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Socio-technical changes brought about by three-dimensional printing technology

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1. Introduction

In this article, we try to identify the possible socio-technical changes that 3D printing effectuates and their larger consequences on businesses, the economy and society at large. To this end, we first track the emergence of three-dimensional printing technology. We draw the analogy with development of other digital technologies, particularly in media. In that way, we understand consumer 3D printing as the latest addition to this kind of developments. We then undertake to sketch some of the next developments we expect in 3D printing in general. Framing 3D printing in the context of 'industrial revolutions' leads us to understanding it as part of more general, socio-technical developments that drive lateral power structures, distributed control and a networked society beyond the Internet in the physical realm. Technological and societal developments rising from 3D printing create corporate concerns and opportunities. Governments are typically in a position to create the frameworks that mollify concerns and let opportunities flourish, so we ask what governments can do in this regard. We provisionally conclude that an open minded approach is most promising.

2. The emergence of three-dimensional (3D) printing technology

Ideas to produce three-dimensional objects using methods of stacking layers of material rather than cutting off excess material from solid blocks of matter date back to the late 19th century – particularly for the creation of topographic models and busts (Bourell *et al.*, 2009). Under the name of '*solid photography'* such an approach was patented in the late 1970s by *Dynell Electronics Corp*., the technology was marketed under '*Sculpture by Solid Photography'* and '*Robotic Vision'* (Wohlers, 2011). '*Laminated object manufacturing*' is an additive manufacturing method that appeared on the market in 1991. Laminated object manufacturing machines bond layers of plastic sheet material and cut them with a digitally controlled laser cutter.

In the second half of the 20th century a new method of additional manufacturing appeared that makes use of a characteristic of some specific materials, mainly resins, called photo polymerization: under the influence of lasers or even regular light those materials harden. This method is called '*stereo lithography*'. First experiments took place in the 1960s at Battelle Memorial Institute; various methods were developed in Japan, France, Germany and the U.S. with many patents granted in the 1980s. Probably the most interesting one was Charles Hull's U.S. patent [U.S. Patent 4,575,330], granted in May 1986, which led to the formation of Hull's company *3D Systems*. For a short period in 1989 all claims in that patent were rejected on the base of evidence of prior art produced by Du Pont. Only after providing strong evidence to support the claims, Hull's patent was reinstated, but with considerably narrowed scope. More companies entered the stereo lithography market in the early 1990s: German *Electro Optical Systems* (EOS), and *Teijin Seiki* and *Denken Engineering* in Japan.

A further development of stereo lithography appeared on the market in 1991 under the name of '*solid ground curing*'. This method uses a liquid polymer that can be solidified by applying ultra-violet light. This technology allows solidifying complete layers of an object in one pass by projecting UV-light onto the resin through a variable mask.

Also in 1991 a company called *Stratasys* commercialized '*fused deposition modeling*'. This technology feeds thin wires of thermoplastics (filaments) through a heated extruder, which is moved along the contours of an object. The melted thermoplastic materials are deposited and harden at room temperature to form the object layer by layer.

Two other additive manufacturing technologies are '*selective laser sinter-*

ing' and variations on inkjet printing. Selective laser sintering uses powdered metals that are deposited layer-by-layer and melted to form solid objects by selectively applying high power lasers beams. The best know inkjet type technology has been commercialized by *ZCorp* from 1996: a liquid binder is applied to layers of starch – or plaster-based powder to 'glue' together the powder to form solid objects. Other approaches deposit wax or photo polymers using inkjet print heads.

The term '3D printing' was first used in 1996 by *ZCorp*; only as of 2006 or 2007 did it become generally known as an umbrella term for all additive manufacturing methods. It was in those years that the technology became popular outside specialist industries. Two developments contributed to that popularity. A research team around Adrian Bowyer at Bath University (UK) developed the '*Replicating Rapid Protoyper*' – or *RepRap* for short – a table-top sized 3D printer extruding thermoplastic filaments. The vision of the researchers was to create a machine that would be able to produce its own parts – except some standard hardware and electronics parts like rods, nuts and bolts, stepper motors, cables and microchips – and by doing so 'replicating' itself. To that end, the team made engineering and electronic designs, a bill of materials, the control software and the building and operating instructions publicly available as 'open source'. This development sparked the commercialization of consumer 3D printers such as the *RapMan* and *Makerbot* (2009), *Ultimaker* (2010) and the vast amount of projects that mushroomed in the years to follow and fuelled *Gartner*'s evaluation of the technology being at the "*height of inflated expectations*" – both in terms of capabilities and market potential (Gartner 2013).

