2013

Fabricating futures and the movement of objects

Thomas Birtchnell
University of Wollongong, tbirtchn@uow.edu.au

John Urry
Lancaster University, UK

Publication Details

Birtchnell, T. and Urry, J. (2013). Fabricating futures and the movement of objects. Mobilities, 8 (3), 388-405.

Fabricating futures and the movement of objects

Abstract

This paper assesses possible futures concerning so-called 3D printing in relation to socio-technical systems and consumption and production. Drawing on an Economic and Social Research Council funded project, the paper details the results of research exploring possible futures of the manufacturing industry and impacts upon the transport of objects. Such 'printing', or 'personal fabrication', could permit many objects to be produced near to or even by consumers themselves on just-in-time 'printing' machines. Widely known about in engineering and design, the impacts of these technologies on social practices and transport have yet to be much examined by social science. These technologies may become as ubiquitous as networked computers, with consequences just as significant. The paper reports on this recent research that seeks to understand some economic, social and environmental implications of what may be a major new socio-technical system currently in the making and which might have major consequences for the trajectory of the twenty-first century.

Keywords

movement, objects, fabricating, futures

Disciplines

Arts and Humanities | Law

Publication Details

Birtchnell, T. and Urry, J. (2013). Fabricating futures and the movement of objects. Mobilities, 8 (3), 388-405.

Fabricating Futures and the Movement of Objects

Thomas Birtchnell and John Urry

Abstract
This paper assesses possible futures concerning so-called 3D printing in relation to socio-technical systems and consumption and production. Drawing on an Economic and Social Research Council funded project, the paper details the results of research exploring possible futures of the manufacturing industry and impacts upon the transport of objects. Such 'printing', or 'personal fabrication', could permit many objects to be produced near to or even by consumers themselves on just-in-time 'printing' machines. Widely known about in engineering and design, the impacts of these technologies on social practices and transport have yet to be much examined by social science. These technologies may become as ubiquitous as networked computers, with consequences just as significant. The paper reports on this recent research that seeks to understand some economic, social and environmental implications of what may be a major new socio-technical system currently in the making and which might have major consequences for the trajectory of the twenty-first century.

Key Words

- 3D printing,
- additive manufacturing,
- rapid manufacturing,
- mobilities,
- transport,
- systems

The rigid uniformity and long runs of identical products which characterize our traditional mass-production plants are becoming less important ... Numerically controlled machines can readily shift from one product model or size to another by a simple change of programmes ... Short product runs become economically feasible.

(Industrial Engineer Boris Yavitz, cited in Toffler 1971, 243)

1 Introducing 3D Printing

This article assesses a possible future concerning developments in so-called three-dimensional (3D) printing. Such technologies could become as ubiquitous as networked computers have become since the initial emergence of web browsers in the early 1990s. And this might generate huge reductions in the scale of transportation and objects worldwide. Could printing many kinds of objects dramatically reduce the 'miles' currently travelled by manufactured objects on container ships, aeroplanes, trains and lorries? Such 'printing', or what can be referred to as 'personal fabrication', 'additive manufacturing' or 'rapid manufacturing', would permit many objects to be produced near to or even by consumers themselves on just-in-time printing machines.
Philosophers have typically regarded the physical world as made up of unambiguous objects, such as tables or chairs. Such objects possess various properties, which ensure the

enduring objectness of such things. Many such objects are 'made', but in order to be made, materials have to be worked on by humans who directly turn wood or indirectly turn chemicals into a table or chairs. There is a co-present relationship between humans and the objects that are being manufactured deploying various kinds of design. These designs are located within each person or in books and drawings or in computer software. The objects once 'made' are then transported elsewhere to be used for eating or sitting upon. Key here is what we might call 'co-present manufacturing', even if the using of the objects that are manufactured mostly takes place well away from their site of production. Indeed, there are increasingly huge distances travelled by many such objects.

We assess here some possible transformations in manufacturing known as '3D printing' or 'personal fabrication'. Since the development of digital printing, it has been common for such printing to occur both locally and remotely. But now what can be 'printed' is taking a different form. Dating from around 2003, various printers developed which enable the printing of 3D shapes and not just printed two-dimensional (2D) text or pictures. What are printed are objects, and those objects can be printed or manufactured thousands of miles away from where the digital designs are located. The designs are transmitted virtually and then turned into objects through remote 3D 'printing'.

There are various technologies involved here, the main differences being in how the layers of the print are built up as they are laid one on top of the other in micro-millimetres of detail. As they are laid down, so a 3D object gets to be produced. Each layer is in effect a digital slice generated through a given computer-aided design. After each layer is complete, the next layer is added by a fraction of a millimetre until the object is fully printed or we should say 'manufactured'. Low-cost printers simply use plastic, which is heated into a liquid and then extruded. More expensive printers use binding agents and powders, lasers and electron beams and exotic materials – resin, nylon, plastic, glass, carbon, titanium or stainless steel. The latest machines can also mix together a number of materials in the same print. These processes are together known as 'additive' manufacturing, by contrast with most previous 'subtractive' manufacturing processes that cut, drill or bash wood or metal or other materials and hence generate much 'waste'.

Such 3D objects were initially developed so as to print prototypes of an object before tooling up of a workshop or factory in order to produce the 'real' object. Manufacturing individual prototypes is very expensive but 3D printing made it much cheaper and 'rapid prototyping' has become widespread. As 3D printing has developed, it came to be realized that a much wider range of shapes and materials could be produced and not just prototypes of something else, but of real objects. Something like 20% of 3D printing is now thought to be of final products rather than the printing of prototypes (Kross 2011). And with online retailers and on-demand manufacturing already in place, the next stage would be for objects to be downloaded in real time and 'printed' in the manner of contemporary music and literature. And websites including Thingiverse, Cubify, The Pirate Bay – which offer a 'physibles' category – and instructables are already catering for this.

Some objects that can now be 'printed' include medical implants, car parts, jewellery, football boots designed for individual feet, furniture, lampshades, batteries, bikinis, formula one car parts, parts for aircraft, stainless steel gloves, dental crowns and customized mobile phone covers. Researchers are envisaging 'printing' the entire wings of an aircraft, an electric vehicle or even whole buildings, as there is a planned scaling up of such 'printers'. For example, engineers at the University of Southampton printed an electric-powered aircraft with a 2 m wingspan with a top speed of 100 miles per hour (Marks 2011). And in the USA, the companies Kor Ecologic and Stratasys have printed a hybrid electric car called the Urbee (BBC News 2011). Moreover, rapid manufacturing offers designers the option of printing complex geometric designs practically impossible in other forms of manufacturing or of exotic materials impossible to use in a factory environment. A team at Cornell University has invented the Fab@home printer that uses a syringe enabling it to print with a wide range of materials (Pearce et al. 2010). The Cornell team is also working on 'food inks' to create new printable food-based products and recipes and new social practices in cooking, preparation and dining (Sandhana 2010). The health implications of 3D printing are in the short term, the 3D printing of models of organs and prosthetics (Clarke 2011), to in the long term the actual printing of organic transplants, such as teeth, using stem cells and organic matter (Science Daily 2011).

