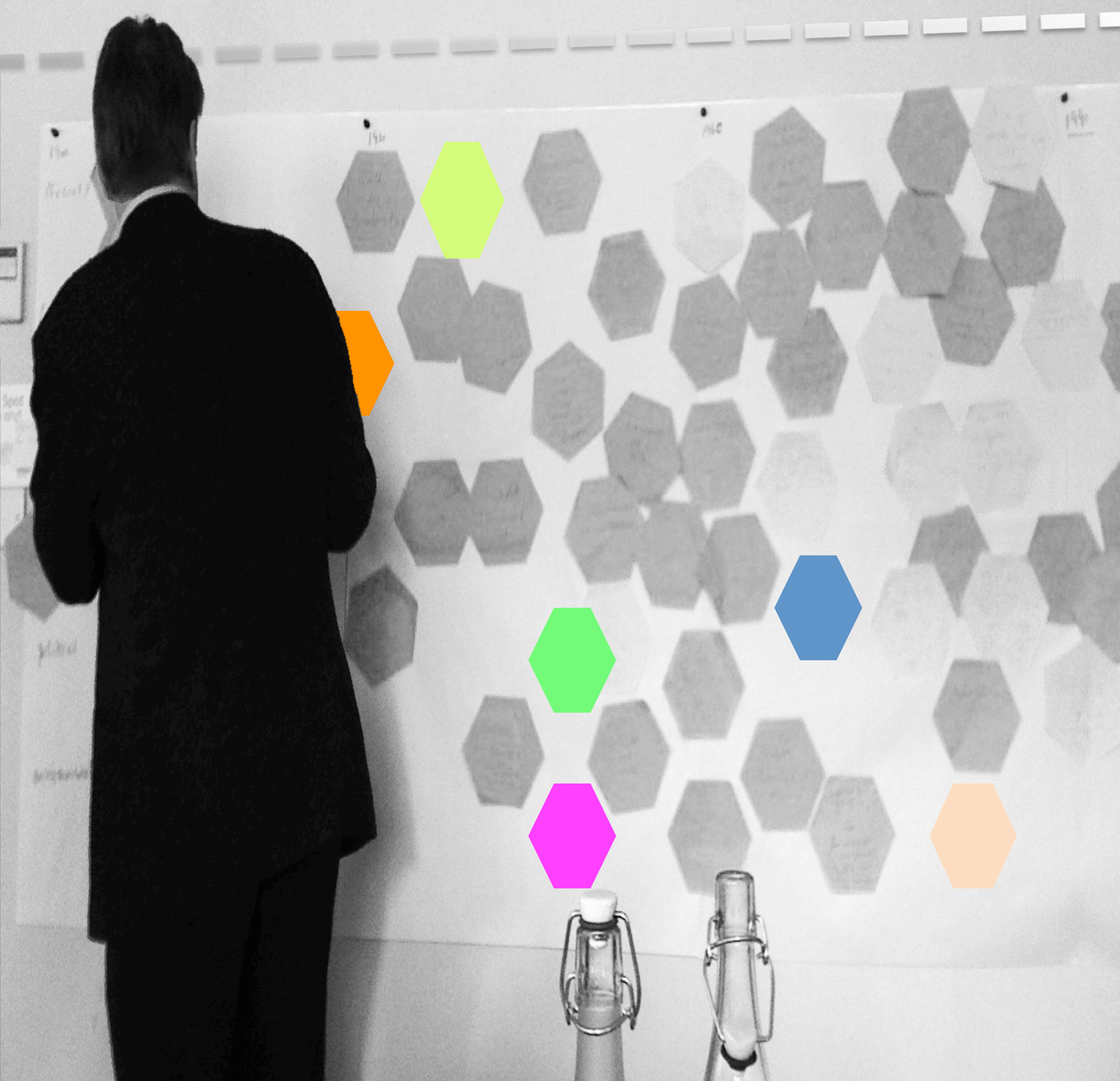
Freight Miles

The Impacts of 3D Printing on Transport and Society

Thomas Birtchnell, John Urry, Chloe Cook and Andrew Curry



LANCASTER UNIVERSITY

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

the futures company

Freight Miles

The Impacts of 3D Printing on Transport and Society

Thomas Birtchnell *University of Wollongong*
John Urry *Lancaster University*
Chloe Cook *Futures Company*
Andrew Curry *Futures Company*

ESRC Project ES/J007455/1

Table of Contents

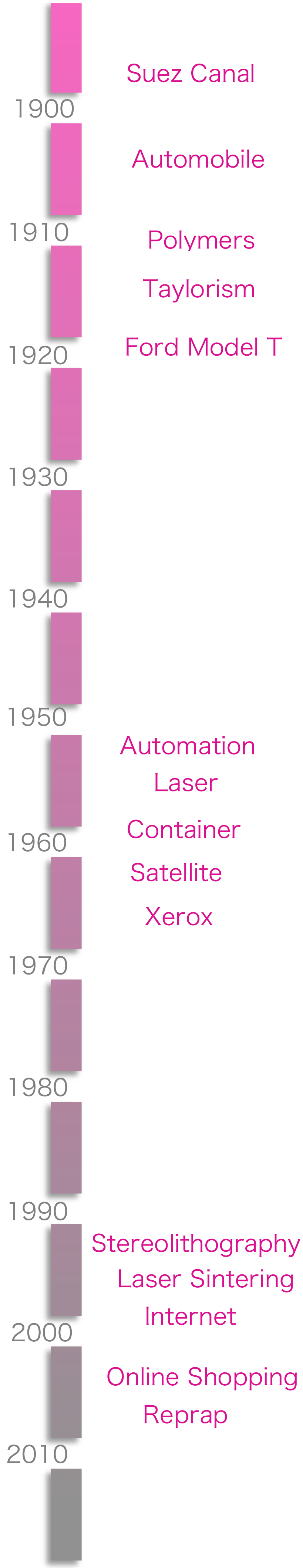
Executive Summary

Imagine trucks and lorries no longer ply the highways. The freight trains are gone and the container ports stand empty. Containers rest rusty and hollow on the dock. The assembly lines are quiet and the warehouses still. People's homes are now filled with activity as people download and simply 'print' the objects they desire like pieces of paper on a home printer. And just like paper once people are done with these objects they simply recycle them, reusing the same materials again and again. And most designs and printers are open source and available online. Some people just swap and share designs, others contribute their own expertise to communities of fellow innovators and databases of shareable designs, ranging from a new kitchen sink plug to a replica antique train model.

Now imagine another future—a future filled with more local deliveries and freight spurred by the return of regional industry due to the ubiquitous spread of the digital 'factory in a box'. People print out objects at print shops, which rely on standardized and government regulated supply chains delivering all sorts of industrial materials from metal powders and polymer filaments to exotic liquids and resins. The ease with which objects can be printed leads to an intensification of movement, with roads and railways busy distributing the many items people constantly order online through a plethora of corporate suppliers and finance systems. This is a world where objects are cheap, they are moved about and products quickly become obsolete.

In these two futures a significant social and technical transition has taken place in the production and consumption of material objects. Regardless of which future emerges, a recent technological innovation allowing virtually transmitted digital bits of information to be made into real-world atoms is likely to be significant. These are just two futures involving a radical recent innovation representing a conjunction of digital information, automation, materials science and computer-aided design: 3D printing or 'layer-by-layer' additive manufacturing. This process for making things represents a possible revolution both in manufacturing and in transportation. Turning bits into atoms in real-time is as profoundly unfamiliar as the idea of instantly sharing thoughts across the world would appear to a nineteenth century observer who would marvel at this readily available feature of modern communications.

This Report thus asks how might the development of 3D printing technologies affect transportation up to 2030? Lancaster University's CeMoRe (Centre for Mobilities Research) and The Futures Company collaborated in an Economic and Social Research Council (ESRC)-funded scenario planning exercise looking at the consequences of developments in 3D printing technologies upon global patterns of freight transport and the related travel of consumers.

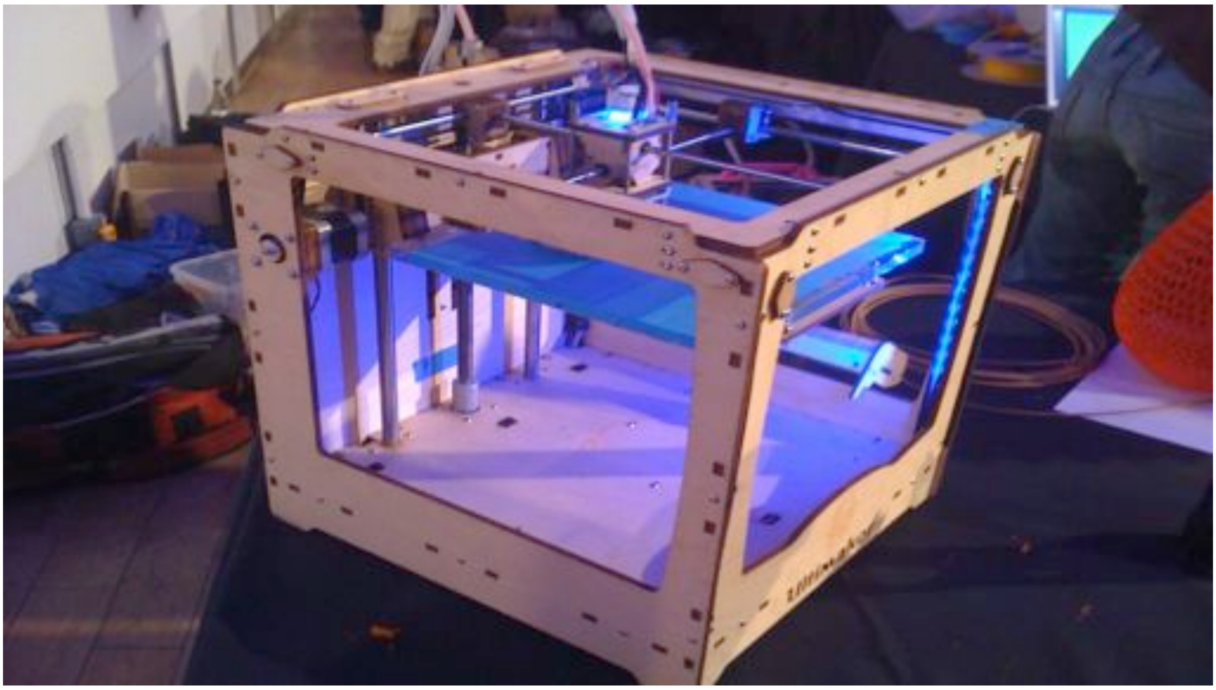


Whether the future of freight is one of increased stillness or heightened mobilities, a significant impact will be the changing climate and the mitigation of resource depletion, as well as the capacity for governments to moderate the peaks and troughs of a global financial market intertwined with the demand of consumers and the supply of manufacturers. So there is merit in assessing the impacts of emerging innovations through futures work on such a potential new 'system'. In developing this Report, a number of principles have shaped our thinking:

- The ways that life is organized into relatively stable and enduring social practices are as important as technological innovations in socio-technical transitions from one system to another.
- Digital data, in virtual and online creation, storage and exchange, will undergo a profound shift towards materialization into the physical world with consequences as significant as the digitization of other human intellectual activities in music, science, literature and so on.
- The global movement of objects through containerization is a recent phenomenon tied to the expansion of reserves of energy and there is no guarantee that the system will continue to be dominant.
- Subtractive mass manufacturing is only one form of making objects and is often inefficient and increasingly undergoing standardization, computerization and automation.
- There is much social interest in customization, craft, repair and personal fabrication, which is currently unfulfilled by the system of containerization, which privileges standardization, pre-assembly, obsolescence and mass-production.
- Supply of transport infrastructure, energy and investment is for the most part for consumption demands and material cultures rely on this system to be seamless, streamlined and intermodal.
- 3D printing affords an organic way of making complex geometries: designs can be 'grown' in real-time.

