreneur?', NESTA hosted three leading practitioners in the world of 3D printers and other small-scale manufacturing technology. **Adrian Bowyer**, senior lecturer in the Department of Mechanical Engineering at the University of Bath, is inventor of the RepRap, a self-replicating open-source 3D printer. **Haydn A. Insley** is Manager at FabLab Manchester, the UK's first FabLab where you can turn up and use their equipment, software and expertise to prototype your ideas. **Alice Taylor**, previously Commissioning Editor for Education at Channel 4, is now the founder of start-up Makieworld, which wants to use 3D printers and other technologies to make customisable dolls.

The event considered how 3D printing is changing their industries and the impact it is having on entrepreneurs. With the costs of prototyping coming down, what does this mean for start-up companies that have a product to manufacture? Will this lead to a wave of new 'digital manufacturing' start-ups? And what does this mean for incumbent manufacturers?

Hot Topics is a series of NESTA events driven by ideas and technologies. They aim to introduce the technological tools that will change how we do things in the coming years, and are designed to bring together the best of business, academia, start-ups and investors.

Find out more at: http://www.nesta.org.uk/events/hot_topics

The speakers

Adrian Bowyer is responsible for the RepRap project, the self-replicating rapid prototyper that is designed to be able to print a significant fraction of its own parts. At the moment that's about 50 per cent, but the other parts are easy to obtain from a hardware shop or online. This open source project has formed the basis for many commercial ventures as well, including Makerbot Industries (in which Adrian owns shares) and Bristol-based Bits from Bytes, which both make and sell 3D printers and printer kits. There is also a website, Thingiverse, where you can download designs that others have created to print on your printer. If all this seems improbable, it once seemed inconceivable that we would have a computer in every home. As Adrian pointed out, many people have a CD plant, a printing press and a photographic lab at home – why not a factory? He sees the technology as analogous to MP3 sharing, but for solid things.

> "Most people in the developed world run their own CD pressing plant, photo lab and printing press. Why not their own factory?"
>
> **Adrian Bowyer**

Haydn Insley described five elements you need to get started with personal manufacturing, all of which are available at FabLab Manchester. In addition to the prototyping equipment, you also need: the design software and IT to control and design for these machines; people who can teach you how to use it; the facility itself, which provides a nucleus for a community that learns and improves; and accessibility – anyone can use a FabLab, and Fridays and Saturdays are free. Manchester is one of 50 FabLabs worldwide and the future vision is to bring many more FabLabs to the UK through the UK Fab Lab foundation, and to see accelerated innovation from the open innovation and rapid prototyping that this technology and these locations make possible.

Alice Taylor "gave up her cushy job", as she described it, at the end of 2010 to create her second start-up. In 1998 Alice created StorTroopers – customisable online avatars that you could dress up in different outfits. Now she wants to do something similar for dolls. Dolls have seen relatively little innovation, and lack the sort of customisation that is possible with your online avatar or game character. She is looking for the technology to produce smooth, pre-coloured printed dolls that are also biodegradable (*"so you can feed them to the dog when you're done with them"*). The existing technology isn't quite able to do all these things together yet, but she is betting that it will get there in the next year and a half.

The technology

What is a 3D printer?

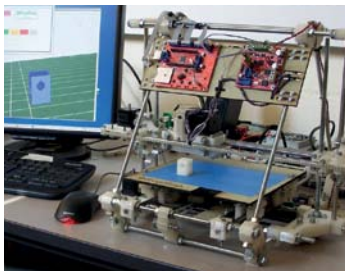
Personal 3D printers work much like inkjet printers, but squeeze plastic through the print nozzle instead of ink. By covering the same area over and over again, layers of plastic can be built up, creating a three-dimensional object. The size of the object is limited to the size of your printer, much the same as paper printers, but large pieces can be put together from multiple parts (Adrian showed an intricate Gothic cathedral that was made in 20 parts). Because the plastic is laid down where it is required, rather than moulded or carved, there is virtually no waste with this technique. The range of plastics is currently limited, but is expanding all the time, with wood, paper and metal substrates being developed as well.

Cathedral by Skimbal – www.thingiverse.com/thing:2030

Rapid prototyping machines, which include 3D printers, laser cutters and CNC routers (see box on page 4) have been used in industry for many years. Manufacturing companies such as Dyson use them to create prototypes of new designs, which can then be quickly tested, and the designs refined, without having to set up a manufacturing process. These industry printers, made by companies like Stratasys and EOS, tend to be large and expensive, costing from $15,000 to hundreds of thousands of dollars, but over the years have been developed to produce high quality results, which means smooth, robust products, printed faster.