Such a manufacturing system has many potential cost savings as economies of scale develop and user groups grow. These include customizing objects for particular consumers, printing or manufacturing on demand, savings on raw materials since little gets thrown away and the local adaptation of design elements so as to suit particular environments or sets of customers.

But the biggest saving is that objects can be manufactured next to or even by consumers with their own 'printer'. If these are too impractical for home use, what could proliferate are local 3D printing shops on the high street, in warehouses, or in shopping centres. In McDonald's science fiction Brasyl shops called 'Atom Shops' print 'necklaces, hats, earrings, formal masks, body armor, watches, costume shades, I-clothing' (2007, 120). Overall, there are possibilities of much greater localization of manufacturing especially as a further innovation here is that of 'self-replicating printers' based upon open source software. More generally there is for some products the capacity to scan an object and then make endless copies and this would produce huge cost savings (although would in turn generate many issues in copyright and ownership).

What could develop here would be something like the current downloading of digital music or films. People would not so much buy objects as pay for accessing or gaining a license to produce or download the design of one or more of the objects in question. This would be part of a growing 'access', rather than the 'ownership', economy that has developed with the growth of the digital 'Internet of things' (See Rifkin 2000). There is already a vast online open source network of designs and blueprints available for download.

Within a couple of decades it may be that low-cost manufacturing centres, as in the global south, would no longer possess the comparative advantage in manufacturing objects in bulk that are currently 'container-ized' to markets often over thousands of miles. It is possible that 3D digital manufacturing could replace the transport of many manufactured objects, even eliminating the whole business of 'logistics' or turning it into a 'materials economy' based around standardized supply chains of material feedstocks solely for printers. Digital objects can travel almost for free although significantly oil is the basis of many of the materials used in the rapid manufacturing process. If this set of developments went global this could bring the incipient 'southern' century to an abrupt slowdown or shift to service and research sectors trading knowledge and innovation rather than labour and manufacturing capacity, so perhaps less like China and more like India today (Mills 2011).

We now examine whether and to what degree such a new socio-technical system might be emerging here. We must avoid techno-hyperbole but at the same time note that new systems do sometimes get established and add to the ecology of technologies, practices and innovations. In the next section, we examine a brief history of fabrication and transportation. In the third section, we detail some of the features of this new potential system. Following this, we examine certain transportation and sustainability aspects, before presenting a brief conclusion on just what it is we might be identifying here.

2 A Brief History of Fabrication

Our approach here is that system innovations: 'are not merely about changes in technical products, but also about policy, user practices, infrastructure, industry structures and symbolic meaning, etc'. (Geels 2006, 165). The social is thus core to innovation as all 'innovation is social innovation. Innovation does not happen "out there" in the world of objects, but in society and in minds' (Tuomi 2003, 5). We will thus examine whether and in what ways a new socio-technical innovation might be developing here, not just a new technology.

While there is much archaeological evidence for extended transnational trade routes, most objects people used prior to the industrial revolution were sourced and repaired locally. These were systems of personal fabrication. Most non-agricultural objects were made or repaired by craft specialists including milliners (hats), ironmongers (iron goods), blacksmiths (metal-work), wainwrights (carts, wagons and chariots), coopers (barrels), sawyers (wooden furniture), tinkers (tin domestic items) and cobblers (shoes). Goods repaired or procured from these trades, now captured in many occupational surnames, were complemented by a few high-status exotic items garnered through long-distance trade and barter, often taking pride of place in ritual offerings or as grave goods in burials.

With the shift to industrial manufacturing, many crafts became less significant as unskilled workers entered factories. Here, industrial fabrication was performed by machines involving highly routinized operations and assembly by industrial workers based upon a complex division of labour, famously elaborated in Adam Smith's eighteenth century account of a pin factory and its resulting economies of scale.

With the introduction of complex mechanics and computing into factories in North America and Western Europe in the 1960s, automated mass-produced manufacturing allowed manufacturers to undermine and replace skilled craft labour with standardized mechanized assembly lines. These became based upon what Rodnick terms Detroit Automation, which linked machines of production as an integral line through automatic transfer devices (1966, 396). At the peak of the golden age of Detroit, for the car manufacturing capital and a model of computerized factory automation, the standard was set for large-scale manufacturing operated by computers and involving on-site production and assembly. This is the model of Detroit automation.

But despite becoming the world leader in manufacturing techniques, the American car industry underwent 'de-mobilization' within only a few decades. This involved the offshoring of much manufacturing to countries offering various advantages over the USA, especially cheap and non-unionized labour. The growing use of machine-labour involved relocating the manufacturing bases of many multinational companies from North America and Western Europe to various Asian countries including China. As mechanical technology progressively became more complex, cheap unskilled labour in the global south engendered the offshoring of manufacturing. Company headquarters could remain in control of distributed and remote manufacturing through communications technologies, digitized networks and air travel. As this digital technology was introduced into manufacturing, greater levels of precision, efficiency and speed were afforded, and human labour was pushed to the global periphery (see on offshoring, Bhagwati and Blinder 2009).

And in that socio-technical system, the container ship has been a key innovation in the mobilities of cargo. As Sekula writes:

The cargo container, an American innovation of the mid-1950s, transforms the space and time of port cities … The container is the very coffin of remote labour power, bearing the hidden evidence of exploitation in the far reaches of the world (2001, 147).

Container ships are constantly on the move between selected routes and vast ports such as Felixstowe, Rotterdam and Bremerhaven where the goods are then freighted by rail and road to consumer centres. A powerful symbol of global mobilities, the average twenty-foot equivalent unit (TEU) cargo container is an element of a wider socio-technical system shaped by global production, consumption, provision, investment, inequality, status and wealth. As a protective shell around the fragile artefacts that are consumed in the rich global north but largely produced in the poor global south, container ships now dominate the oceans and the massive ports that facilitate them. China accounts for 30% of all containerized traffic moving into the USA, with Japan in second place at 10%. In early 2005, the world container ship fleet consisted of 3478 vessels with an aggregate capacity of 7,708,524 TEUs (Cudahy 2006, 236–241).

Manufacturing since the 1970s has thus been 'offshored' from major production centres to Mexico, China, India, Vietnam and other countries offering low incomes for assembly lines, using local energy, mostly coal, and bearing the environmental costs. The offshoring of production and manufacturing was a key factor in the growing power of the Brazil, Russia, India and China (BRIC) economies and the rapidly escalating emissions of greenhouse gases (GHGs) from the global south, where regulation is complicated by issues of development and claims on the world's resources. Indeed: 'There is a key misconception about China's manufacturing prowess. The Western Industrial Revolution began with technology innovation, whereas China's urbanization was mainly driven by global demand for manufactured products and thriving private businesses' as well as the vast movement of workers from countryside to conurbations (Wang 2010, 73).