Conceptually then 3D printing is a sea change in the way production is done (supply) and in the expectations of consumers (demand) and it could require unique policy instruments (Sissons and Thompson 2012). Parallels here can be drawn with the automobile and the shift from animal to motorized transport. While technologies and practices can change existing elements also readjust and continue to play a role in new systems (Edgerton 2006).

In the workshop there were four scenarios for 2030 on two axes: first, the extent of corporatization of manufacturing, design and distribution systems; and second, the overall degree of individual engagement with 3D printing. This Report summarizes the output of this workshop in some detail. The workshop participants are listed at the end.



The research involved bringing together twenty-four engineers, designers, consultants and logistics experts in a scenarios workshop in London in 2012 facilitated by the Futures Company. In combination with semi-structured interviews with fifteen experts and participatory observation in information-rich sites a range of futures were assessed in this workshop in order to predict futures.

The workshop started with developing a timeline going back to the 1900s to understand patterns of change and also particular types of change. Participants worked together to build the timeline covering key areas of society, economics, technology, policy and sustainability related to manufacturing. Then four scenarios set the scene for an investigation of the key drivers of change in the next 20 years. The names of the scenarios are intended to capture the main features of each world.

Why is it 3D ‘Printing’?

3D printing is an evocative term and works well in explaining the physical appearance of an object rendered in real-time (although not always rapidly and often somewhat slowly) from a two-dimensional ‘flat’ computer design. So why did commentators term this process ‘printing’? Instead of subtracting or removing quantities of material through machining or cutting, or forming objects by moulding or stamping, additive manufacturing uses precision techniques that build up the product layer by layer (Hopkinson et al. 2006). This process is much like the 2D process of printing on paper. The fact that many 2D printing companies were forerunners of many 3D printing patents, from HP to Kyocera, reinforces the conceptual relationship between 2D and 3D printing (Shankland 2010). Yet, as in any new technology, the cutting edge companies come from leftfield. Two in particular are emerging as market leaders: 3D Systems, who recently acquired competitor Z Corporation, and Stratasys, who recently merged with competitor Objet, to create a further major corporation. Both these companies were early pioneers of this innovation.

The origins of 3D printing lie in a patent dating from 1977 for a process where a laser forms a solid polymer from a liquid on a tray lowered into a vat (Bradshaw et al. 2010 p. 29). In the US 3D Systems and stereo-lithography found its way into the public imagination in a science segment on the television show Good Morning America on 30 January 1989. The feature describes how 'the auto industry spends twice as much money designing car parts as making them' and used to make models out of clay—'both expensive and time consuming'. President of 3D Systems and inventor of stereo-lithography Charlie 'Chuck' Hull in this feature maintains 'I think a good way to describe it is a three-dimensional printer … in the broader sense you might say it does for engineering and manufacturing what the Xerox machine or word processor or both of those do for the office environment'. Raymond Freed, CEO of 3D Systems, elaborates further:

> I think the technology is capable of what I call just-in-time manufacturing, which is what the world is trying to really do, which means that you would produce the part just as you need it—now we're not there yet, we've probably got five years or more of hard research and development, but think if we could make a whole car door in less than a minute without any tooling and change it by just changing the computer model. I think we would revolutionize the way industry works. (Good Morning America 1989)

Already at this early phase experts are starting to think about the wider implications for transportation and society (Birtchnell and Urry 2012). Stereo-lithography was integrated into rapid prototyping machines for the purpose of what became known as 'rapid prototyping', whereby a designer, engineer, or architect could produce an experimental or unfinished object for testing without having to resort to costly factory settings which are only economically feasible for large numbers of finished products. Alongside polymers other heat sensitive materials became popular as rapid prototyping went mainstream. The most important early innovation at the high-end of printers was wax extrusion and many large wax-melting printers began to appear in industrial settings for prototyping, replacing hand-modelled clay.

There are many competing terms for the phenomenon known colloquially as 3D printing and each of these has its own historical place: stereo-lithography, rapid prototyping, rapid manufacturing and, the most recent, additive manufacturing (Mellor et al. 2012). There are also many different processes here: heated extrusion, laser sintering, electron beam melting, chemical binding and so on. Various innovations in scanner, sensor, laser, electron beam and chemical technologies have been pivotal in bringing each of these processes into product development and allowing certain printers to be applied to new and exciting purposes. Interestingly, as the technologies grouped under the umbrella of the conceptual notion of 3D printing have matured into consumer and industrial products they have come to look more like 2D printers, whether this is the latest desktop unit or the larger model of 'office' type printer.

Materials

As much as appearances deceive, 3D 'prints' do not just appear out of thin air. Each object requires feedstock as well as some additional material for scaffolding and, in some models of printer, enough excess material to fill the build tray to capacity. Feedstock refers to stock material that is fed into a printer, whether in the form of powder, liquid, gel, filament, gas or some other standardized raw material (Pearce et al. 2010). Initial innovations in the printing of objects occurred in experiments with lasers, chemicals and binding agents and were a progression from the moulding of materials to change their state, e.g. from a liquid to a solid. Rather than pouring or injecting a material into a mould (as in the modern process of 'injection moulding' and in the practice of metal casting where metal is melted and poured into a mould) a computer solidifies material feedstock layer by layer with micro-millimetre detail. Because of the visibility of the layering in many cases of 3D printing, some form of minor 'finishing' is required for the object to be aesthetically satisfactory to likely consumers/users.

Before computer-aided manufacturing the machining or milling of an object from a block of material in a tooled factory setting involved a subtractive 'cutting' process, first by using blades and eventually lasers. In 3D printing all material can be accounted for, including the 'scaffolding' for objects that cannot support themselves, which is printed alongside the object itself so reducing human intervention in the production process.

In low-end 3D printing an object is produced using affordable and widespread composite plastic filament (known as ABS or acrylonitrile-butadiene-styrene) through a process of melting, extrusion and solidification. This innovation made 3D printing affordable and also freed the process from control by material patents and expensive printer technologies. And more importantly with the use of an end product material such as ABS the idea of 'rapid manufacturing' became a possibility. And there is even open source desktop laser sintering on the horizon (Scott 2012).

Most printers on the market use some sort of cartridge system in the same fashion as their 2D relatives. Just like in paper printers various manufacturers have sought to render their models compatible only with their own branded cartridges or those from preferred suppliers (many 3D printers also use standard powdered colour cartridges by 2D printer companies such as HP). As a rule the larger companies demand model-specific cartridge types and some even control their entire supply chains in-house.

According to one corporate supplier, one of the largest 3D printer companies for office and industrial models, runs a recycling service from a single corporate site in the US where it restocks all of its customers' cartridges via its own facilities and supply chain. Many users have sought to transgress this supply chain monopolization. Another 3D printing community user we interviewed noted how they had managed to successfully hack their obsolete industrial printer, which was a model no longer supported by the manufacturer, in order to use their own refilled cartridges and continue to use the device without upgrading.

A great leap forward for open source innovators has been to use generic stocks of raw materials, which are readily available to consumers to purchase or accumulate. Of issue here is the diameter of the filament 'wire' in relation to the extrusion head. By using generic feedstock inventories are greatly reduced, as stockists only need to order a single kind of product that can be used in a wide range of different printers. Hence, in the use of generic feedstock there is the potential for considerable efficiency gains in transportation and storage.

About 2 per cent of global oil is used to make a wide variety of manufactured goods in a rainbow of different polymers and as much as 95 per cent of packaging and bottling worldwide is derived from oil products. 3D printing in many low-end machines relies on ABS, which is a polymer derived from oil, or in some cases corn ethanol derived PLA, which generally requires oil-based fertilizers anyway. High-end machines, which integrate lasers and even electron-beams, are able to experiment with many exotic materials—Objet patented a rubber-like material called 'Tango'. The mail-order 3D printing company Shapeways provides users who upload designs with sandstone, glass, ceramics and even gold. In one novel process an open source robotic arm 3D prints using soil.

An important question in assessing the transportation impacts of 3D printing is whether this particular innovation will lead to more or less travel of both objects and people overall. This question is tied to issues of recycling and reuse because much of the haulage involved in moving manufactured objects will be less. However, considerable reductions in the transport of objects would emerge as a result of innovations in object design, mixed material printers and also in the adoption of design repositories by the producers of larger objects such as vehicles or white-goods. Instead of raw materials being transported from the source of extraction to the factory, it goes straight to the consumer with only minimal treatment, such as atomization, ‘cracking’ or other processing. This has many ramifications for how materials are moved about in global productions networks.

Moreover, what could emerge is the downloading of designs by users to replace broken or malfunctioning parts in a modular process where no technical tools or expertise are required. So in this future global manufacturing would be augmented or replaced by a circular economy where objects would be printed, used and then locally recycled into further printable feedstock. Something like this has already been imagined in work by the Ellen MacArthur Foundation, which flagged 3D printing as a key innovation in a future circular economy at the 2012 Davos conference of business elites (MacArthur 2012).