2009 saw the first consumer-directed 3D printing service, *Shapeways*, coming online; others followed, such as *i.Materialize* and *Ponoko*. Also in 2009, the *ASTM International Committee F42* on additive manufacturing was set up to standardize terminology around 3D printing processes and lay the foundations for product, process and material certification. The term '3D printing' has not been adopted by this committee, they use 'additive manufacturing' instead. 3D printing became the vernacular equivalent at *Euromold 200X* (the main annual business exhibition for moulding, 3D printing and packaging where many new 3D printers used to get launched). Applications for 3D printing then went way beyond producing presentation and functional models and visual aids and included assembly aids, tooling, and direct part manufacturing (Wohlers 2011).

The business consultancy company *Gartner* started to include 3D printing in their reports on emerging technologies as of 2008 and quickly classified it at being on the "*peak of inflated expectations*" where it stayed until today – except that now *Gartner* decided to split 3D printing into "*consumer 3D printing*" and "*enterprise 3D printing*" (Gartner 2013). The latter is supposed to reach its plateau of productivity within the next few years; the former remains at the peak of inflated expectations awaiting its "*through of disillusionment*" (Gartner 2013) before (maybe) moving towards productivity.

This distinction between consumer 3D printing and enterprise 3D printing is useful in two ways. Firstly, many developments of 3D printing are relatively close to commercial utilization in a business environment, which is essentially what *Gartner* argues. Secondly, there is 3D printing as a consumer technology that could quickly be following enterprise applications. Such a development is not uncommon, and many industries have experienced the consequences of the 'tools of the trade' becoming available to consumers – just think of all the software to create and manipulate media (photos, sound, video, games) that has become ubiquitously available on networked personal computers.

3. Social developments that build on the possibilities of digital and Internet technology

Before we discuss the potential consequences of (consumer) 3D printing, we want to have a look at how the media and content industries in particular have seen the disruption of business models and the emergence of new products triggered by social developments.

Take the music industry, for example. In the late 20th century the industry established its distribution and business model: major labels securing the rights of artists and selling music stored on first analogue and later digital media (LPs, cassette tapes, digital compact discs). It was common practice, at that time, to create compilation cassette tapes and share them with friends. However, this did not seem to have any major impact on media sales. As the Internet appeared and with it publicly available formats to store music in reasonable quality in highly compressed file formats, people moved from sharing cassette tape compilations to sharing music over the Internet. Roughly at the same time, media sales started to crumble; and the industry quickly jumped to the conclusion that music sharing over the Internet was the root cause – a claim that never was properly proven. Dubbed 'piracy' online music sharing became the target of heavy policing by the industry — to no avail, as sales kept tumbling. Some artists noticed the signs of the time and reverted to what musicians are supposed to do: playing music. In general, income from concerts started to increase as ticket prices went up. Also, artists experimented with various ways of creating a closer band with their audience, (e.g. Masnick 2009). Further, there had always been an undercurrent of small bands and labels that would cater for a niche clientele and that were virtually not affected by the alleged piracy. In response to dwindling sales of media there emerged new distribution models for music content – *Apple*'s *iTunes* ecosystem was the first large scale service; innovative particularly as customers could buy music by the song rather by the album (and without being restrained to the predetermined single). Streaming services like *Spotify* and *LastFM* are another type of music delivery where customers buy listening access to an online music library for a flat fee. So in fact, the music industry had to put up with the new reality of the Internet and had to learn how to handle this new reality in a way that would be profitable over all – as singer-songwriter Neil Young put it in an interview: "*Piracy is the new radio*" (Young 2012).

The division between production and music consumption stayed relatively stable in music. In other content industries, this has been quite different and the impact of the digital revolution in terms of empowering consumers to become producers. The best-known example with a very much global reach is in the field of encyclopedia – *Wikipedia*. Traditionally, encyclopedias were written by a knowing elite with the aim of enlightening and educating the general public (Diderot 1778). Production and distribution followed traditional means of book publishing, libraries provided public access. *Wikipedia* changed that model fundamentally. An Internet-based platform allows for collective editing of texts and thus also encyclopedic entries. An evolving ecosystem of paid professionals is maintaining the platform infrastructure. Volunteers write articles, and more importantly, keep an eye on conformity of the contributions with set standards of 'encyclopedic value' – such as neutral-point-of-view, no-original-research, verifiability etc. *Wikipedia* as a crowd-sourced and laterally governed collection of encyclopedic information has outgrown printed encyclopedia in volume, depth, recency and use (Okoli *et al.*. 2012).