The cargo container is part of a system that includes the goods they contain, the ships that carry them and the resources that power the ships and ports. Such shipping is dependent on low oil costs. To reduce fuel consumption, container ships are growing larger. Maersk plans to produce a new range of 'mega' triple-E container ships 20-storeys high and as wide as an eight-lane motorway and taking 4–5 days to be unloaded. The added size is to reduce GHG emissions and cut the costs of transportation despite making them incompatible with many ports in North or South America (Vidal 2011).

The container is part of a socio-technical system that depends upon economies of scale with low incomes and cheap unskilled labour; cycles of innovation and spaces of creativity and design; low energy costs and pollution standards; and flows of labour chiefly originating from the south to the north and rural to urban areas (Kelly 2010). The ubiquitous 'made in China' logo (or the less common 'assembled in China designed in California') and the container are features of such systems made up of these elements assembled together (Saunders 2010). When the cargo container is emptied of meaning it might be synchronized with another ecosystem: converted into student housing in Amsterdam, a shanty town in Ghana, a small bar in Melbourne or an art installation in London.

Mass production by poorly paid and generally unskilled labourers in the global south is thus linked with mass consumerism and consumer fantasies and desires in the global north. This represents a further upward shift in this exceptional socio-technical system that has remade global trade, production, transportation and consumption over the past decades since, especially, China became the new 'workshop of the world' following the economic reform movement beginning in 1978.

In the next section, we consider whether a different socio-technical system might now be emerging. We call this the system of 'personal fabrication', that is to return in a way to pre-industrial fabrication.

3 Fabricating Futures

In Fab, Neil Gershenfeld draws upon his MIT experience in his course 'How to Make (Almost) Anything' (2007). This is a vision of a manufacturing revolution away from large systems of transport, infrastructure, factory assembly lines and mass labour (Day 2011). Personal manufacturing using pervasive, ubiquitous home computing and open source software involves a possible merging of digital and material worlds.

Personal fabrication is a 'lead indicator' of how digital resources and techniques are moving into the physical environment. They are being pushed not only by large corporations but also by grassroot community enterprises, through a 'materialization of digital information' (Ratto and Ree 2010). Companies at the top and consumers at the bottom may both move towards the digital materialization that synchronizes into a new socio-technical system. Could this make redundant the current system based on assembly lines, factories, mass production, China, ports and containers?

There are various software packages both costly and open source, which allow complex and custom designs to be 3D printed into finished products. Freely distributed files of designs include bespoke objects, toys, replicas, models, prosthetics, musical instruments, clothes, bicycles, cars, houses and even life-like and miniaturized 3D models of people. The most affordable 3D printer is somewhat similar to an inkjet desktop printer where in current methods a 'print head' extrudes or squirts liquids through a nozzle from a cartridge additively depositing the raw material layer by layer (Lipson and Kurman 2010). Computer-aided additive manufacturing in the home, through local 'print-shops', or through Amazon style online suppliers like the company Shapeways, indicates how objects might be designed, made, consumed and transported in a user-led, personally managed process.

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, Hague, and Dickens 2006). Therefore, personal fabrication means that artefacts are not mass produced but individually produced from digital bits, transferable via online networks, translated into atoms by computers and computer-controlled interfaces. Automated manufacturing has induced economies of scale for many decades. However, personal fabrication suggests a new system and is something Futurologist Alvin Toffler foresaw in the extract at the beginning of this article from the book Future Shock.

Various universities such as MIT, Cornell, Sheffield, Southampton, Newcastle, Bath, Loughborough and private sector companies are leading research and development in this new system. These include a range of suppliers of 3D printers from small-scale startups such as Makerbot to large specialist producers such as Z Corporation. As well, existing printer companies such as HP are investing in research and development and selling products through tie-ups with smaller companies such as Stratasys on a range of small to large consumer and industrial 3D printers (Shankland 2010).

The open source community is also innovating 3D printing. The inventor of the RepRap, University of Bath's Adrian Bowyer, makes clear the attraction of open source to distribution: 'it's designed to copy itself because that's the most efficient way of getting a large number of them out there' (Stemp-Morlock 2010, 1). By self-replicating itself in essence it 'leapfrogs' the gradual development and adoption of the technology, disrupting incumbent and niche suppliers, and instead allowing small users, including schools, community groups and pioneer individuals, to quickly adopt and adapt the technology for themselves without effort or cost beyond assemblage and the purchasing of the feedstocks and the non-printable components.

Therefore, a major factor in the growth of home or office-based 3D printing has been open source designs that come in kits assembled by the user and that can print, or self-replicate, the technology for others. These innovations offer possible futures of rapidly demobilizing global manufacturing, distribution and production (Shapira 2004).

First, this is because self-assembly and stripped-down materials bring costs down. Second, open source licenses and designs mean that users can also modify and customize the printer technology, encouraging further innovation. Third, self-replication means that once a single unit is purchased there is no limit to the number of printers that can be produced. A pioneer in open source 3D printing, Bowyer notes the similarities to the early computer revolution where enthusiasts built their own desktops from generic parts around printed circuit boards. These were initially much more expensive than 3D printing is today (Thomson 2010).

3D printing could lead to a decentralized, onshored manufacturing system based on current shifts in consumer practices towards online browsing and shopping. The key disadvantage of current Internet-based online stores and suppliers is that buyers have to wait for products to arrive, so they cannot try out or touch the product beforehand, usually relying on conventional mail systems (BBC News 2010). As well there has been a dramatic shift from professional logistics supply chains to personal logistics. Online purchasing systems that depend on personal channels (home addresses, individual accounts and local post offices) have changed how organizations such as the UK's Royal Mail distribute and manage deliveries. So while the Internet and email have reduced demand for personal communications such as postcards and letters, they have upscaled demand for larger volumes of packages and products transported through personal logistics. There are increased volumes of parcel and package delivery stemming from online retail. These deliveries cannot be shifted by bicycle or foot but demand larger warehouses, vehicles and logistics. As one expert we interviewed in retail supply chains made clear when asked about the impact of the Internet on mail delivery in terms of online retailing:

Hand-written letters gone. But the unexpected bit of that was that everybody now shops and buys stuff online from jewellery, cosmetics, DVDs and books and all of that needs to be delivered. So if you actually look at what a Postman delivers these days a lot of it has been sourced online but is being delivered by the Postman. So what that means, interestingly, is that we won't have as many bicycles in the Royal Mail fleet as they can't carry all those packages. So it's gone from letters to packages and the volume is much bigger.