With the development of infinite bandwidth and zero latency in online networks combined with personal fabrication the conventional trading pattern could be ‘turned on its head’ with artisans in the developing world ‘crafting products for 3D printing’ in the developed world, in the process reengineering current craft value chains (Bell and Walker 2011).

Designs

3D printing design companies are competing to offer user-friendly interfaces for customers with no experience in CAD software—current contenders include Ponoko, Shapeways, Materialize and Fluid Form. But the real challenge is to facilitate the creative act of designing, including the user in the design process, without users and co-producers having to learn complicated software packages, notably 3D-CAD (Chen et al. 2012).

A further issue for designers with limited experience of 3D printers is adjusting to the parameters of each printer and the practicalities of 3D printing. Currently in the home, convenience, comfort and cleanliness are key influences in what constitutes normal practices (Shove 2003). These aspects impact considerably on how people use technology as well as on more novel uses, such as Dutch designer Wieki Sommers who imagines the 3D printing of meaningful household items from the powder residue of cremated loved ones (Crespo 2012)!

There are considerable legal complexities around 3D printing from files downloaded from the Internet as with music and text. US patent attorney Daniel Harris Brean notes that under existing law distributors of digital representations of products, such as CAD files, are not ‘making’, ‘selling’, or ‘using’ the products or any ‘component’ thereof. Indeed, the legal implications of 3D printing are not clearcut and could entail black (or at least grey) swans for policymakers (Brean 2012).

Moreover, additive manufacturing offers designers the option of printing complex geometric designs that are practically impossible in other forms of manufacturing with exotic materials difficult to use in a machining factory environment. Also possible is the printing of organic matter such as food or organs for the body grown from a patient’s cells.

Additive manufacturing comes into its own with the capacity to customize products. Unlike traditional manufacturing end users can participate in the very design of products. Additive manufacturing, even with increased printing speeds, will not be able to match the efficiency, scale and speed of the global freight industry and next-day delivery models. But what it does offer is a new market for bespoke and unique objects, which will set consumer standards unmatchable by mass manufacturing. High quality low cost manufacturing systems will change how consumers shop and where objects are made and this could cascade into the supply chains and logistics of freight companies (Rosen 2004).

This Report is being written soon after the global event of the London Olympics. Perhaps the most ‘futuristic’ of the sports and one that could have featured in a science fiction story is the cycling held in the Velodrome. Team Great Britain excelled in cycling. The androgynously garmented men and women hurtle round the track at over forty miles per hour, only protected from serious danger by bespoke custom-fit helmets. These deploy various technologies, of new materials, CAD design, 3D laser scanning, 3D modelling and 3D printing (Hopperton 2012). This represents a spectacular example of a mundane object, a bike helmet, being transformed through various combined technologies including 3D printing into a ‘space-age’ garment.

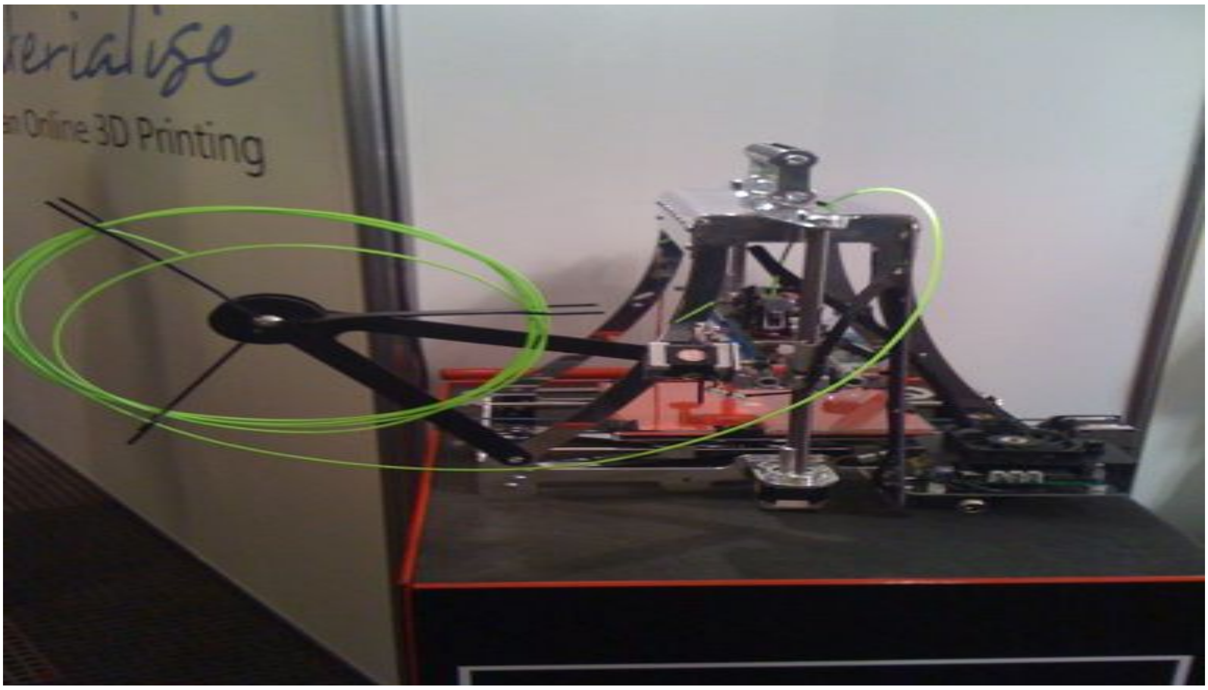
3D printing is thus an aspect of a wider technology movement where digital information becomes materialized and empowers users through ‘future craft’; therefore, consumer practices and interests are not compromised by mass-manufacturing and branding (Bonanni et al. 2008). Part of this process is the creation of completely new designs that are self-assembled and modular, that users can assemble a little like Ikea furniture (Halfacree 2011).

Technologies

It has become a cliché to highlight that the introduction of Internet, email, digital memory and computer word processing software and hardware was accompanied by great excitement about the redundancy and even obsolescence of paper, particularly in office settings. But commentators of the paperless office point out that we have more paper than ever (Dimopoulos 2008)!

Truly, paper remains an important part of many workplaces; however, there has indeed been a marked shift in how paper is used. The increase in the sheer capacity of digital storage devices has meant paper records are rarely kept on-site and for long periods. A terabyte, at the time of writing, is the standard disk size for an affordable portable USB powered drive—this is a staggering one million million bytes. The digitized reduction in physical space afforded by digital storage is remarkable, keeping in mind that most word processing or spreadsheet documents, not including images or videos, remain under a megabyte (one hundred bytes) in size.

The changing ‘ecology’ of the office has been occurring behind the scenes and is not a simple substitution of paper by digital information. While many workers continue to print out copies of online material the shrinking and even disappearance of ‘Lazy Susan’ or physical storage systems in many offices has been matched by the affordability of desktop paper printers, allowing digital documents to be printed in real-time and then disposed of through centralized recycling systems. Equally with desktop scanners being integrated into many paper printers documents can be easily converted back into digital files for distribution via email or for digital storage. So rather than a paperless office it seems many workplaces have shifted to a 'printerful office' alongside many shared, desktop and portable printing and scanning technologies. Generations growing up with computers in 'paperless schools' will further impact on the office ecosystem in future. Perhaps it is ominous that the Tasmanian logging and pulping industry is in downturn, blaming the decline in per capita paper demand (Gale 2012).



So 3D printers technologies are more likely to impact on current production and consumption ecosystems rather than directly substitute for the shop or factory. If anything is to be learned from paper printing, the user and the consumer are almost certain to get closer to the production process, whether through printing objects on their desktops, on local office printers or in special print shop or community facilities. In all of these cases the user takes responsibility for the range of choices to be made about what the final print will look like and involve, including layout, scale, cost per unit, number, quality and so on. It can be expected then that the opposite of what might occur with feedstocks will take place with finished objects—inventories, containers, supply chains and malls will all face upheaval as consumers seek to manage their own printing processes on technologies closer to them.

At the low end of the scale of 3D printers are very cheaply built open source machines such as the Reprap, produced by Bath University's Adrian Bowyer. These print objects with plastic filament wire and use open source motherboards. There are similar machines already available as a kit or pre-built by startup companies such as Makerbot.

It is though surprising how much low-end printers can do. Objects with moving parts (i.e., cogs, gears and wheels) can be printed pre-assembled. Scans of faces and other detailed images are rendered in excellent detail depending upon the printed layer size—the finer the better.

Innovation at the low-end of the market for 3D printers is directed towards even finer print-layers; printers with mixed materials and colours; intuitive user interfaces and design-by-wire software packages; the embedding of circuits into designs; so-called 'self-replication' through the printing of printer parts; universal CAD file formats that can be used across software packages and printer types; and the creation of online repositories with inventories of designs printable at low cost, with different materials and by non-technical users.

Because 3D printers use digital design files blueprints can be traded in the same way as digital music and text. Websites including Thingiverse, Cubify, The Pirate Bay—which offers a 'physibles' category—and Instructables are already catering for this new demand for filesharing of designs.

Multiple colours are available thanks to the mixing of different powder colours in high-end models. More expensive printers also use binding agents and powders, lasers and electron beams, and exotic materials such as resin, nylon, plastic, glass, carbon, titanium, sand or stainless steel. The latest machines can also mix together a number of materials in the same print and produce durable parts for cars, bikes and planes.

Engineers at the University of Southampton have even printed out an electric-powered drone aircraft with a two-metre wingspan and a top speed of 100 miles per hour (Marks 2011). And in the US the companies Kor Ecologic and Stratasys have printed a hybrid electric car called the Urbee.

Social and Transport Implications

> Most predictions are based on a technological analysis that compares the abilities of the new 3D desktop printers with the industrial capabilities of mass production … if we follow this argument, we would see the Internet as no more than a technical improvement on the telegraph. (Ilan 2011 p. 48)

For the past two hundred years fabrication has been typically conducted in workshops or factories distant from consumers. Even though automation in factories has been speculated on at least since the 1950s, up until now consumers were imagined as recipients of complexly produced objects from elsewhere. An animation from a special issue of Life Magazine on the 'Good Life' shows labour being pushed by automation into services ("Cause of Breakthrough toward Life of Plenty" 1959). The piece suggests Laundromats as an example of these services, which are ominously now entirely automated in the UK! The impacts of automation were thought to be more goods made available to consumers, unemployment for a 'few' factory workers, more profit for manufacturers and more leisure time and 'the good life' for all. However, differences in labour conditions and incomes across the world disrupted this idea of a rapid shift from people to machines. Instead, since the 1960s the movement of manufacturing to countries in the Global South has led to a slow transition to automation, as factories in the Global North are unable to compete with offshored manufacturing involving a vast supply of labour in China, India, Vietnam and elsewhere (Blinder 2006).