The news industry has undergone similar changes. In a first wave, the change mainly affected printed news. The Internet with its fundamental characteristic that everyone joining it can be a sink and a source of information allowed people to publish content on their own account. A few specific tools intended initially to keep online, web-enabled logbooks (blogs) of private nature led to people publishing their own version and interpretation of the events that were going on around them. Social media platforms such as Twitter, Facebook and Google+ enabled even more people to share their interpretation of reality. Traditional newspapers – even when using the Internet as an additional distribution platform – struggled to keep up with the pace and the variety of points of view that blogs and social media enabled. Even more so as time pressure in traditional journalism led to shallow reporting that was prone to factual errors and a superficial understanding of the underlying issues of a given event. Newspapers are still struggling to reposition themselves as 'quality journalism' as some blogs such as the *Huffington Post* have managed to get exactly that reputation. Currently, a second wave of displacement of traditional news media by crowd-sourced Internet content is taking place: television is finding itself confronted with user-generated YouTube videos that are displacing corporate news teams (Pew Research Center 2012).

These three examples of music distribution, creation and curating of encyclopedic content and the production of fast-paced and well-informed news depict a social development that builds on the possibilities of digital and internet technology – a technology that requires little central control and allows for lateral participation and collaboration across continents and time zones. But disruptive change could only arise with social practices developed around this technology that embrace the absence of central control and allow for individual and even (to a certain extent) idiosyncratic contribution. The social developments in music, encyclopedia and news form the backdrop of what is the expected impact of 3D printing technology over the years to come.

4. Consumer 3D printing – so far the latest addition to digital evolution

Consumer 3D printing is the latest addition to digital evolution. As 3D printing technologies become available to consumers, they are changing the way consumers (and even professional manufacturers) think about producing goods. 3D printshops, web-based service bureaus, shared machine shops and even home printers have become readily available for consumers over the past decade. 3D design software is freely available and can be easily used, even by kids. Online platforms allow the sharing of 3D designs and 3D print instructions. Together, services, machines and platforms form an evolving digital manufacturing ecosystem (Marsh 2011).

The availability of 3D printing technology is opening up new ways how people 'consume' goods. Traditional ways of consumption were buying what designers and mass-manufacturers provided or choosing from a pre-defined set of options in what is called mass-customization (Pine II, 1993). With 3D printing technology, it has become possible to manufacture goods oneself on computer-controlled machines (such as 3D printers). This possibility is a new step in the emergence of what has been called the '*prosumer*' – the producer-consumer who achieves "*complete customization*" by manufacturing one-of-a-kind products (Toffler, 1981, 183). This shift from mass-customization to complete customization could bring to (mass-)manufacturing a development that in many ways parallels the early development of digital music formats for the consumer market: the distribution of blueprints for items in peer-to-peer sharing networks and via web-platforms that drive local and individual manufacturing and diminish the dominant market share of traditional manufacturers and retailers.

Consumer use of 3D printing is not only challenging mass manufacturing on the level of scale – being able to produce one-of-a-kind products. The things shared on *Thingiverse* already paint a picture of consumer 3D printing being hedonistic and playful. As such it forms a counterpoint to the traditional position of manufacturing as part of working life. As was the case in the early days of the personal computer, it is hard to foretell what prosumer would do with 3D printing. A good guess, however, would be that people would do other things than what manufacturers do.

Personal use of computers is not normally payroll or inventory management – filing tax returns and electricity meter readings is probably the closest we get to using computers in an industrial way. Personal use of computers, as we have seen above, is also more than individual content consumption; it is digital creation and social interaction across time and distance using a variety of digital media. It is quite likely that people would use personal fabrication not for producing machines or standard components, and beyond individual consumption for creation and social interaction – as this is what people do.