But if this trend from professional logistics to personal logistics is carried through to personal manufacturing then organizations that have seen unexpected growth from the Internet, such as the mail, would undergo a rapid decline along with the container freight that supplies these online products.

So personal fabrication could replace or augment the production of many consumer objects and this will increase with the innovation of very fine printing layers and units that offer mixed materials. Current high-end units print in steel and titanium and have produced finished parts in Formula One cars, motorbikes and aeroplanes.

However, like all new innovations, 3D printing is not without much debate and controversy with the strength and durability of parts produced on some printers being questioned. For example, the feature Known Universe on the National Geographic Channel shows host John Hopkins University theoretical physicist David E. Kaplan visiting Z Corporation to 3D scan and print a crescent wrench he brought with him for the purpose. The sight of Kaplan drawing the printed wrench from the powder bed in the machine met with great excitement in the media. He, however, released a second video on Youtube apologizing for inaccuracies in the original video (Kaplan 2011). Some viewers had spotted that the resin-based printed wrench, which was able to tighten a nut, was different from the metal one he supplied in the beginning of the video. What had been left out of the feature was that the 3D scanned image had been manipulated using stock designs. Off camera, and with an exact resin replica of the metal wrench, Kaplan's initial effort to tighten a nut and bolt with the printed spanner actually caused it to break leading some commentators to question his claim that printed tools could be printed and used by astronauts 'in space'.

Nevertheless, as Kaplan points out, these issues do not refute the premise of the video that any object can be stored and transmitted digitally and printed from a range of materials including metal, glass and plastic depending on the printing technology. Kaplan countered that he had simply chosen the wrong material for printing an exact metal replica. A 3D design and bureau company we interviewed with its own in-house printers also noted similar experiences with powdered resin objects and noted that in using exotic materials, new design techniques and customizations need to be made to match the strengths of forged steel items. However, the ability to rapid prototype on-site means the strength of objects can be tested within the actual design process itself. And once these designs are established they can be shared between users digitally and even with users in space as Kaplan predicts.

The possibility of personal manufacturing disrupting existing global supply systems is due to a number of current elements: political interest in 'homeland' security and manufacturing jobs, growth and resilience; interests in resource security, scarcity and efficiencies; widely available domestic Internet connectivity, competence in computing and 2D printing and innovative software companies; and the leisure hobbyist ethic currently active in open source communities that is transferable to 3D printing.

Carl Bass, CEO of Autodesk software describes how 'you just hit print … rather than a piece of paper with an image on it, here's the actual thing coming out of the 3D printer' (Vance 2010). In the same way, cars in the early stages of automobility in the late nineteenth century and early twentieth century at first looked like horseless carriages; 3D printing technology has similar forms and builds to traditional 2D printers. And the convenience of simply printing an object has parallels with the convenience of cars over horses at the turn of the twentieth century.

At current levels of development, 3D printing technologies are at best implementable, using affordable technology that is based on industrial additive manufacturing technology, like the RepRap, for household products, replacement parts and repairs (Bowyer 2010). However, some anticipate that the technology will become rapidly more refined to include complex and diverse products of near faultless quality. At the moment, the possibility of personally run, widely distributed domestic, self-replicating RepRap 3D printers will impact on the low end of the consumer markets, including unbranded, cheaply made, mass produced replaceable or modular products and parts. A distinct advantage from mass-manufacturing systems is that efficiency can evolve organically as the technology self-replicates and is customized or modified to its task, by contrast with a factory, which mostly builds to a standardized model:

Every person with an Internet connection can contribute to the evolution of products in this mass-manufacturing system. No longer will products be bound to sluggish supply-chain forces: digital designs from anyone will be instantly accessible and free to flourish, or die depending on how well they have been designed. An elite will not determine the range, and energy will not be wasted by forcing physical products through an expensive supply chain before they are presented to the market. Giving people control over what they can make means they can get exactly what they want, and through the collective, designs can rapidly strengthen. (Sells 2009, 173).

Taking this further, some analysts are forecasting a different onshoring 'future' for US manufacturing enabled through the existing boom in services and information technology in the global north. In this future, 3D printing offers the potential for the USA to revitalize its manufacturing base and regain economic independence from China and other overseas economies. Thus:

You could imagine a 3D printer making homemade apple pie without the need for farming the apples, fertilizing, transporting, refrigerating, packaging, fabricating, cooking, serving and the need for all of the materials in these processes like cars, trucks, pans, coolers, etc. (Eiben et al. 2011, 5)

Some commentators inspired by 3D printing have even initiated discussion about 'after the factory', where largely services-based regions such as the USA and India could innovate the fusion of services and manufacturing in new ways (Fox 2010). Web-based digital technologies play a central role in this idea of an 'Internet of things': literally global networks of digitally transferable and downloadable files containing designs and blueprints that ultimately portable computers could then build or print anywhere and out of anything.

Regardless of which personal manufacturing technologies come to dominate, there remains the question of the raw materials and feedstocks – the paper, ink and toners for a 3D printer – for personal manufacturing technologies and the production and transportation of these resources. Currently, some tested feedstocks include nylon, plastic, resin, carbon, glass, stainless steel, sandstone and titanium. It is possible that many resources will still be required for feedstocks and existing infrastructures now in place could be retrofitted for the purpose, although in many cases these resources could be managed strategically via local 'refineries' – in the same way as existing systems for petroleum or gas – rather than globally. As retail supply chains and markets move from creating, storing and distributing a myriad of manufactured products to feedstocks, a materials 'rush' might occur where companies compete to produce and market feedstocks. Corporations might adopt business models in order to produce and control supply chains of reduced (powder, filament, gel, liquid) resins, plastics, metals, nylons and even foods, which would be transported in standardized cartridges, perhaps similar to those used in inkjet printers.

Moreover, the feedstocks in many consumer printers will be primarily acrylonitrile butadiene styrene petroleum-derived plastics and to a lesser extent petroleum-fertilized polylactic acid cornstarch plastics, currently used in many 'biodegradable' plastic products including cups, shopping bags, tableware and other packaging. Thus existing supply chains for these resources are likely to continue or even grow relative to demand. Yet efficiencies will emerge from additive manufacturing techniques, including the possibility of zero waste, as well as reduced transportation costs.

One possible direction for feedstocks is closed-cycle processes where redundant, broken or unwanted 3D printed objects could be recycled (most likely through an industrial process) into further feedstock for new printing. Indeed, consultants McKinsey and Company and yachtswoman Ellen MacArthur championed 3D printing in a report on a 'circular economy' presented to the 2012 World Economic Forum in Davos (Ellen MacArthur Foundation 2012). Currently, powders and other composite feedstocks have been derived from, for instance, recycled glass powders or other patent-protected resins: companies such as Z Corporation use their own 'non-hazardous, eco-friendly' powders. One solution that raises the possibility of a circular economy is a 'recyclebot' where plastic wastes, including old 3D 'prints', produce more feedstocks for new products in the home from a machine that accompanies or is built into the Makerbot 3D printer (Peels 2011). Students at Victoria

University in New Zealand developed a machine that recycled old milk jugs, producing a high density plastic filament feedstock that could be fed and extruded from a 'Makerbot' 3D printer (Burgess 2010).