Already estimates are being made that the global 3D printing market will reach approximately US$3 billion by 2018 according to the executive summary of the report '3D Printing—A Global Strategic Business Report' by Global Industry Analysts (Raby 2012). And personal manufacturing technologies will profoundly impact the design, making, transportation, and consumption of physical products (Lipson and Kurman 2010).

As Mark Ganter, a professor of mechanical engineering at the University of Washington maintains 'they're either going to get to the ubiquity of Kinko's, or lots of people are going to have them in their house' (Chen 2012). The current offshoring system is significant here, as this has become one of the most complex systems of transportation (Blinder 2006). 3D printing innovations offer possible futures of rapidly demobilizing global manufacturing, distribution and production. Already 3D printing has featured in a Delphi panel on the future of air cargo. This research envisaged a 'wildcard scenario' called the 'Fabbing Society' where personal home fabricators and decentralized additive manufacturing facilities combine to wreak havoc on the existing air-freight industry (Linz 2012).

As well as upturning the global production network there is also scope for some levelling of income inequalities and tackling poverty through 3D printing. An ambitious project by entrepreneur Kartik Gada foresees personal manufacturing substituting for aid and charity in reducing poverty. Gada created the 'K Prize' for innovators in 3D printing to encourage low cost manufacturing and reduce 'fixed costs and volume necessities associated with manufacturing' so that 'the scale of Chinese mass manufacturing is no longer a requirement to be cost competitive' (Gada 2011). The prize money will go to the innovator able to produce a fully self-replicating printer that can make ninety per cent of its own parts.

Additive manufacturing offers production technologies that can compete with offshored manufacturing by changing the rules of the game. The speed with which rapid prototyping is emerging as an alternative method for making things, coupled with advances in technology over the last few years, has innovators talking of 'wealth without money' (Bowyer 2010). The Reprap is 'designed to copy itself because that's the most efficient way of getting a large number of them out there' (Stemp-Morlock 2009). This 'game-changing' is not in the same paradigm as the 1959 imagination of the impacts of automation—anthropomorphic machines directly replacing physical labour, 'pushing' them out of factories. Instead, additive manufacturing will involve transitional features already witnessed in other digital innovations, potentially returning manufacturing to post-industrial regions (Roos 2012).

In a world with 3D printers present in the home, office, high street or library, there is the temptation to predict substitution, just like in the online retail revolution. It is necessary to reflect critically upon suppositions that technological innovations accompany a substitution of one technology for another (Mokhtarian and Salomon 2002; Andreev et al. 2010).

Already there are prototypes of portable, laptop-style printers and these have the potential to be used on trains, planes and on the go. The Stonespray project by researchers in Spain shows a portable extrusion 3D printer with a laptop-guided robot-arm being used on a beach (www.stonespray.com). A video of the larger ‘solar sinter’, which magnifies the sun in combination with solar cells to melt sand into objects layer-by-layer, shows industrial designer Markus Kayser hauling the printer on foot in the Egyptian desert (although he is given a lift at the end in a Land Cruiser) (www.markuskayser.com).

So if 3D printers become ubiquitous in a similar fashion to the personal computer (and the laptop, smart phone and tablet) then this will substitute for some permanent travel. What can be expected in a world of low corporatization are freely available printers, open source designs and possibly open source and printable (so-called self-replicating) printers. In a world with a high engagement of individuals in the printing process there are likely to be peer production networks, a lack of safety and standardization unless regulated by government, and corporations seeking markets elsewhere, most likely in digital rights management, insurance services, energy supplies and other utilities, recycling and disposal and in materials and resources provision and procurement.

CEO Cathy Lewis of company The Desktop Factory asserts that their goal is one day to make 3D printing as common in offices, factories, schools and homes as laser printers are today (Easton 2009). There are a number of trends converging in additive manufacturing, which seem to be changing the rules of the game: the cost of the printers is dropping dramatically, indicating economies of scale and rapid innovation; printer design files are beginning to be stored, shared and sold; and the material base is expanding to include ceramics, metal alloys and even food (Sandhana 2010). Moreover, 3D model creation is being 'democratized' through alternatives to traditional CAD programs that use visualizations and templates. This convergence is exciting venture capitalists and fuelling investment. And there is even scope to print fully assembled gadgets with multiple materials, different colours, embedded electronics and moving parts (Graham-Rowe 2003). So 3D printers could be 'network technologies' connected to online repositories of designs downloadable in any location (Wolfe 2012). This could be in the home, the high street, the community centre, or the office. Each of these spaces, or combinations of them, will have distinct implications for society and transportation and whichever dominates will set the tempo of its world. Each space will involve different implications for transport patterns.

As the management and organizational sociologist Gerald Davis summarizes, it is already possible to imagine equipping every town with a high-end DIY facility capable of producing products from scratch based on digital designs—from furniture and prosthetic limbs to replacement auto parts—there are already many possibilities (2012). And this would entail a dramatic 're-imagining' of the corporation. Factories with 3D printing technologies will be distributable near consumers because the cost of setting up a 3D printer is the same whether it makes one item or many different items. The possibility for 'real-time mass customization' consequently blends the shopping and making experience (Tien 2012). Overall there are many possibilities for a much greater localization of manufacturing—for some non-critical products the capacity to scan the object and then make endless copies (an 'infinite aisle') by or near consumers would produce large cost savings and reduce transport-related emissions and oil use, assuming that roughly the same number of products is being manufactured worldwide (Anderson 2012 p, 226).

Many users of printing shops will not be passive consumers, but 'makers' who design and craft their own objects relative to their identities. For example the artist Bathsheba Grossman designs artworks with complex geometries at home and then takes the designs to her local company, ProMetal, which prints them using fine steel powder. Grossman then takes the work home for finishing before selling her art. 'Advanced prototyping went from something that was completely in-house at Boeing to something you walk in off the street and order' (Parks 2005 p. 29). Manufacturing close to the consumer could eliminate or augment many stages in existing supply chains: inventories, excess raw materials, transportation, logistics and warehousing activities (Krogmann 2012).

And it is not only retail stores that may change, spaces such as libraries and bookstores would also experience a transition. These knowledge providers are now places for networking, meeting and collaborating with peers and also for accessing information. The library's role is no longer as a repository for collections of manuscripts, but as a community space where information can be retrieved and shared. The book is the traditional vessel for information, yet with the mass digitization of text this function is changing and the space itself (with its servers, interfaces and technicians) is becoming a massive storage vessel. As shelves are being removed in favour of workspaces and repositories are being automated and barcoded for rapid retrieval of information, the library is becoming a place to go for the materialization of digital data, shared through site-specific books, scans, photocopies, protected files, e-readers, computers, micro-film units and cinema displays (Ratto and Ree 2010). It is a space to use data, and equipment that enables data, unavailable from elsewhere. In light of this changing functionality some innovative centres and libraries are experimenting with 3D printing in the same way libraries and community centres were early adopters of Xerox machines (Mathews 2012). What this does is offer a space for people to experiment in their own free time without necessarily being concerned for time or budget.

3D Printers and the resources they use will be integrated into the organizational logistics of the space in the same way a library manages the delivery, storage and procurement of its collection. On top of being the place to go for Internet access, copying, scanning and printing and accessing digital collections 'the library would become a 'creative space for making things' (Griffey 2012 p. 23).

Workshop Methods

The potential impacts of 3D printing for transport and society are indeed significant as inventor Sir James Dyson summarizes:

> You can be independent. You don't need toolmakers. You don't need moulders. You don't need casters. You don't need foundries. You can do it all yourself with a relatively simply (I hope) machine. So you can make things all over the place. You can make them very locally to each country that you are selling it and get rid of freight costs and import duties and all those sort of things. I think it will eventually transform the ways products are made (Cellan-Jones 2012).

In the workshop we set out a range of possible scenarios for 2030. These are built up from a 'double uncertainty matrix', which produces a typical 2x2 matrix. There are a number of social and economic changes, which will structure 2030. These are growing population, rising energy prices, and increased impacts of climate change.

Four scenarios were developed for 2030. The 'x' axis describes the extent of corporatization of manufacturing, design and distribution systems. The 'y' axis examines the overall degree of 'engagement' with 3D printing. The question is, which of these futures are more likely to have developed by 2030?

To explore these and further develop the implications for transport, workshop participants were divided into four groups, each of which worked on one scenario using the 'Ethnographic Futures Framework'.[1]

The four different groups explored how in each world people's needs in the built environment might be different and how policymakers would react according to a framework characterized by seven descriptors:

- Create: What is produced in this scenario? How is it produced? Why is it produced?
- Consume: What do people consume? Where? Why? How do they think about resources?
- Destroy: How do people dispose of materials when people have finished with them?
- Connect: How do we connect to people at a distance? What communications technologies and networks are important? What transportation systems do people depend on?
- Relate: How do we live together? What are our (physical) communities like? What are the most important social relationships? What sorts of organizations express our social values?
- Define: What concepts, ideas, and paradigms inform the way people understand the world in this scenario?
- Transport: What are the transport and mobility implications?

After a review of outcomes, the groups used a second tool—the 'Technology Axis Model' [2] —to deepen their understanding of potential points of disruption within each scenario. The Technology Axis Model helps analyse the impact and uptake of emerging technologies—in this case 3D printing. This enables a 'socio-technical' approach to be taken, understanding both the enabling technologies and the infrastructure needed for the technology to evolve rapidly, as well as the social values and practices that frame its development.

The Technology Axis Model is designed to consider the impact of each of the four elements: applications, societal norms, technology and systems. It can be read in either a clockwise and counter-clockwise direction: there is no starting point. It is not deterministic: there is feedback and interaction between each element. For the purposes of the workshop, the model was applied to each of the four scenarios.

[1] Framework developed by Michele Bowman and Kaipo Lum.

[2] Developed by Bill Sharpe (formerly a Research Lab Director at HP Corporate Labs in the UK).