Looking at 3D printing this way, its future is more than just technology for a market of one, producing one-of-a-kind products, more than "*personal expression in technology*" (Gershenfeld, 2006). It's not only consuming personal fabrication as a commodity provided by a new branch of the entertainment industry. The main impact of making will be a social one. So in essence, consumer 3D printing would develop into *social* fabrication, not personal fabrication.

The constituents of social fabrication are participation, collaboration and sharing. Its goals are self-realisation in a cosy social context that is built on interdependence, preserving one's cultural identity in a multicultural world. Social fabrication is cosmopolitan, not territorial. Social fabrication is much more closely related to the notion of "*deep play*" (Rifkin, 2011). In essence, social fabrication a possible realisation of a "*third wave*" (Toffler, 1981) or post-industrial society.

5. An outlook with regard to 3D printing

What the development of 3D printing technology will bring might not be easy to assess, but its consequences for business, the economy and society at large are equally difficult to foretell. Let us start with a look at food. *NASA's* interest in printing tasty pizza aboard spaceships travelling to Mars may sound like an episode from *Star Trek*, but the American space agency is trying to achieve exactly that. If the agency succeeds, it's not just astronauts who will have their preferred meals, but ordinary people will benefit from the technology as well once food printers become available. This summer, the world's first hamburger was created from cell tissue using 3D printing technology. It remains to be seen if food processed in a 3D food printer will have the same qualities as the food we consume today. Will it be as nutritious, and will it be accepted by consumers as an alternative? 3D food printing is being experimented with and may be successful in ways that could seriously alter our lives: for example, by fabricating printable foods locally, we could cut transportation costs and time, and print food adapted to specific dietary needs such as low-salt or gluten-free, or food containing added vitamins or medication.

For people who value their vegetable garden, there is nothing to stop them from growing their own zucchini and experience the pleasure of sticking their hands in the soil and watching nature at work. The reality, however, is that we do not make (grow, process, bake) much food ourselves nowadays. Most of it we leave to others, because we have jobs to go to and live in urban areas without farmland of our own. People do have opinions about food though, for example that it should be healthy, fresh and sustainable, not fabricated with the added emulsifiers, fats, salts and sugars that have become associated with mass produced food. In this respect our expectations of food are changing. This poses a challenge to the food industry, which is adopting sustainability and needs to keep providing for the masses. It is unlikely that food production facilities in the next decade or so will use 3D printing to meet the expectations of modern food consumers. The food industry caters to the needs of their current clients, not potential ones that they do not know. There will be experiments and research into 'food printing', but for the most part the food industry will not seriously get involved in 3D printing. Whether or not 3D printing can at some point be of service to consumers who want to 'print' their evening meal is unclear. Despite the world's first printed hamburger, the option is not expected to become available for consumers for a long time. Wherever developments in 3D food printing go, new methods in food production should not be a repetition of old habits – adding emulsifiers, etc. – with new technology.

More generally speaking, if 3D printers can achieve higher levels of sophistication, how will this serve us? The short answer: 3D printing would enable people to have more options (compare Lanier 2013, p. 186). Though sophisticated, 3D printing is still 'just' a technical process that can fulfil certain useful functions. It will not take over our lives, as it is still us, people, making the choice of how we want to use the technology. Just as digital information and the information society in which we live do not define us as persons, or make us less special, or irrelevant. Through 3D printing, we simply have more options than we had before. This, as was already apparent with food, is not yet reality. Across sectors of industry, the use of 3D printing technology is limited, except for some medical applications and for prototyping. The technology is not yet widely accepted and incorporated in operational practices. This fits in with the pattern in the music industry when it was confronted with massive sharing over the Internet and more recently in the news industry and with televised content. Industries as a whole are no early adapters. Rather, small groups lead and at some point the majority follows. Where that point is and to what extent adaptation takes place depends on past experiences, choice, and the inevitability of change (for example, technology that everyone has been waiting for is lucrative).