Disposable packaging could become a resource in itself. Instead of being thrown away, litter could be added to a converter that would process it and add to the feedstock of the domestic 3D printer. Even more dramatically new social practices might render continuous supplies of raw materials redundant. Instead of having a surplus cache of consumer items 'to hand' for specific purposes, items could instead be printed when they are needed. Rather than using a plastic fork and then washing it up, the item could be 'recycled' as part of a hygienic, but possibly energy intensive, process into a spoon for dessert and so on. Clothes could be printed as needed and then recycled instead of cleaned as a new 'normal' way of laundering similar to how line drying was replaced by machine dryers (Shove 2004).

Design plays a key role in these circular transitions and the rapid manufacturing of clothing promises zero-waste design practices, as the materials that go into clothing or other objects could be made compatible with the feedstock of 3D printers, which would be sustainably recycled using the same materials with lifetimes as long as the raw materials (Delamore 2004).

We have thus examined a range of possible technologies and practices. The issue is what kinds of system might get to be engendered here to bring the various elements together so forming a new system.

4 Transportation

The technologies and practices in personal fabrication could significantly disrupt existing systems of consumption, manufacturing and transportation. These would have cascading effects throughout the world's supply chains. As Scott Summit, a co-founder of Californian company Bespoke, which designs and 3D prints custom products observes: 'There is nothing to be gained by going overseas except for higher shipping charges' (Vance 2010, 2). Companies for a long time have been looking at the cost of freight and the possibilities of dramatically reducing costs by using reduced materials rather than finished commodities. Personal manufacturing offers a tipping point in how this might occur.

Many see this progression emerging from the convergence of open source software, increasing home bandwidths and Internet access, widespread 2D home printer ownership and online shopping practices. As one expert notes in a BBC report: 'entire businesses that are built around managing huge numbers of the exact same part and shipping them all over the world and creating them and distributing them all of the sudden need to change because that role is not as critical to the economy (Sieberg 2010). Thus the 'threat to the logistics firm's business is clear: why would a company airfreight an urgently needed spare part from abroad when it could print one where it is required?' (The Economist 2011, 2).

Companies around the world have also cottoned on to the potential of open source ideals in the idea of coproduction, where 'the individual is the coproducer of what he consumes' and this is now at the heart of the strategies of public and private firms that are no longer 'making things' (Marazzi 2011, 46). Factories-in-a-box would enable those unable to purchase objects produced elsewhere to produce them at low cost at the press of a button with the potential to rebalance the global knowledge economy through printing and consuming, rather than trading, the knowledge produced (Gorz 2010).

As already noted, integral to such an Internet of things could be the open source model that some see as the most important aspect of domestic 3D printing and personal fabrication. Part of this is a revolution from digital information to digital spaces, factories to homes and more fundamentally digital bits to physical atoms (Gershenfeld 2007). The development of the open source 3D printer, in particular the RepRap and its progeny, the US startup company Makerbot, stems from a 'hobbyist ethic' for 'future craft' (Bonanni, Parkes, and Ishii 2008) that mirrors successful innovations in software development, including Linux, Wikipedia and the Apache web-server standard (Doyle et al. 2010; Facer 2011).

However, not all foresee positive effects from this potential new system. According to Easton, the new system that 3D printing heralds will undermine the authenticity of cultural artefacts through flawless replicas from 3D scanned originals or from the dissemination of original blueprints or designs (2011). The greatest impact will be felt in what Easton calls the economy of trust wherein organizations and investors in valued objects will lose the trust of consumers and valuers in their products.

However, the shift away from production has been going on for the last 30 years and pervades much product development. Consumers of mass-produced commodities do not necessarily 'trust' the value of these items, but often the brands associated with them. Branding has enabled companies to introduce all sorts of standardization into product design and also to replace quality with quantity. As one futures expert we interviewed who works with many multinationals, noted:

For example, if you think about any kind of liquid product. If you can get the consumer to add the water at the end, rather than add the water at the factory and transport all that water that's going to be a huge money saving. Hair products if you can just turn them into a powder – and the consumer benefits can be framed as freshness – even for shampoo (this might sound surprising), even for hair products, then you can build a very strong argument for a consumer benefit, plus a logistical cost benefit and an environmental benefit and they are all very aware of that ... so if there are any ways you can limit transport costs.

The efficiencies gained from dramatically lowered transportation costs as well as greatly more efficient additive manufacturing standards mean that personal manufacturing can consume fewer resources than current systems and fits into the development trajectories of many companies. Indeed, if closed-cycles of feedstocks can be innovated, as domestic 3D printer use increases on par with 2D printers, new ways of procuring feedstock might be imagined along with new consumer practices of mass customization, which many companies already adopt in coming to terms with the 'age of access' (Rifkin 2000).

Organizations like this would not need the global logistics and business models that current multinational companies deploy. One alternative to this would be the 'community enterprise', where localized cooperatives exist to provide public goods without central planning or control (Frey, Luethi, and Osterloh 2011). Such headless and/or bodiless organizations would act as communities rather than corporations, but would encounter resistance from existing powerful corporations.

Forecasting of personal manufacturing centres on both re-skilling and demobilizing manufacturing processes by placing manufacturing within the control of the designers of products. These implications have already encouraged speculation about the revival of US manufacturing (McKendrick 2011; Perry 2011). According to Autodesk's CTO, Jeff Kowalski:

Manufacturing is probably going to be more localized than it has been. We won't be shipping as many raw materials around the world, producing things in lower-cost labor areas then sending it back. If manufacturing the actual production of something is effectively free, and more importantly, complexity is free, that can be performed locally. (Karlgaard 2011, 1)

These processes of de-mobilization and onshoring reverses trends to outsourcing and offshoring, where the responsibility for recruiting, housing, training, managing and paying for labour is shifted away from the product and brand owners and designers to remote locations governed by different values, legalities, human rights, social pressures and standards of living. In the past, this has allowed companies in the global north to offshore labour, GHG emissions and social responsibilities, but there is now gathering attention to holistic business practices and Corporate Social Responsibility that may come to limit these offshoring business models and encourage onshoring.

Personal fabricators potentially allow print-to-demand and even print-to-need practices rather than conventional patterns of order, stock, supply and procure. As well, currently popular practices in fashion, hobbies and craft of personalization, repair and customization may increase and become mainstream within retail and leisure. 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, 532).