Future Scenarios

Each scenario involved a distinct rendering of the future in 2030. *Desktop Factories in the Home* is a future in which 3D printing is ubiquitous and pervades especially people's homes. *Localized Manufacturing* is a future where a shift has occurred in the systems around manufacturing. The technology has affected business, industry and the economy as well as the organizations involved in the distribution and supply of objects. *Community Craft* is a future of commons-based peer production where the relationship between consumers and producers is oriented towards 'not for profit' and altruistic making. *Only Prototyping* is a future where financial and corporate control and influence is dominant. Each is a vision of the future in which certain aspects perceivable now dominate. We now set out these scenarios.

Desktop Factories in the Home

My name is Ben and I was born in 2020. I'm trying to finish my homework but my sister, Lucy, is using the printer again for the new bracelet she's been designing all weekend. Everyone at school has a 3D printer at home now (we finally got one last year) and the teachers regularly give us assignments to design and print out all sorts of things to bring to class.

- In this scenario, trends in technology ownership and development of easy-to-use design software have culminated in consumers having the desire and ability to fabricate their own goods—and as a result most homes have their own desktop 3D printer.
- With people becoming used to printing on demand, new social practices around hygiene and convenience are emerging.

- Coupled with increasing expectations for immediate gratification, this means people are printing more—the side-effect being a growing demand for storage space and concern about waste.
- However there is a greater reuse and repair ethic than there used to be as more people fix things by printing off a new version of the broken part. Recycling facilities are also being developed to help reduce the amount of waste and clutter in homes.
- A persistent problem is design piracy, facilitated by the proliferation of filesharing networks.
- While in-home 3D printing has disrupted global systems of production, distribution and retailing, supply chains and distribution networks have remained intact due to the rapid growth in demand for powders and other printer feedstocks.

Transport Implications

Desktop Factories in the Home describes a society of unlimited products available at the push of a button. The tactile physical world of consumer objects is developing the same way as digital audio and visual media. In this world, the standardized materials going into 3D printers are taken for granted—they are a 'god given right'—and the constant printing of objects is devaluing products, causing waste and raising thorny legal issues around insurance, safety and liability.

Demand for travel by consumers for shopping has been curtailed by desktop printing or augmented to luxury 'unprintable' complex and electronic objects. Mass manufacturers of cheap and disposable products have been forced to move up the value chain. Infrastructure for the movement of finished products is being replaced by a competing market of feedstock suppliers, all trying to compel consumers to purchase their products. This change has led to greater standardization and automation of freight so that consumer feedstock supplies never run low.

This scenario involves ubiquitous household desktop printers assembled as a kit or bought fully assembled, or even printed pre-assembled or in parts in a self-replicating process from open source designs. Individuals use them to produce many or all of the objects they require or desire from freely shared peer-to-peer and possibly even pirated online collections of designs, alongside formal online design retailers.

In this scenario the social practices of home printing come to the fore and impact on travel occurs through altered consumer patterns, habits and choices. To be sure, the wide variety of materials currently made available to consumers are unlikely to be substituted by small desktop printers without exceptional design or technical innovation, as these are only currently able to print in plastics and not metals and mixed materials. Also innovations are needed in aesthetic appearance of printed objects as well as the ease of use of design software.

Workshop Discussion

The initial reaction to the *Desktop Factories in the Home* scenario was how could global companies allow this scenario to happen, given the potential disruptive threat it poses for current production and distribution companies. This scenario is predicated on low levels of 3D corporatization and participants felt that businesses would seek to re-establish control over the consumption and repair of their products in the home with the result that corporatization would reassert itself. 3D printing will lead to a shift to digital rights management embedded within products, analogous to the digitization of music media and subsequent attempts by music companies to control distribution.

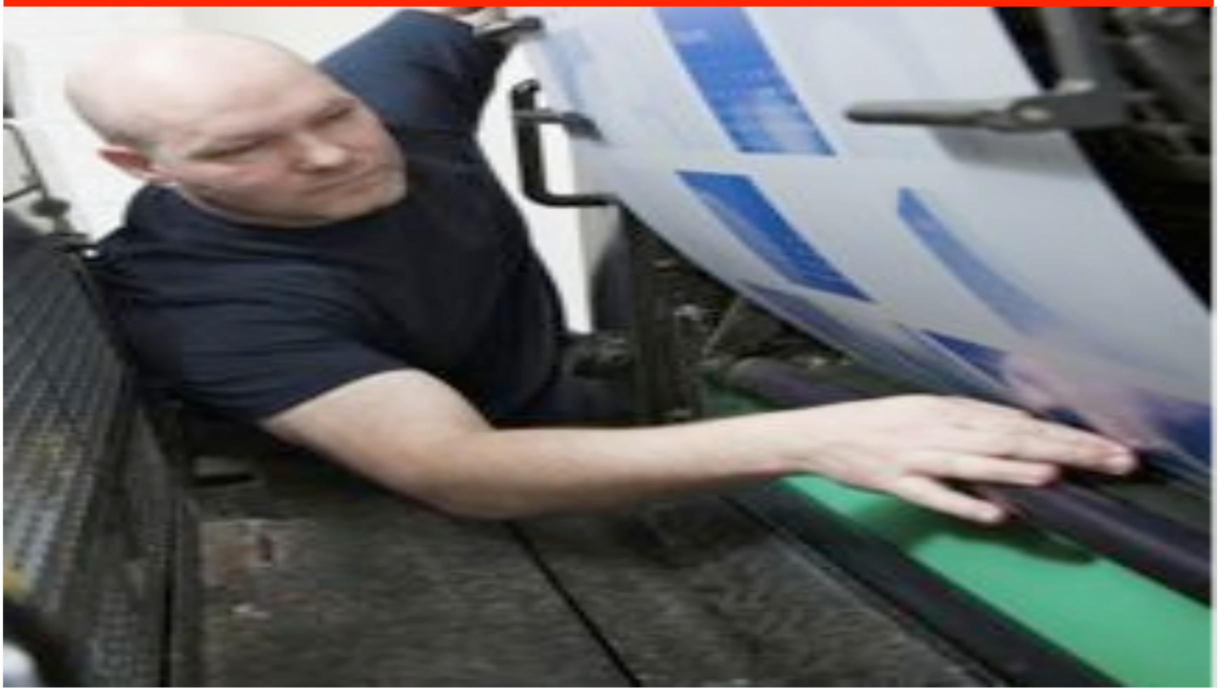
In addition, participants felt that consumers themselves might in this scenario start becoming more specialized in their use of 3D printers, seeking to capitalize their production power—which again might shift towards greater corporatization and at the least marketization. Participants thought that beyond 2030 this scenario could result in a renaissance of (digital) cottage industries in the UK.

Participants identified a tension in the scenario between the greater reuse and repair ethic and the tendency for consumers to generate waste through unnecessary printing. Furthermore, the participants wanted to know how to counter the current culture of non-repair that currently existed. They suggested that an understanding of the future of planned obsolescence in the lifespans of products would give this scenario greater depth. In addition participants suggested that recycling and reuse needed to be separated to a greater extent in the scenario.

A potential consequence of this scenario for participants were issues of authenticity and value in 3D printing in the home— i.e., what value does an object have if it can be produced in the home and is consequently no longer scarce? Participants felt that the antiques market, for example, would become more valuable given the aura of antique furniture. Printed objects would then become less valuable than those that are difficult or illegal to print, that are authentic!

Finally, participants were keen to discuss issues of consumer convenience —asking whether 3D printing would develop along the lines of the division between home cooking and shop-bought ready meals. For example, they imagined that people in this scenario would design and print something if they could be bothered to/had the time and skills—and if they did not, then they would buy the product from a retailer with long supply chains.

Localized Manufacturing



My name is Amran and I was born in 2007. The shift seemed to just happen without anyone realizing. It was shopping-as-usual but behind the scenes everything was changing. The technology seemed second nature to staff already used to printing paper. Hardly any products say Made in China anymore except ones you pick up in the charity store or on computers and those kinds of things.

- In this scenario, consumers' aesthetic and economic concerns have limited 3D printing in the home. However, the opportunities afforded by digital materialization have created a new industry of local print shops and online retailing.
- Consumers go to these print shops to print the personalized 3D designs they have purchased from the databases of suppliers such as Google and Amazon. High street chains are also finding it more efficient to print products locally.

- This means that not only is localized manufacturing now widespread, but manufacturing is 'returning' to the Global North. As a result, the demand for STEM graduates has accelerated in these countries.
- A new market for 'garage entrepreneurs' is opening up, alongside the resurgence in local investment based on protecting regional interests.
- Localized manufacturing has resulted in the replacement of diverse networks for the large-scale transport and distribution of mass-manufactured objects from the Global South—with standardized and monopolized supply chains based for the most part on raw resources. This is causing geopolitical tensions and de-globalization.

Transport Implications

In *Localized Manufacturing* individuals engage with 3D printing not in the home but in the high street. Manufacturing returns to many post-industrial countries fuelled by new market opportunities to satisfy the demand for freightless products. Many large multinational companies abandon their global production networks and invest in local bureau systems and feedstock refineries. This is a 'new industrial revolution'.

Due to the scope for efficiency and inventory gains from additive manufacturing, combined with governmental attention to the offshoring of emissions to China and other manufacturing hubs, transnational corporations meet their emissions targets through reducing the international freight of finished products and greater domestic freight to move printed objects in 'just-in-time' and 'print-on-demand' business models. Key to this domestic freight is door-to-door delivery services and the mail. Consumers are moving just as much, or more, as they continue to enjoy investing their identities in consumer products now affordably customizable and bespoke.

Retail stores are innovating by sharing facilities and training their staff in managing a wide range of consumer products as well as using 3D scanners for customization novelties. Because these market innovators print only what they need, global production networks cannot compete and their inefficiencies are made worse by the appearance of local printshops and bureaus in China, India and other manufacturing countries. These local competitors satisfy their citizens' demands for consumer goods and middle-class lifestyles pushing up salaries as consumption increases and flattening out international income inequalities.

Workshop Discussion

Participants in the '*Localized Manufacture'* scenario discussed how people, while not engaging first-hand with the design and printing process, will access local bureaus or 'print-shops' for printing objects. These services represent a blossoming of regional and local manufacturing, which is corporatized and composed of markets for designs, material feedstocks and 3D printer technologies. Containers full of manufactured objects are a thing of the past and much of the logistics of production and delivery have been retrofitted or replaced by flows of resources for local printing.