There is no sign yet of 3D printing on a large scale, though there are examples of already successful 3D printed products such as translucent braces that can easily be mass-produced at low cost. 3D printing also proves a solution for out-of-stock spare parts for classic cars and scale-models used in architecture. In addition, international '*3D hubs*' are emerging, offering an intermediary service for people in possession of a 3D printer, and people who want an object printed. This sounds like the public is happy to look after itself. True as this may be, one of the questions at this point in time is whether 3D printing will primarily be something for specialized areas governed by science, such as space flight, and possibly used for commercial spin-offs afterwards, or if 3D printers will be designed to meet all of our needs. It could well be that experiments in specialized fields will be complemented by experiments in society, by people and companies who build a printer of their own and try to improve on it. As stated in the previous section, 3D printing technology requires little central control and allows for lateral participation and collaboration across countries. The significance of this here is that developments are taking place across society rather than at a central point, and that the possibilities for governments to follow and steer those developments are more limited. Some comparison can be made with the way in which encyclopedia were democratized by *Wikipedia*.

The larger enterprises such as *Heineken* and *IKEA* are likely to make serious efforts to explore the potential of in-house 3D printing for creating packaging or products on site, or spare parts for the production facility; for others, particularly the multitude of smaller businesses in the industry, ordering packaging or parts from another company or a store (which may or may not use a 3D printer itself) is unlikely to be different than before once 3D printing takes flight. For private individuals, who is going to provide the printing services and where? It could be local collaborations among citizens, professional and amateur, or companies, or educational institutions, or all of them. Will production be in facilities similar to today's factories, or will we see printing locations across towns and cities anywhere where it is convenient? In the foreseeable future it is unlikely that every household will have its own, sophisticated 3D printer. But in cities, which are by design better prepared than small towns and the countryside, 3D service levels could become high, depending on technological advancement, increased printing performance, and enhanced user satisfaction.

6. The third industrial revolution is an assembly of socio-technical developments

In popular media, 3D printing is often called a new ;industrial revolution' – referring to its potentially fundamental impact on industrial manufacturing, as discussed above. However, various authors have framed 'industrial revolutions' slightly differently; a common denominator often being the means of production and core materials used. Marsh (2011) counts four industrial revolutions based on technological changes before the current one while other sources count one (Beniger 1986) or two (for an overview see *Wikipedia*).

Rifkin (2011) suggests an interesting way of identifying 'industrial revolutions' and their driving forces. The premise of his analysis is that fundamental economic change occurs when new communication technologies coincide with new energy regimes.

The new communication medium that was a core enabler of the first industrial revolution was the newspaper, printed on the newly invented rotational press. Together with an increase in alphabetization that was considered a prerequisite for many an industrial occupation, cheaply-to-produce newspapers became the preferred way of keeping the populace informed – and they equally established themselves as that infamous "*fourth estate*" (Carlyle 1840). As A. J. Liebling remarked (1960), the "*freedom of the press is guaranteed only to those who own one*", in other words: newspaper publishing was (and still is) a highly centralized enterprise in which the editors and the owners of a newspaper indeed exert a high level of control over what does get published and what doesn't.

The primary communication channel in the second industrial revolution were 'electrified' media – think of radio, and later television, and think of the telephone. While radio and television very much parallel the production and distribution structures of the newspaper – centralized editorial and distribution facilities, single ownership – the telephone is somewhat different as it allows broader access to the communication infrastructure: anyone who can afford a subscription and receive access to one of the somewhat limited endpoints of the telecommunication network is able to participate. Yet the network itself is still controlled centrally and in fact relies on centralized switchboards for proper operation.

The communication medium intricately tied to the third industrial revolution (and according to Rifkin (2011) one of its triggers) is the Internet. As opposed to newspapers, telephone, radio and television networks, the Internet – essentially invented as a 'network of networks' – has been designed to not depend on central nodes for control (RFC 1105, RFC 4271). Moreover, by definition any node in the Internet can be both a sink and a source of information, and there are no inherent mechanisms ascribing more informational authority to selected nodes within the network.

Rifkin argues that at the core of this third industrial revolution is a fundamental shift from centralized, hierarchical structures to lateral and networked structures. The effect is best explained by analysing the main communication media pertinent to the above-mentioned two industrial revolutions. Initially, this is a technical shift from a requirement for centralized control in newspaper and electric communication media to the abolishment of that requirement with regard to the Internet. Yet design choices made for technical systems are both a tangible expression of societal undercurrents (cf. totalitarian architecture) and an enormous accelerator or inhibitor of practical use of technology. The absence of centralized control for information exchange on the Internet led to a torrent of novel information exchange practices on a previously unknown level – from *Napster* file sharing to the novels of the Wu Ming collective, and from *Wikipedia* to *WikiLeaks*. Already those information exchange practices pose unprecedented challenges to today's legal system and the moral values underpinning it.