Everyday life is increasingly becoming 'wrapped up' with digital information, small technologies worn on the body, trusted by users and bolstering big systems that depend on them to function and 'synchronize' (Birtchnell and Urry 2011; Urry 2011). This 'everyware' represents a colonization of everyday life by information technology (Greenfield 2006).

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, Parkes, and Ishii 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).

3D printing has been likened by critics to Napster, the peer-to-peer filesharing network, which enables the hosting and downloading of copyrighted music files (Hanna 2011). Indeed, an information economy built on the trade and sales of digital designs rather than products faces many challenges that are currently affecting retail and distribution systems. It is also unclear how Digital Rights Management technologies, currently used in music files, might apply to designs that could be readily and easily re-engineered by sight and traditional methods.

There are also problematic consequences of crafting with personal manufacturing technologies. In one instance, a household key was printed from a photograph and an exact replica made that enabled access to a locked house (Brown 2011). As well, 3D printers could be used by anyone, including children and teenagers, to print many artefacts currently licensed or prohibited, such as weapons or counterfeit goods.

Personal fabrication would also affect marketing, advertising as well as people's desire for consumption as a part of global systems of finance, trade and growth:

One of the potential advantages of home fabbing is the massive reduction in goods transport that would be consequent on people's making lots of stuff for themselves, with all the greenhouse gas savings that that implies … By analogy, one can imagine changes in, say, sales tax laws that would increase the cost of finished goods, but reduce that of raw materials used by personal fabricators. This would be revenue neutral for government, but would encourage the use of the technology with consequent transport savings. (Adrian Bowyer in Lipson and Kurman 2010, 94)

Consumers could meet their sustainability goals, including emission reductions, energy efficiencies and recycling, while at the same time suffering no drop in consumption or living standards. The potential for computer-aided manufacturing have considerable efficiency gains. As well, the marked reduction in freight and print-to-order means more controlled production standards. As David Flanders, a technology enthusiast and blogger based in London, makes clear 'imagine I print you a shoe. Your child grows, as they do. You take that shoe, you throw it back in the shredder – the shredder then processes the plastic' (BBC News 2010). As outlined already, there is potential for home recycling and print-to-use practices. New or altered practices emerging from computer-assisted home, or localized, 3D printing can be imagined as aspects of self-sustainability alternatives and indeed wider transition.

'Transition towns', such as Totnes in the UK, imagine communities supported by local manufacturing, small-scale subsistence and craft as well as alternative forms of currency including bartering. The desire for locally accountable skills and products envisaged in the transition towns movement is driven by rejecting the long supply chains of the current socio-technical system. In 3D printing, there is scope for more local manufacturing, sustainability and limited and renewable energy generation.

The 'Walmart' consumption that many in the rich north have grown used to could be met by personal manufacturing in the home or community while at the same time allowing greater sustainability. The middle and lower classes in China and India could also benefit by using self-replicating affordable and customizable 3D printing technology to meet their own development goals, using their designs in combination with open source, reverse engineered and pirated material (Bradshaw, Bowyer, and Haufe 2010).

3D printing will introduce a whole new dimension to debates about ownership, sharing and piracy that parallel discussions of medical patents and genetically engineered crops (Adermon and Liang 2010). Higher end products could also be 3D printed by companies on-site and on-demand using technically superior industrial printers and additive manufacturing technologies. Thus, in the not too distant future, only a small market of products would remain attractive for mass manufacturing. The ball is already rolling as middle-class cosmopolitan lives in the global north already involve elements of a new system conducive to personal manufacturing: mass computer home-ownership; primarily services-oriented sectors such as information technology, design, architecture, education and finance; and cultural interests in customization, individuality and personal expression through fashion, aesthetics and craft. Moreover, there are development gains in the mass adoption of personal manufacturing wherein self-replication techniques, as demonstrated by the RepRap, mean that consumers could print their own 3D printer units at the cost of the raw materials. Potential consumers include the populations of China and India, already building services infrastructures, skills and resources in information technology.

5 Conclusion

We began by examining how the emergence of China and similar economies as manufacturing hubs was a 'game-changer', involving the outsourcing of production to unskilled, low-income workers. Much consumption then necessitated long supply chains deploying new 'container' boxes. This is the current dominant 'cargomobility' system of mass manufacturing, transportation and consumption.

But we then considered in this paper whether this is in part threatened by a new system based around personal fabrication. This new system has the potential to shift manufacturing away from mass production to mass customization and over the next 10–20 years change the landscape of manufacturing. Whether these roll out in the gradual fashion of remote 'home' teleworking in response to the Internet and videoconferencing communication technologies, or in the rapid transitions precipitated by digital photography or the automobile, is totally unclear. Personal fabrication could mean that ships stacked with thousands of TEU containers filled with consumer goods become a remnant of the relatively recent past. We have summarized some of the current developments, which indicate a possible new system.

This is of course a highly speculative paper. We have tried to outline a number of interesting and possibly divergent features of a potentially emergent socio-technical system. We do not know if this will remain a small 'niche' or come to be assembled with other elements into a major system that would displace the mass-production/mass-consumption offshoring system of the last couple of decades (Geels 2006). We have based this article on interviews with 3D developers, designers and enthusiasts who naturally spoke about the significance of their innovation. Writing the history of the present is fraught with many dangers especially in believing the technology hyperbole of those innovating the 'new'. We are clear though that such a 'new' technology will not simply replace the 'old'. Edgerton talks of The Shock of the Old as much as of the new (2006). So when we imagine a future world of fabrication that is not something that would simply replace long supply chains and containerization. Rather the proliferation of 3D printing may change the overall ecology of machines and technologies. Elements of physical transportation will remain but occupy a different place within a changing ecology of transportation and communications in this possible future.

And if there is one thing that we can predict it is that change in capitalism is always unpredictable in its sources, direction and impact. Marx was well aware of this when he and Engels presciently wrote in The Manifesto of the Communist Party that 'all that is solid melts into air' (1992, 6). What he did not foresee was the possibility that 'all that is solid melts into solids'. 3D printing has the potential to 'reshape the world' beginning with the very nature of the physical world that has so much bothered philosophers (Richmond 2011, 1). If it did it would indeed be 'game-changing' in very many senses and would in a way be a wholly new kind of socio-technical system.

Acknowledgements

This paper draws upon current research supported by the ESRC, which includes interviews with experts in 3D printing, transport, futures, retail and consulting. Thanks to our colleagues Christa Hubers, Glenn Lyons and Cary Monreal Clark, as well as Tim Dant, Satya Savitzky and David Tyfield at Lancaster University.