Transport and energy use are affected by gains in efficiency at all stages of the supply chain led by new business models and corporate investments in distributed networks of high-end printers. Some businesses are now dealing directly with suppliers of resources who adapt their facilities to deliver materials in forms compatible with printers. There would be a monopolization of feedstocks and a new patent feedstock (the experts in the workshop suggested the name 'Printium' or alternatively 'Unobtanium') would become crucial for consumer societies to function. The heightened mobilities of the early twenty-first century would be constrained by competing demands for resources for transport and for localized manufacturing and consumers would question the 'burning' of gas and oil and lobby instead for affordable access to materials for making, in the same way as the cost of 2D printer inks inhibits some printing of paper documents.

The question 'could it be the case that you could have an extensive system of localized manufacture?' was debated. Could a transition come into being with the new system disrupting the global systems of production and consumption? It was noted that many products are very complex even the modest 'water bottle' which is made up of various components. It is no easy task even to produce this simple product. Many products in the contemporary world are multi-component and require assembly, mixed materials and electrical conductivity. Recycling was also discussed and whether the recycling of printed products could turn those into an array of feedstocks. The conditions whereby the current global transportation and production system might be disrupted were discussed. The closure of the Suez Canal and massive increases in the costs of shipping were examples of possible significant disruptions to existing fossil fuel or delivery systems. Does Moore's Law apply for 3D printing and if so does this mean there will be a similar trajectory of exponential development and progress?

While 3D printing is unlikely to be economic for large production runs of products by comparison with traditional modes of manufacturing, this scenario would involve all sorts of disruptions to freight due to the adoption of print on-demand business models where products are made for individual consumers willing to pay a bit more for a unique, bespoke product.

Community Craft

My name is Jill and I was born in 1997. Tonight after work I am looking forward to going to the local library for my weekly crafting group. A couple of years ago the council gave the library a big grant to purchase the new range of large multi-material 3D printers in a special centre designed for the community.

- In this scenario, growing up in a knowledge economy with easy access to new technology fostered the emergence of community craft centres and shared 3D printing stations, led by people who hope to spur interest in open-source and co-production.
- The widespread use of open-source and self-replicating machines, as well as easy access to the community craft centres, means that business print shops and suppliers have little market success.
- People tend not to have 3D printers in their own homes due to a lack of interest, time, skill or money—and they continue to buy consumer goods from distant manufacturers or via the high street. However informal, peer-support networks of people participating in designing and crafting 3D products are growing—motivated by the desire to customize products and the opportunities for social interaction.

- Local ‘maker fairs’ are sprouting up, where people go to sell and barter their 3D printed crafts. There are however growing concerns over the environmental impacts of very frequent printer cartridge deliveries.

Transport Implications

Community Craft describes a world where peer production and maker movements find favour over for-profit manufacturing. 3D printing continues to be too technical for most individuals to engage with on their own; instead, community hubs are facilitating technology and personnel for all sorts of small-scale projects.

The international freight of finished products from global production networks continues to dominate for most objects people rely on in their everyday lives, although many disposable and low quality items are simply printed for no cost locally—beyond the raw materials and energy, both subsidized by the state—from Massive Online Open Repositories (MOORs). Localism and sustainability agendas are also cutting into corporate profits as self-organizing community movements are banding together against exploitative labour conditions in China and other manufacturing countries. On top of international production and consumption systems domestic travel increases as people move to and fro from community centres to perform their printing as not all ‘printing’ facilities are within walking or cycling distance. A new freight infrastructure, much like the petroleum sector, has arisen for refined feedstock materials for printers. Governments sympathetic to more equal access to 3D printing heavily subsidize this system.

Workshop Discussion

In the third scenario of *Community Craft*, libraries, community centres and government initiatives substitute for corporate bureaus through the provision of funding and services towards collective printing technologies. Instead of engaging directly with 3D printers, users access facilities where objects are designed and printed under supervision and with formal and informal technical assistance. An important feature is co-creation and collaboration between people forming collectives and groups to not only manufacture objects, but to distribute and sell designs to wider groups of people. In the same manner as organic food and craft movements, the distribution of products occurs locally and items are traded or swapped communally, without the involvement of large corporations and perhaps without currencies (or with digital currencies). The costs of products will be based upon materials used and skill in design rather than by brand or rarity. Informal and tacit networks of users and small-scale suppliers challenge professional supply chains and logistics. There will also be more state intervention in the materials economy so that fluctuations in resources and markets will not negatively impact government investments in the community-centred and user-led manufacturing model.

Mass-customization and peer-production are in the forefront of this future and custom designs, which are valuable to individuals but not necessarily others, are produced from widely available materials. The ‘Mykea’ idea of modular making is useful here, a form of mass co-production to fit the unique demands of the consumer, where objects are interchangeable and include open source design parts. 3D printing would see customizable templates and shareable designs that are readily conformable with the specifications of makers.

In this future standards and safety are important features of how people make things. If everyone produces the things they use according to their own judgements rather than mediators, it is unclear where regulation comes from. Leadership and governance are also issues in this scenario. As well, different trends in consumer fashion could converge. A desire for 1970s 'vintage' designs could be met by printing out scanned or reverse engineered copies. Also, could too much choice be an issue? Instant gratification and print-to-demand might be the new way of 'doing' retail.

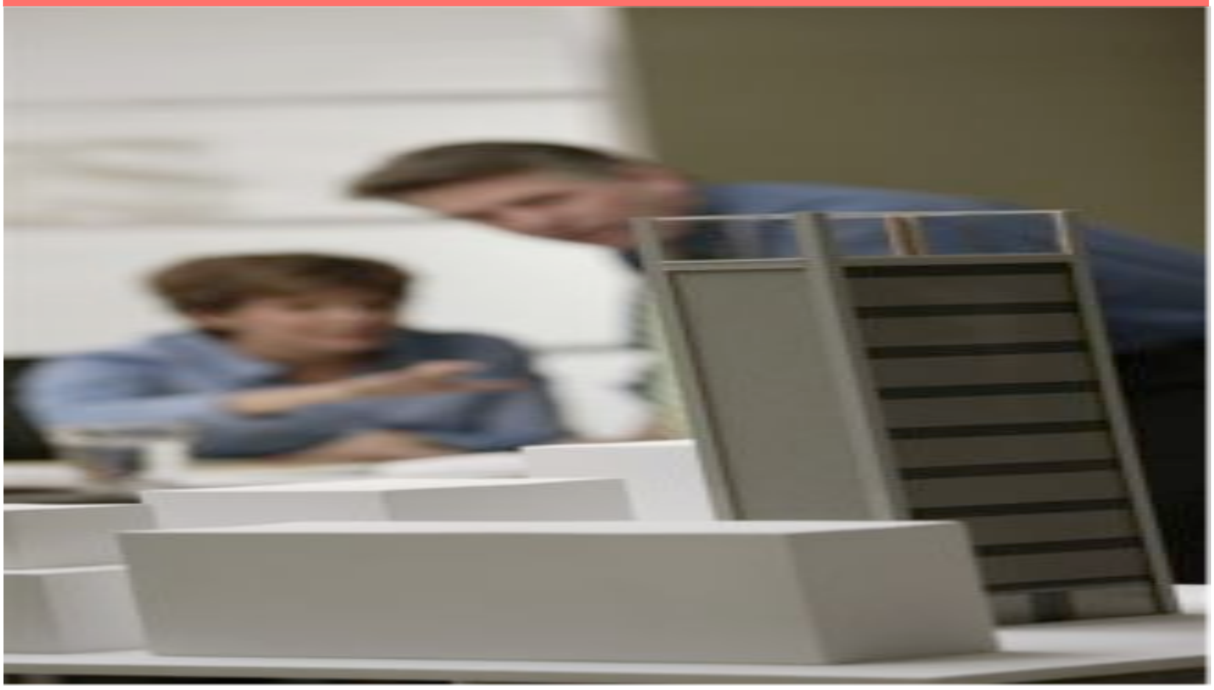
Would 3D printing emerge as an urban or rural phenomenon? It could be that rural communities pioneer innovation as they are already experimenting with localism and community. Network technologies would allow disparate communities of users to troubleshoot and liaise virtually without costly expenditures on travel. Face to face connections are likely to occur on a local level perhaps bringing together people from different backgrounds

The experts wanted to know who pays for this future? If it is neither corporate nor individual, it is unclear where the support of innovation comes from and how entrepreneurship thrives. Examples of fab labs and co-production or peer production networks are useful in clarifying this as well as crowd sourcing and pledge drives, subscription models and these sorts of economies. Angel investors could kick-start innovators whose inventions might have mass-appeal.

'Reverse Ludditism' could disrupt this world where a backlash against personal production, craft and individual making could increase demand for mass-manufactured objects. Also alternative social practices might take hold where virtual identities supersede the need for physical expressions of fashion, choice, diversity of products. If people can print their own objects and clothes then they might choose simplicity and develop their identities online rather than offline. Cyclic economies might be important for communities especially if materials can be recycled and reused by consumers themselves on community atomizers in localized or community facilities. It was felt that the world of *Community Craft* would be defined by much freedom but at the cost of a lack of standards and quality control. Services are unrefined and managed by volunteers, peers and generalists with limited resources for controls. The democratization of additive manufacturing in this world will depend on how accessible and intuitive the technologies are for all parts of a society.

In this world the technology is not distributed in people's homes but rather appears from centralized service providers operating according to open access principles. It could be expected that public transportation will play an important role in connecting users with community resources. As well, facilities for the distribution of feedstocks will be managed by central authorities, in the same fashion as state-run utilities, either by state employees or sub-contractors. The transport implications of this would be highly routinized and planned services in order to bring users from their homes to community spaces. These could even be micro-timetabled according to online making/printing routines.