The third industrial revolution is supposed to bring the fundamentals of the Internet – being lateral, networked, and without any requirement for central control – to the 'real', the physical world. This can have at least two effects on the current system of industrial mass manufacturing; we have alluded to those effects above.

According to the European Commission, Europe is on the verge of a 'third industrial revolution' (European Commission, 2012). This third industrial revolution is supposed to fundamentally change the energy industry from today's centralized structures — three of the worlds four largest companies are energy companies – to lateral structure in which "[it is] *possible for virtually everyone to become a potential entrepreneur and collaborator, creating and sharing information and energy in open commons*" (Rfikin, 2012). Similarly, in manufacturing lateral structures will develop in which everybody will have the possibility to manufacture small batches or single items. The key enabling technologies for distributed manufacturing are three-dimensional (3D) printing technology and other digital manufacturing technologies such as computer-controlled laser cutting and milling.

One possible effect is a change of where manufacturing actually takes place. In its most fundamental version, a 3D-printing-based manufacturing industry would delegate all or at least large parts of manufacturing to the customers – going way beyond *IKEA*'s delegating the final steps of furniture assembly. A less fundamental way of distributed manufacturing would consist of corner shop style local 3D printing facilities. This was touched upon in Section 5. Both scenarios, however, would have a major impact on current retail practices.

As items could be produced from widely available, standardized raw materials, the downstream supply chain would change considerably. Retail as we know it might disappear to a large extent. There would be no need for stocking up on single items for 'retailers' – the 3D print shops –, and no need for manufacturers to 'feed' the retail chain for an unknown or quickly changing demand. Time-to-market could possibly be cut massively, and 'manufacturers' would equally be able to push product updates to market with almost immediate effect. This would lead to 'manufacturers' putting much more emphasis on pushing out products quickly – time would become a much more important factor in competition.

A second possible effect is a change of ownership structures away from a few large corporations owned by a few (professional) shareholders to many small cooperatives owned by prosumers themselves. Ownership in such mutual and co-operative models is ambiguous (Davies 2009) as is profit-making as the ultimate purpose of the enterprise: co-ops have to take into account "*social externalities*". Davis further points out, that knowledge as one such social externality

> "has an ambiguous public-private character, both morally attached to its author or inventor, and publicly available to an audience. The legal licenses which aim to nurture the digital commons never rest on a binary or zero-sum notion of private and public knowledge, but seek to restrict uses of knowledge for public purposes." (Davis 2010, p. 13).

3D printing and other digital manufacturing technologies that are easily accessible and are able to turn information into products can easily be 'mutualised' as manufacturing technology. As such 3D printing fits well the mutual models of ownership. It is an essential ingredient for those socio-technical developments that form the basis for lateral power structures, distributed control and networked society beyond the Internet in the physical realm.

7. Corporate concerns and opportunities rising from 3D printing

The development of lateral structures – be it only with regard to actual product manufacture or more fundamentally in terms of overall industry configuration – results in a few challenges. Many economies in Europe, the Netherlands being a good example, are aimed at providing services to corporations – financial, legal, etc. Recently in the Netherlands the manufacturing industry was 'rediscovered'; manufacturing had been outsourced to low-income countries for decades, but when products got more sophisticated, people in a position of power did not immediately realize that a 'knowledge economy' can bring forth 'smart products'. Now all is set for a new era in the 'smart manufacturing economy'. 3D printing fits this model perfectly. It is smart by design – it did not exist until a while ago and it needs tomorrow's technology to succeed – and it is about 'making things'.

The industrialized world is best equipped to develop this technology, and an important question is: who will benefit? The technological advantages that, for example, the Netherlands has, will benefit the Dutch. There is no obligation to share invented technology with other equally equipped, competitive countries, such as in the relation between the US and Europe, or between European countries. Here we enter a difficult reality: that of trade policy and (claims to) rights of property. 3D printing as we know it today has been developed to a large extent in open design networks. Networks through which various parties and private individuals collaborated on new technologies and on new ways of building printing devices. Until people and companies in that network realized that there was money to be made out of 3D printing. From then on, inventions became the object of patents which now protect the interests of companies that contributed to today's 3D printing technology. But these companies, at first, worked in a spirit of cooperation. With patents and trade secret protection, the outlook has changed; what seemed an opportunity for many, now is now a concern for many – for those who don't hold the rights.