References

- 1. Adermon, A., and C.Y. Liang. 2010. Piracy, Music and Movies: A Natural Experiment [online]. Uppsala, Uppsala University. Accessed August 15, 2011. http://www.nek.uu.se/Pdf/wp201018.pdf.
- 2. BBC News. 2010. "3D Printing Offers Ability to Print Physical Objects" [online]. BBC News. Accessed August 12, 2011. http://www.bbc.co.uk/news/technology-11834044.
- 3. BBC News. 2011. "Urbee 3D Printed Car Goes on Display in Canada" [online]. BBC News. Accessed December 4, 2011. http://www.bbc.co.uk/news/technology-15007018.
- 4. Bell, S. and Walker, S. 2011. Futurescaping Infinite Bandwidth, Zero Latency. Futures, 43(5): 525–539. ,
- 5. Bhagwati, J. and Blinder, A.S., eds. 2009. Offshoring of American Jobs: What Response from U.S. Economic Policy?, Cambridge, MA: MIT Press.
- 6. Birtchnell, T., and J. Urry. 2011. Small Technologies and Big Systems. Lancaster: Report for ESRC Technologies and Travel Project, UK. http://www.eprints.lancs.ac.uk/40794/
- 7. Bonanni, L., A. Parkes, and H. Ishii. 2008. "Future Craft: How Digital Media is Transforming Product Design" [online]. Design. Accessed August 12, 2011. http://www.chi2008.org/altchisystem/submissions/submission_leonardo.bonanni_2.pdf.
- 8. Bowyer, A., 2010. "RepRap" [online]. Vimeo. Accessed August 12, 2011. http://vimeo.com/5202148.
- 9. Bradshaw, S., Bowyer, A. and Haufe, P. 2010. The Intellectual Property Implications of Low-Cost 3D Printing. ScriptEd, 7(1): 5–31.
- 10. Brown, J., 2011. "Hacking Your House Key" [online]. Macleans.ca. Accessed August 13, 2011. http://www.macleans.ca/2011/07/06/hacking-your-house-key/.
- 11. Burgess, P., 2010. "Recyclebot Digests Milk Jugs to Feed MakerBot" [online]. Hackaday.com. Accessed August 12, 2011. http://hackaday.com/2010/08/05/recyclebot-digests-milk-jugs-to-feed-makerbot/.
- 12. Clarke, T., 2011. "How Printing in 3D Could Save Lives" [online]. Channel 4. Accessed August 14, 2011. http://www.channel4.com/news/how-printing-in-3-d-could-save-lives.
- 13. Cudahy, B.J. 2006. Box Boats: How Container Ships Changed the World, New York, NY: Fordham University Press.
- 14. Day, P., 2011. "Will 3D Printing Revolutionise Manufacturing?" [online]. BBC News. Accessed December 4, 2011. http://www.bbc.co.uk/news/business-14282091.
- 15. Delamore, P., 2004. 3D Printed Textiles and Personalised Clothing [online]. London: The University of the Arts London. Accessed August 12, 2011. http://ual.academia.edu/PhilipDelamore/Papers/952906/3D_Printed_Textiles_and_Personalised_Clothing.
- 16. Doyle, R., E. Froede, D.S. John, and R. Devon. 2010. "Understanding Open Source Design: A White Paper" [online]. Accessed August 12, 2011. www.asee.org/documents/sections/middle-atlantic/fall-2010/01-Understanding-Open-Source-Design-A-White-Paper.pdf.
- 17. Easton, T. 2011. "A Recession in The Economy of Trust". In Values and Technology: Religion and Public Life, Edited by: Ricci, G. 159–169. New Jersey, NJ: Transaction.
- 18. Edgerton, D. 2006. Shock of the Old: Technology and Global History since 1900: Technology in Global History since 1900, London: Profile Books.

• 19. Eiben, A.E., N. Ferreira, M. Schut, S. Kernbach, and U. Amsterdam. 2011. Evolution of Things [online]. Ithaca, NY: Cornell University Library. Accessed December 3, 2011. http://arxiv.org/pdf/1106.0190.
• 20. Ellen MacArthur Foundation. 2012. "Towards the Circular Economy: Economic and Business Rationale For An Accelerated Transition" [online]. Ellen MacArthur Foundation. Accessed January 14, 2012. http://www.thecirculareconomy.org/uploads/files/012012/4f26c6959d31c63107000018/original/120130_EMF_CE_Full%20report_final.pdf?1327941269.
• 21. Facer, K. 2011. Learning Futures, London: Taylor and Francis.
• 22. Fox, S. 2010. After the Factory [Post-Industrial Nations]. Engineering and Technology, 5(8): 59–61.
• 23. Frey, B.S., R. Luethi, and M. Osterloh. 2011. "Community Enterprises: An Institutional Innovation" [online]. SSRN. Accessed December 3, 2011. http://ssrn.com/abstract=1831123.
• 24. Geels, F.W. 2006. "Multi-Level Perspective On System Innovation: Relevance of Industrial Transformation". In Understanding Industrial Transformation: Views from Different Disciplines, Edited by: Olshoorn, X. and Wieczorekm, A. 163–186. Dordrecht: Springer.
• 25. Gershenfeld, N. 2007. Fab: The Coming Revolution on your Desktop – From Personal Computers to Personal Fabrication, New York, NY: Basic Books.
• 26. Gorz, A. 2010. Ecologica, London: Seagull Books.
• 27. Greenfield, A. 2006. Everyware: The Dawning Age of Ubiquitous Computing, Berkeley, CA: New Riders.
• 28. Halfacree, G., 2011. "Objet Demonstrates Ready-To-Use 3D Printing" [online]. Thinq. Accessed December 3, 2011. http://www.thinq.co.uk/2011/7/25/objet-demonstrates-ready-use-3d-printing/.
• 29. Hanna, P., 2011. "3-D printing: The Napster of Manufacturing?" [online]. CNN World. Accessed July 12, 2011. http://globalpublicsquare.blogs.cnn.com/2011/07/21/3-d-printing-the-napster-of-manufacturing/
• 30. Hopkinson, N., Hague, R.J.M. and Dickens, P.M. 2006. "Introduction to Rapid Manufacturing". In Rapid Manufacturing: An Industrial Revolution for the Digital Age, Edited by: Hopkinson, N. and Hague, R.J.M. 1–4. Chichester: John Wiley and Sons.
• 31. Kaplan, D.E., 2011. "3Dresponse" [online]. Youtube. Accessed December 5, 2011. http://www.youtube.com/watch?v=1yt8ZZGFkFc.
• 32. Karlgaard, R., 2011. "3D Printing will Revive American Manufacturing" [online]. Forbes. Accessed August 5, 2011. http://www.forbes.com/sites/richkarlgaard/2011/06/23/3d-printing-will-revive-american-manufacturing/
• 33. Kelly, K. 2010. What Technology Wants, London: Viking.
• 34. Kross, R.B., 2011. "How 3d Printing will Change Absolutely Everything it Touches" [online]. Forbes. Accessed August 5, 2011. http://www.forbes.com/sites/ciocentral/2011/08/17/how-3d-printing-will-change-absolutely-everything-it-touches/.
• 35. Lipson, H., and M. Kurman. 2010. "Factory@Home: The Emerging Economy of Personal Fabrication" [online]. US Office of Science and Technology Policy. Accessed August 6, 2011. https://www.ida.org/stpi/occasionalpapers/papers/OP-5-2010-PersonalFabrication-v3.pdf.