Only Prototyping

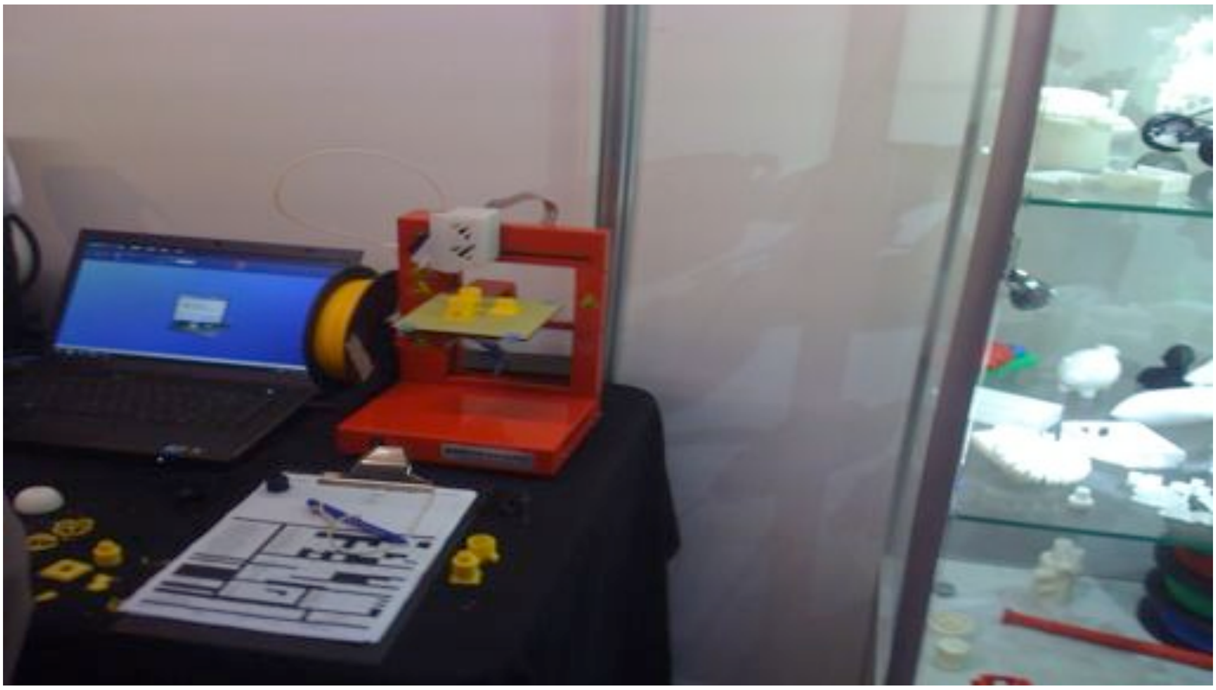


My name is Juliet and I was born in 2004. I read about 3D printing in the news and that's why I got together a bunch of friends and an angel investor to put together a garage of industrial printers. We wanted to be part of the next computer revolution, although at the time we'd forgotten about the dot.com bubble.

- Contrary to some expectations at the beginning of the century, 3D printing has failed to develop alongside the growing trend of people shopping online and mass-manufacturing technologies moving up the value-chain in producer countries.
- This failure happened because even though many 3D printers were developed, the printed products were judged by consumers to be of too low quality and the printers too technical to use and run rather like the problems with videoconferencing around 2000.
- As a result, most people continue to depend upon traditional and online retailers and purchased goods are still manufactured in distant factories according to regional cost advantages.
- With the hype around 3D printing quickly fading, those who had invested in the technologies, or who had set up their own manufacturing businesses, face a technology bubble that bursts.
- Those in contact with 3D printing tend to use them for rapid prototyping or for hobbies only—and as a result 3D printing ended up being the preserve of niche users and technical experts.
- The technology has had little impact upon transport or travel patterns, but added more disruption and confusion due to shifting agendas and ‘shadow chasing’ by policymakers.

Transport Implications

Only Prototyping describes a world where corporate, media and finance investment in 3D printing has not matched consumer and individual engagement. Spurred by the success of the rapid prototyping industry and the ubiquitous spread of printers in specialist niches, ranging from architecture and urban planning firms to university engineering departments, many entrepreneurial startups and niche suppliers threw money at research and development.



Emboldened by the lure of economic growth from a new innovation, planners shifted resources away from freight infrastructures, causing bottlenecks and chokepoints to proliferate. Faced with disinvestment many retail high streets lost customers through poor services and domestic freight increased due to the success of small to medium size online retailers. As well safety issues emerge in transport contexts as 3D printed parts do not match expectations and this causes unforeseen circumstances. Niche users are also engaging with 3D printing in unforeseen and unintended ways by illegally printing weapons, customized vehicle parts, drug factories and black market goods. These users cause more unpredictable criminal and terrorist activities disrupting travel and transport planning further.

Workshop Discussion

Additive manufacturing could remain a process for producing objects only undertaken by small numbers of experts who continue to use the technology for rapid prototyping as well as highly technical applications. As in the dot.com bubble in the 1990s, hype and media excitement do not generate widespread investment or development of 3D printing. Disappointment with onerous design software as well as other unforeseen issues in fashion or taste, such as unusual textures on 3D printed products, will lessen consumer interest. Additive manufacturing will blend with existing manufacturing techniques and many companies do elect small runs of products and parts through rapid prototyping as an alternative to inventories and long-distance freight. Companies become the main beneficiaries of the technologies and integrate it into their business models and systems. 3D printing would become, as in the shift to containerization, something within corporate structures and operated especially by trained experts. It does not develop as anything like a new system but adds to the range of current manufacturing within large-scale factories and workshops.

The discussion ended by considering whether it was possible, if the niche uses of 3D prototyping such as in medical or post-disaster applications, would have enough of a disruptive effect that eventually this scenario would change its position on the axis—would over time the greater use of 3D printing resulting from its success in niche areas mean that it does come to be of much wider significance?

Conclusions

There are already intimations of what a future 3D society might look like in the present day. The conventional retail high street includes both suppliers of manufactured objects, suppliers who craft or repair an already manufactured item, as well as suppliers who combine various prefabricated ingredients into a product onsite. A shopper might choose to purchase a mobile phone from a specialist shop, then have their shoes re-heeled and, while they wait, buy something to eat from a donut stall where an operator uses an extrusion machine to combine a mixture of dough, sugar and other ingredients into a donut that is deep-fried by a heat process.

The donut seller, with a 3D printing-like extrusion technology, runs in conjunction with stores selling mass manufactured items transported long distances. Indeed, the ingredients for the donut seller's wares are more likely to have been transported some distance. The economic and logistical benefits of extruding onsite stems from profits made in standardizing and optimizing the weight, density and packaging of the ingredients, which keeps overhead costs down. And the donut seller can also advertise their donuts as 'freshly made' regardless of the reality.

Similarly, coffee shops are places for meeting with people, wiling away the time, working or reading and, of course, for getting a quality coffee. A recent iPhone app called 'London Coffee' illustrates the growing success of boutique cafes in central London alone with an impressive listing of small businesses, apart from the franchises and those not recommended.

Most cafes of worth will have an espresso machine—another heat extruder—alongside other types of coffee equipment, such as filter varieties, and a range of coffee beans for processing in a blender or as pre-blended coffee powders. Having a successful café is not only about stocking the best coffees but also about hiring, or training, the most proficient 'baristas'—experts in crafting coffee.

Baristas pay attention to the cleanliness of their equipment, the length of time they heat milk, the angle of the frothing wand, the consistency of the crema and the movement of the jug as they pour milk to make 'marbling' effects on the surface of the coffee. There is an acknowledgement of the artistry in coffee preparation and baristas receive accredited training, with some going on to compete in regional, national and international competitions where they receive additional credit for their skills. Being a barista is a career for people and combines technical skill, presentation and a degree of 'flair'.

The growth of boutique cafes alongside a wide range of affordable home espresso machines, including automated varieties, is a useful analogy for thinking through 3D printing and its future. Like coffee making, 3D printing necessitates a material feedstock, i.e. loose powders or cartridges, a technical process involving blending, heating and extrusion, and some technical skill in making all this work together. And like 3D printing there are high-end coffee machines for industry purposes and low-end home units too. As well there are a wide range of product quality types and consumer expectations.

So what does the café industry suggest for the possible future of 3D printing? First, the widespread proliferation of home or desktop 3D printers does not necessarily spell disaster for industry, craft or boutique printing. While it is true that innovations in digital printing saw the demise of the ubiquitous camera film print shop, there remains some niche demand for digital print shops where consumers can print out copies of their digital photos. Unlike the camera film industry the café industry has grown alongside the development of a huge market of highly technical and affordable home espresso machines.

The production and consumption of coffee offers a useful analogy for 3D printing where different forms of making coffee are like different worlds in which both low-end and high-end printers have degrees of significance. While the PC market certainly suggests there could be a 3D printer that meets the requirements of all consumers/makers, at the moment predictions of transport impacts need to take into account the range of printers and the power and significance of existing interests including patterns of low cost manufacturing, containerization and long supply chains.

Freight Miles are a key feature of contemporary transportation. Figuring out how 3D printing might be transformative of very many freight miles requires attention to various contrasting scenarios for 2030 and the forms in which novel sociotechnical systems might emerge here and generate different forms of personal and object transportation in the coming decades.

About the Authors

Thomas Birtchnell is a Lecturer in Sociology at the University of Wollongong and a Research Associate in the Centre for Mobilities Research at Lancaster University.

John Urry is Distinguished Professor in Sociology and Director of the Centre for Mobilities Research at Lancaster University.

Chloe Cook is an analyst in the Trends and Futures team of The Futures Company with a background in social research and a specialism in digital anthropology.

Andrew Curry jointly leads the Public Sector team in The Futures Company and specialises in futures and scenarios projects with a prior background in financial journalism and new media.

Contact

For further information about this Report, please contact John Urry:

j.urry@lancaster.ac.uk

Workshop Participants

1.	David	Barlex	Nuffield Foundation
2.	Heather	Bewers	KPMG
3.	Michael	Browne	Westminster University
4.	Natasha	Carolan	Lancaster University
5.	Amit	Chandra	Loughborough University
6.	Ian	Christie	University Of Surrey
7.	Philip	Delamore	London College of Fashion
8.	John	Fitzgerald	Newcastle University
9.	Oliver	Grant	Foresight, BIS
10.	Liang	Hao	Exeter University
11.	Christa	Hubers	UWE
12.	Julian	Lea Jones	STEM Ambassador
13.	Tamar	Kasriel	Futureal
14.	Andrew	Kluth	Andrew Kluth Associates
15.	Glenn	Lyons	UWE
16.	Cary	Monreal Clark	Newcastle University
17.	Jon	Pengelly	Gray's School Of Art
18.	Matthew	Robinson	Accenture
19.	Glen	Searle	London Hackspace
20.	Marcia	Tavares Smith	Lancaster University
21.	Martin	Spring	Lancaster University
22.	Martin	Stevens	A1 Technologies
23.	Chris	Tuck	Loughborough University
24.	Martin	Watmough	UCL

References

Anderson, C. (2012). *The Long Tail: How Endless Choice is Creating Unlimited Demand*. London, Random House Business Books.