So far, this is a familiar tale – a new technology is developed for industry, gradually the cost shrinks to a reasonable level, and they start to be produced for home use and by small businesses, and then new consumer models are developed.

But rapid prototyping has an alternative development track as well. The RepRap, or Replicating Rapid prototyper, was conceived as an open source project, although as Adrian Bowyer admits, it wouldn't have worked any other way. The printer is able to print a significant fraction of its own parts – about 50 per cent. The rest of the parts are deliberately obtainable from a hardware shop or online store without too much difficulty. You can assemble one yourself for about £300, and anyone who has a RepRap can make one for a friend. The opportunity for viral replication of printers makes the growth dynamics interesting and unpredictable. If you don't fancy doing that, you can get access to them, and to other personal manufacturing equipment and expertise, at places like Manchester's FabLab or Hackspaces around the UK.



RepRap, a free desktop 3D printer capable of printing plastic objects http://reprap.org

Current outputs from the RepRap and other small-scale printers are a little limited right now. The outputs can only be printed in plastic, are often ridged, and can't always print in colour. However, all these things are being developed, as is the ability to print metal, wood and softer rubber-like plastics. Some of the immediate possibilities include making spare parts at home if you break something, creating intricate sculptures, and producing improved parts for your printer. The cost of developing a prototype with these machines has halved in the past year, and is likely to continue to fall this year.

The economic potential

Personal 3D printers are a technology that has been on the horizon for a long time, but 2011 is likely to be the year they start to become mainstream. The Economist has already featured the technology in a cover story. The MakerBot 'Thing-o-matic' was Forbes' best in show at CES, the Consumer Electronics Show held in January. Based on the RepRap project that originated with Adrian Bowyer, it can print plastic gadgets based on 3D computer models. You can design them yourself, or download the designs of others from sites like Thingiverse.

2010 saw a step up in corporate investment in this technology. In January 2010, HP did a deal with 3D printer company Stratasys to produce HP-branded desktop 3D printers. In October, Shapeways, a 3D printing service, received a $5 million venture capital investment from Index Ventures and Union Square Ventures. Also in October, NASDAQ-listed 3D Systems acquired Bristol-based Bits from Bytes, which produces RepRap-based printers and printer kits from $1,300.

Personal manufacturing – the machines

Personal manufacturing refers not only to 3D printers, but to a range of other machines.

3D printer – many of the machines listed in this article, including the RepRap and the Makerbot Thingomatic, are 3D printers that deposit plastic in layers to build up an object. 3D printers can also use Selective laser sintering to fuse specific points within a box of powder, creating a solid object surrounded by un-fused powdered plastic. This is more commonly used with industrial machines.

Laser cutter – the most popular machine at FabLab according to Haydn Insley, this uses a high-powered laser to cut designs into wood, plastics, leather, metal, glass and ceramics. Their precision makes it possible to use very intricate designs, and flat, laser-cut pieces can be assembled into 3D objects.

Desktop routers and milling machines – these are usually numerically controlled (CNC) machines that use a physical blade or drill to carve shapes into materials including wood, metal or even porcelain. CNC stands for 'computer numerical control' and refers to a range of machinery that can be precisely programmed, rather than manually operated.

3D scanners can also be used to create a design to be printed, rather than starting with an original design. This makes it possible to hand-carve an object, then scan it to be replicated on a printer in a different material.

Other machines include high-tech embroidery machines that will accept computer designs, and desktop circuit board makers.

Where to use them:

Manchester FabLab provides access to a wide range of machinery and software. A list is provided on their website, http://www.fablabmanchester.org/

Hackspaces around the UK also have equipment for public use. You can find a list of hackspaces on the website http://hackspace.org.uk/

Various online services will print your design for you, including Shapeways, Ponoko and i.materialise.

How might the technology develop?

At the event, discussion covered the current state of the personal manufacturing industry, something that the US government is already describing as an 'emerging economy', and many parallels were drawn with other industries to predict how the industry might evolve.

Adrian made the point that manufacturing has historically been dominated by economies of scale, which lead to production being concentrated in larger and larger firms. It is much cheaper and more efficient to produce in large quantities, so there are a few, large locations for production rather than many smaller ones.