- 36. Marazzi, C. 2011. The Violence of Financial Capitalism, Los Angeles, CA: Semiotext(e).
- 37. Marks, P., 2011. “3D Printing: The World’s First Printed Plane” [online]. New Scientist. Accessed December 12, 2011. http://www.newscientist.com/article/dn20737-3d-printing-the-worlds-first-printed-plane.html.
- 38. Marx, K. and Engels, F. 1992. The Communist Manifesto, Oxford: Oxford University Press.
- 39. McDonald, I. 2007. Brasyl, London: Orion Books.
- 40. McKendrick, J., 2011. “3D Printing May Bring US Manufacturing Back Home” [online]. Smart Planet. Accessed August 6, 2011. http://www.smartplanet.com/blog/business-brains/3d-printing-may-bring-us-manufacturing-back-home/17093.
- 41. Mills, M.P., 2011. “Manufacturing, 3D Printing and What China Knows About the Emerging American Century” [online]. Forbes. Accessed August 12, 2011. http://www.forbes.com/sites/markpmills/2011/07/05/manufacturing-3d-printing-and-what-china-knows-about-the-emerging-american-century/.
- 42. Pearce, J.M., Blair, C.M., Laciak, K., Andrews, R., Nosrat, A. and Zelenika-Zovka, I. 2010. 3-D Printing of Open Source Appropriate Technologies for Self-Directed Sustainable Development. Sustainable Development, 3(4): 17–29.
- 43. Peels, J., 2011. “How Soon Before we get ‘Green’ 3D Printing?” [online] Quora. Accessed December 6, 2011. http://www.quora.com/How-soon-before-we-get-green-3D-printing.
- 44. Perry, M., 2011. “How 3D Printing will Revolutionize and Revive American Manufacturing in the 21st century” [online]. Daily Markets. Accessed August 6, 2011. http://www.dailymarkets.com/economy/2011/07/09/how-3d-printing-will-revolutionize-and-revive-american-manufacturing-in-the-21st-century/
- 45. Ratto, M., and R. Ree. 2010. “The Materialization of Digital Information and the Digital Economy Knowledge Synthesis Report” [online]. Thingtank Lab. Accessed August 5, 2011. http://thingtanklab.com/wp-content/uploads/2011/02/SSHRC_DigEcon_DDF.pdf.
- 46. Richmond, S., 2011. “3D printing: The Technology that Could Re-shape the World” [online]. Telegraph. Accessed December 12, 2011. http://www.telegraph.co.uk/technology/news/8666516/3D-printing-the-technology-that-could-re-shape-the-world.html
- 47. Rifkin, J. 2000. The Age Of Access: The New Culture of Hypercapitalism, Where all of Life is a Paid-For Experience, New York, NY: Putnam.
- 48. Rodnick, D. 1966. An Introduction to Man and His Development, New York, NY: Appleton-Century-Crofts.
- 49. Sandhana, L., 2010. “The Printed Future of Christmas Dinner” [online]. BBC News. Accessed August 6, 2011. http://www.bbc.co.uk/news/technology-12069495.
- 50. Saunders, S.G. 2010. Consumer-Generated Media and Product Labelling: Designed in California, Assembled in China. International Journal of Consumer Studies, 34(4): 474–480. ,
- 51. Science Daily. 2011. “Print Your Own Teeth: Rapid Prototyping Comes to Dentistry” [online]. Science Daily. Accessed August 6, 2011. http://www.sciencedaily.com/releases/2011/07/110714101509.htm.

- 52. Sekula, A. 2001. “Freeway to China (Version 2, for Liverpool)”. In Millennial Capitalism and the Culture of Neoliberalism, Edited by: Comaroff, J. and Comaroff, J.L. 147–158. North Carolina, NC: Duke University Press.
- 53. Sells, E.A., 2009. “Towards a self-manufacturing rapid prototyping machine.” PhD diss., Bath University.
- 54. Shankland, S., 2010. “HP Joining 3D Printer Market With Stratasys Deal” [online]. CNET. Accessed August 5, 2011. http://news.cnet.com/8301-30685_3-10436841-264.html.
- 55. Shapira, P., 2004. “Advanced Technology and the Future of U.S. Manufacturing Proceedings of a Georgia Tech Research and Policy Workshop” [online]. Technology. Accessed August 5, 2011. http://www.cherry.gatech.edu/PUBS/04/gtworkshop-task1e-summary-report-rev.pdf
- 56. Shove, E. 2004. “Sustainability, System Innovation and the Laundry”. In System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edited by: Elzen, B., Geels, F.W. and Green, K. 76–94. Cheltenham: Edward Elgar.
- 57. Sieberg, D., 2010. “World News America: 3D Printing Creates ‘Something Out of Nothing’” [online]. BBC News. Accessed August 7, 2011. http://news.bbc.co.uk/1/hi/programmes/world_news_america/9318390.stm.
- 58. Stemp-Morlock, G. 2010. Personal Fabrication: Open Source 3D Printers Could Herald the Start of a New Industrial Revolution. Communications of the ACM, 53(10): 14–15. ,
- 59. The Economist. 2011. “3D Printing: The Printed World” [online]. Accessed August 12, 2011. http://www.economist.com/node/18114221.
- 60. Thomson, I., 2010. “Q and A: Dr Adrian Bowyer and Open Source 3D Printing” [online]. v3.co.uk. Accessed August 6, 2011. http://www.v3.co.uk/v3-uk/news/1998019/q-a-dr-adrian-bowyer-source-3d-printing.
- 61. Toffler, A. 1971. Future Shock, London: Pan Books.
- 62. Tuomi, I. 2003. Networks of Innovation. Change and Meaning in the Age of the Internet, Oxford: Oxford University Press.
- 63. Urry, J. 2011. Climate Change and Society, Cambridge: Polity Press.
- 64. Vance, A., 2010. “3D Printing is Spurring a Manufacturing Revolution” [online]. The New York Times. Accessed August 6, 2011. http://www.nytimes.com/2010/09/14/technology/14print.html.
- 65. Vidal, J., 2011. “Maersk Claims New ‘Mega Containers’ Could cut Shipping Emissions” [online]. Guardian. Accessed August 5, 2011. http://www.guardian.co.uk/environment/2011/feb/21/maersk-containers-shipping-emissions.
- 66. Wang, H. 2010. The Chinese Dream: The Rise of the World’s Largest Middle Class and What it Means to You, New York, NY: Bestseller Press.