Andreev, P., I. Salomon and N. Pliskin (2010). "Review: State of Teleactivities." Information/Communication Technologies and Travel Behaviour; Agents in Traffic and Transportation **18** (1): DOI: 10.1016/j.trc.2009.04.017: 3-20.

Bell, S. and S. Walker (2011). "Futurescaping Infinite Bandwidth, Zero Latency." Futures **43** (5): DOI: 10.1016/j.futures.2011.01.011: 525-539.

Birtchnell, T. and J. Urry (2012). "Fabricating Futures and the Movement of Objects." Mobilities: published online: 26 Nov 2012 DOI: 10.1080/17450101.2012.745697.

Blinder, A. S. (2006). "Offshoring: The Next Industrial Revolution?" Foreign Affairs date accessed 20 August 2012 http://www.foreignaffairs.com/articles/61514/alan-s-blinder/offshoring-the-next-industrial-revolution.

Bonanni, L., A. Parkes and H. Ishii (2008). "Future Craft: How Digital Media is Transforming Product Design." Design: DOI: 10.1145/1358628.1358712: 2553-2564.

Bowyer, A. (2010). "Reprap." date accessed 23 August, 2012 http://vimeo.com/5202148.

Bradshaw, S., A. Bowyer and P. Haufe (2010). "The Intellectual Property Implications of Low-Cost 3D Printing." ScriptEd **7** (1): DOI: 10.2966/scrip.070110.5: 5-31.

Brean, D. H. (2012). "Asserting Patents to Combat Infringement Via 3D Printing: It's No "Use"." date accessed 23 August 2012 http://works.bepress.com/context/daniel_brean/article/1000/type/native/viewcontent.

"Cause of Breakthrough toward Life of Plenty." (1959) Life Magazine, 28 December (Chicago: Time Inc.)

Cellan-Jones, R. (2012). "3D Printing - a New Industrial Revolution?" date accessed 30 October, 2012 http://www.bbc.co.uk/news/technology-20137791.

Chen, A. (2012) "3-D Printers Spread from Engineering Departments to Designs across Disciplines." The Chronical of Higher Education date accessed 17 September 2012 http://chronicle.com/article/3-D-Printers-Arent-Just-for/134440/?cid=at&utm_source=at&utm_medium=en.

Chen, L., T. Djajadiningrat, L. Feijs, S. Fraser, S. Kyf!n and D. Steffen (2012). "Design and Semantics of Form and Movement", Wellington, Victoria University of Wellington date accessed 23 October 2012 http://www.northumbria.ac.uk/static/5007/despdf/designres/2008proceedings.pdf.

Crespo, N. A. (2012). "Homes and Kitchens: Rethinking on the Works of Susan Glaspell, Tennessee Williams and Lynn Nottage", Universitat Jaume I, Castellón. date accessed 23 October 2012 http://dialnet.unirioja.es/descarga/articulo/3867461.pdf.

Davis, G. F. (2012). *Re-Imagining the Corporation*. Ann Arbor, The University of Michigan.

Dimopoulos, G. (2008). *Paperless Joy: Paperless Business and Lifestyle Design with Information and Communication Technology*. Baltimore, Digital Life Artist Inc.

Easton, T. (2009). "3D Printers, Desktop Factories, Early Adopters." date accessed 13 August, 2012 http://www.isa.org/InTechTemplate.cfm?template=/ContentManagement/ContentDisplay.cfm&ContentID=75394.

Edgerton, D. (2006). *Shock of the Old: Technology and Global History since 1900: Technology in Global History since 1900*. London, Profile Books.

Gada, K. (2011). "Reducing Poverty through Personal Manufacturing." date accessed 20 August, 2012 http://www.ssireview.org/blog/entry/reducing_poverty_through_personal_manufacturing.

Gale, F. (2012). "Scale Back: The Corporate Lessons of Tasmania's Forestry Debacle." The Conversation date accessed 5 September 2012 http://theconversation.edu.au/scale-back-the-corporate-lessons-of-tasmanias-forestry-debacle-9215.

Good Morning America. (1989). "Science Segment with 3D Systems." date accessed 5 September, 2012 http://www.youtube.com/watch?v=NpRDuJ5YgoQ.

Graham-Rowe, D. (2003). "'Gadget Printer' Promises Industrial Revolution." date accessed 24 August, 2012 http://www.newscientist.com/article/dn3238-gadget-printer-promises-industrial-revolution.html?full=true&print=true.

Griffey, J. (2012). "Chapter 4: Absolutely Fab-ulous." Library Technology Reports **48** (3): 21-24.

Halfacree, G. (2011). "Objet Demonstrates Ready-to-Use 3D Printing." Thinq date accessed 20 August 2012 http://www.thinq.co.uk/2011/7/25/objet-demonstrates-ready-use-3d-printing/.

Hopkinson, N., R. J. M. Hague and P. M. Dickens (2006). "Introduction to Rapid Manufacturing". *Rapid Manufacturing: An Industrial Revolution for the Digital Age*. N. Hopkinson and R. J. M. Hague. Chichester, John Wiley & Sons: 1-4.

Hopperton, L. (2012). "Rapid Prototyping Used to Create Bespoke Helmets for Team GB." Eureka Magazine date accessed 12 October 2012 http://www.eurekamagazine.co.uk/article/42767/Rapid-prototyping-used-to-create-bespoke-helmets-for-Team-GB.aspx.

Ilan, Z. B. (2011). "From Economy of Commodities to Economy of Ideas: Hardware as Social Medium." Design Management Review **22** (3): DOI: 10.1111/j.1948-7169.2011.00139.x: 44-53.

Krogmann, C. (2012). *The Impact of Direct Digital Manufacturing on Supply Chains*. Berlin, GRIN Verlag.

Linz, M. (2012). "Scenarios for the Aviation Industry: A Delphi-Based Analysis for 2025." Journal of Air Transport Management **22**: DOI: 10.1016/j.jairtraman.2012.01.006: 28-35.

Lipson, H. and M. Kurman (2010). "Factory@Home: The Emerging Economy of Personal Fabrication". US Office of Science and Technology Policy date accessed 12 September 2012 http://www.ida.org/stpi/occasionalpapers/papers/OP-5-2010-PersonalFabrication-v3.pdf.

MacArthur, E. (2012). "Towards the Circular Economy." date accessed 15 August, 2012 http://www.thecirculareconomy.org.

Marks, P. (2011). "3D Printing: The World's First Printed Plane." date accessed 23 August, 2012 http://www.newscientist.com/article/dn20737-3d-printing-the-worlds-first-printed-plane.html.

Mathews, B. (2012). "Facing the Future." date accessed 5 August, 2012 http://vtechworks.lib.vt.edu/handle/10919/18649.

Mellor, S., L. Hao and D. Zhang (2012). "Additive Manufacturing: A Framework for Implementation" date accessed 24 October 2012 http://www.medifas.net/IGLS/Papers2012/Paper123.pdf.

Mokhtarian, P. L. and I. Salomon (2002). "Emerging Travel Patterns: Do Telecommunications Make a Difference". *Perpetual Motion: Travel Behaviour Research Opportunities and Application Challenges*. H. S. Mahmassani. Oxford, Elsevier Science Ltd.: 143–182.

Parks, B. (2005). *Makers: All Kinds of People Making Amazing Things in Their Backyard, Basement or Garage*. Sebastopol, O'Reilly Media, Incorporated.

Pearce, J. M., C. M. Blair, K. J. Laciak, R. Andrews, A. Nosrat and I. Zelenika-Zovka (2010). "3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development." Sustainable Development **3** (4): 17-29.

Raby, M. (2012). "3D Printing Market to Hit $3 Billion by 2018." date accessed 3 August, 2012 http://www.slashgear.com/3d-printing-market-to-hit-3-billion-by-2018-23239870/.

Ratto, M. and R. Ree (2010). "The Materialization of Digital Information and the Digital Economy Knowledge Synthesis Report". Toronto, University of Toronto. date accessed 12 August 2011 http://thingtanklab.com/wp-content/uploads/2011/02/SSHRC_DigEcon_DDF.pdf.

Roos, G. (2012). "Manufacturing into the Future". Department of the Premier and Cabinet, Government of South Australia. date accessed 24 October 2012 http://www.thinkers.sa.gov.au.

Rosen, D. W. (2004). "Advanced Technology and the Future of US Manufacturing", Atlanta, School of Public Policy and the Georgia Tech Economic Development Institute, Georgia Institute of Technology date accessed 2 August 2012 http://smartech.gatech.edu/jspui/bitstream/1853/41854/1/101112_gtworkshop-task1e-summary-report-M-26-6H2-1.pdf.

Sandhana, L. (2010). "The Printed Future of Christmas Dinner." BBC date accessed 20 August 2012 http://www.bbc.co.uk/news/technology-12069495.

Scott, D. (2012). "An Open Source Powder Based 3D Printer : Is Desktop Laser Sintering on the Horizon?" date accessed 19 August, 2012 http:///blog/archives/1559-An-Open-Source-Powder-Based-3D-Printer-Is-Desktop-Laser-Sintering-on-the-Horizon.html.

Shankland, S. (2010). "HP Joining 3D Printer Market with Stratasys Deal." CNET News date accessed 20 August 2012 http://news.cnet.com/8301-30685_3-10436841-264.html.

Shove, E. (2003). "Converging Conventions of Comfort, Cleanliness and Convenience." Journal of Consumer Policy **26**: 395-418.

Sissons, A. and S. Thompson (2012). "Three Dimensional Policy: Why Britain Needs a Policy Framework for 3D". London, Big Innovation Centre. date accessed 16 October 2012 http://biginnovationcentre.com/Reports/23/Three-Dimensional-Policy-Why-Britain-needs-a-policy-framework-for-3D.

Stemp-Morlock, G. (2009). "Personal Fabrication." Technology (1): DOI: 10.1145/1831407: 2-3.

Tien, J. (2012). "The Next Industrial Revolution: Integrated Services and Goods." Journal of Systems Science and Systems Engineering: DOI: 10.1007/s11518-012-5194-1: 1-40.

Wolfe, J. (2012). "3D Printing, Shapeways, and the Future of Personal Products." Forbes date accessed 19 July 2012 http://www.forbes.com/sites/joshwolfe/2012/06/19/3d-printing.