Alice Taylor, founder of start-up Makieworld

However, as Adrian described, economies of distribution are also important. China is the world's favourite location for manufacturing, but those who receive goods are constrained by the capacity and frequency of sea and air freight deliveries. If shipping or fuel costs rise significantly, as well as wages in China, the advantages may wane.

The move away from large scale is not unprecedented. In some industries, the trend has been for greater localisation or greater customisation rather than greater scale. Laundries used to be important businesses, but now you are much more likely to have a personal washing machine than to visit a laundrette (at least in the UK). Similarly, although printing documents is much cheaper in bulk at a print shop, most people choose the convenience of a desktop printer.

Where you need greater expertise to operate the technology, you are more likely to use an outside agency. Photo printing at home is very popular, but there are still many high street and online services that will do it for you, because it requires expertise and experience to produce a high quality result.

Although it is convenient and quick to print photos at home, it seems less of a good deal if you need to change to a more expensive print cartridge, and then print ten different versions until you get one you are happy with.

Film-making is another area with both high-end industrial technology, and cheap, consumer versions that popularised home film-making. While giving everyone a video camera doesn't make everyone Steven Spielberg, it certainly lowers the cost of getting started, and makes the pool of potential Spielbergs much larger.

The development of personal computing and the internet could also be a guide to the development of this industry. Personal computers started out as the province of hobbyists. Engineering students would think nothing of building their own computer, modifying it, shopping for a new motherboard, buying huge catalogue-sized magazines with tips, how-to guides and long price lists of components. The Apple II was developed with feedback from the Homebrew Computer Club, a club of hobbyists in Silicon Valley. But then came Windows, and Dell, and the new Apple iMacs, and most people preferred their machine to just work, rather than to build it themselves and keep improving it.

The early days of the internet, as archived in places like Geocities, were full of people creating their own directories, their own pages. 'David and Jerry's Guide to the World Wide Web' became Yahoo!, but many others were lost and abandoned. A criticism of this technology is that most people don't have the skills to design in 3D, or the interest to learn. But just because 99 per cent of the web is uninteresting, that doesn't devalue the 1 per cent that's great – as long as there are ways to find the good stuff.

If there is one thing we have learned about the dynamics of the web, it is that the real value is captured by the brokers: search engines; those that can connect the makers with the buyers; and the app designers with the users.

Princess by Eric von Straaten – i.materialise.com
More photos at: www.flickr.com/photos/imaterialise/5226600722/

"Rather than printing a dolls' house why not print a dolls' science lab?"

Alice Taylor

The future of personal manufacturing

Given these possible routes, and the current capabilities of the technology, what can we expect will happen next?

Firstly, it seems certain that the current industry-standard technology will continue to improve and become cheaper, in a similar way to personal computers, desktop printers, and many other technologies. It also seems likely that the open source printers will improve in quality and reliability, as well as diversifying into more specialist devices that are optimised for certain types of product.

Secondly, more intermediaries are likely to crop up. Shapeways has

raised investment from Index Ventures, a European venture capital firm. Ponoko, Threadless, Inventables and similar sites are likely to proliferate. The marketplaces for made objects are also likely to proliferate, and then consolidate. Etsy is a forerunner in this area, but mainly aimed at craft producers. More high-tech versions are also likely to emerge.

Intermediaries will not just exist online. There are likely to be commercial versions of FabLab or Hackspace, the 3D equivalent of Kinkos, that will produce same-day prints for you in a high street location. One of the appealing elements about e-books and 'app stores' is the instant gratification to be had from a purchase and immediate consumption. If ordering a physical object to be delivered to your home printer could become as easy as installing a phone app, the potential for 3D printers as a distribution channel for many industries is significant.

Barriers – and opportunities

Adrian Bowyer inventor of the RepRap

Some are sceptical about the likely adoption of this technology. Given the opportunity to produce something themselves rather than buy it from a shop, will people do it? NESTA's research into user innovation[1] suggests that three million people in the UK already make and modify equipment and software. This represents a large opportunity for UK innovation.

Opportunities

As well as the makers, the aggregators, the designers and machine builders, there are opportunities for other adjacent services:

- 3D design software is nothing like as usable as desktop publishing software yet. Some will want to design their own objects from templates; others will want designs to download without modification. There is an opportunity for the 'iPhoto' of 3D design.
- Testing specialists – making sure that your toy or tool is safety compliant, and providing verification, is likely to be an important service.
- Marketing specialists – as search engine ads and websites spawned a digital marketing industry, there is likely to be another group that will tell you "how to promote your 3D print business and earn $$$!!!"
- Learning specialists – books, websites, training courses, e-learning, podcasts on both the design and building of objects, are likely to proliferate.
- For large companies, there are opportunities to produce personal manufacturing toolkits, customised final products, screened or quality-assured designs and printers, and template downloads.
- 'Long tail' opportunities – large and small companies, as well as individuals and other organisations, should be able to target niches that would be uneconomical to address with traditional manufacturing techniques. This will also create opportunities for online information about this 'long tail' of niche products, as well as ways of submitting user needs.

Any disruptive new technology creates problems for business models, legal structures and regulation. Personal manufacturing is no exception, and some of the issues are already coming to light.

Intellectual Property

Many of the IP challenges associated with digital content are shared by digital designs for 3D objects. The IP regime will need to accommodate modification

1. Flowers, S. *et al.* (2010) 'Measuring user innovation in the UK.' London: NESTA.

and improvement, large-scale sharing, and still make some provision for protection against piracy and counterfeiting. When you can scan any object and produce your own replica, you need to think carefully about where the real value exists.

There is a question of whether patents, copyright, designs or some hybrid IP form will be most appropriate for 3D designs. Alice's view is that *"you need to have an internet attitude: everything is copied, shared, imitated. You need to stand out by being different, better, lucky."*

> "3D printing brings authenticity and availability at the expense of quality and cost. Soon it will deliver all four." **Nicholas Lovell via twitter @nicholaslovell**

Standardisation and health and safety issues

The industry is highly fragmented at the moment, with interoperability a major issue. Standards will be needed at the levels of design software, as well as raw materials and machine parts.

Liability is a question that was raised at the event: if I'm a designer, but my customer is the manufacturer, who is liable for damage or injury? As Adrian pointed out, the UK already has provisions that cover machine tools like lathes which have been around for decades: for faults with the lathe, the manufacturer of the tool has liability; if the lathe is not at fault, but is used to make something that is dangerous, the user of the lathe is at fault.

However, just as piracy regulations have been strained by changes in digital distribution, it remains to be seen whether existing legal provisions will be robust enough to withstand these technical changes.

Eco-opportunities

As Alice described it, many of the attributes of 3D printed objects – eco, local, less shipping, made in Britain – have great appeal, and additional benefits. Adrian Bowyer commented: *"when things get cheaper, people make more of them. One of the most ecologically beneficial things we could do would be to make things to throw away"*. There is potential for this trend to converge with the emerging bioplastics and biopolymers sectors. As Adrian pointed out, a material that made use of atmospheric CO_2 in its production, used for disposable products, would be a form of carbon capture. He sees the effectiveness of such a scheme as driven by *"the most powerful force on the planet – human greed and stupidity"*.

Other issues

There are many other questions about how the industry will evolve that are yet to be answered. How will personal manufacturing deal with the supply chains needed to provide raw materials and parts? If everyone makes music/videos we are just left with some bad digital music, but with 3D there will be a lot of stuff that we need to store instead – where will it go? How will the 'long tail' effect of access to large numbers of small markets shape the industry? What will be the impact on financing and investment in manufacturing businesses – with lower start-up costs, will more of these businesses proliferate?

Choosing an object to buy – a lamp, a doll, a cookie cutter – is an exercise in compromise. You set out to buy what you want, and then choose the best fit from those available to you. The web makes it possible to access the 'long tail' of options, and increases the chances that you will find a match. However, having something designed and made for you is only for the wealthy and time-rich. What if getting just what you wanted was standard, not a high-end service?

What does this mean for the future of personal manufacturing? While this is an industry firmly in 'hobbyist' territory for now, the pace of improvement in the technology indicates that this phase won't last for long. The open source foundations of this movement are likely to mean that innovation will be rapid, and propagate the best modifications very fast. As soon as a good enough version stabilises, then expect consumer devices as well as consumer-friendly print services. Foresight's report into 2020 technologies said: *"It is likely that over the next 20 years there will be increasing demand for personalised products in the same way that we already expect tailored services"*.

Hayden A. Insley, Manager of FabLab Manchester

For more about this event, visit the NESTA website to watch the video, access a list of links and videos on the resources page, and find out more about upcoming events.

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