Let us briefly consider intellectual property rights in regard to 3D printing (see in greater detail, Mendis 2013). As 3D printing builds on the possibilities of digital and Internet technology, a key element is working with digital files for downloading and sharing, and modifying. This activity, as the experiences with music and videos have shown, is likely to include copying and using and distributing copies. Therefore right holders to the original industrial design (copyright, design laws) or invention (patent law) face acts they may consider 'piracy'. This situation immediately begs the question whether they are indeed right holders, and if so, what their options are. Are technical drawings of an 'invention' indeed protected under intellectual property laws? Or is there no actual infringement as 'copying' technical stuff for private use is not covered by patents? Are copies of files of protected industrial designs, or printed objects of such designs, infringing someone's rights per se? Is unauthorized uploading, or downloading a print file an act of infringement? Given that 3D printing is new territory, there are no ready answers.

Assuming a legal right, right holders can still be clueless, or plainly wrong, about what acts constitute an infringement of their rights. 3D printing involves certain ways of dealing with digital information (files) and manufacturing (printing). Each type of act has to be assessed and classified from a legal point of view, and since intellectual property laws are territorial rights, the outcome in one country does not necessarily determine what is allowed in another.

As with the traditional music industry, right holders might be tempted to use their corporate power against suspected infringers, but are there other options? Right holders could choose to abstain from acting against people using unauthorized copies or making unauthorized 3D prints. There is a strong precedent for this line of reasoning. In the case of the traditional music industry, the way in which people viewed digital music files differed wildly from what the industry wanted them to do. On a large scale, people copied, shared, stored, assembled, and put online – we use past tense, but this was not long ago. Though the industry lobbied for more stringent rules and some people were sued or prosecuted, the battle was lost. New business models by *Apple* (*iTunes*) and others succeeded in attracting the very audiences that the music industry had come to see as 'pirates'. For the entertainment industry, and perhaps for most lawyers, seeing clearly what to do instead is hard. What made this so difficult was that there was no real precedent – the digital age had arrived and people's behaviour did not fit in well with copyright laws. Technically speaking, everybody copied illegally, but the scale of downloading and sharing and copying was such that enforcement was hardly an option. Apparently the majority of people wanted something else. As Lanier puts it, it only makes sense to talk about enforcement when a small minority of a population are offenders (Lanier 2013, p. 320).

If this is indeed the future, is enforcement of intellectual property rights, without which none of those rights can survive, redundant? Enforcement means giving a right holder the tools to act against others; without enforcement he only has a right by name. Redundant, no, but enforcement is not an answer to socio-technical change. How then can right holders prepare – can they still rely on protection of their inventions and designs in the future or should they deploy different strategies altogether? Can they afford to go through the lengthy process and smarter using 3D print technology to their full potential? These are of registration, often a requirement by law, when others may innovate faster tough questions to answer when the impact of mass-market 3D printing is not yet known. It makes sense to think about alternatives to 'traditional' intellectual property management, or indeed about suitable responses by corporations to 3D printing developments (see also, Mendis 2013). 3D print technology demands special attention of all stakeholders because there is a risk that a fast-growing industry picks up the tricks of intellectual property protection all too soon and comes down hard on alleged acts of infringement – printed designs used or modified by others without authorization, 3D printing technology, design of 3D machines, etc. Such attitudes befit highly competitive environments in fully developed markets but they do not help to build a dynamic, diverse and international 3D printing industry. Fear of trespassing on someone else's rights to intellectual property creates uncertainty among those who are experimenting with 3D printing technology and are seeking new purposes in a collaborative spirit. Of course, certain legal questions deserve an answer, such as what being a 'prosumer' means. But more importantly, this paper proposes, there should be room for experimenting, particularly in areas that are the world's common concern, such as – to name a few – practical, 3D print solutions to problems related with global warming, drinking water, disaster relief, and basic transport, without anyone having to fear potential legal threats from right holders. A big challenge, but it is worth investigating right from the start what solutions can be achieved with 3D printing technology with suitably constructive support of law and policy.

As Jeffrey Sachs puts it, "[T]*he defining challenge of the twenty-first century will be to face the reality that humanity shares a* common faith on a crowded planet. *That common faith will require new forms of global cooperation…*" (as quoted by Horrigan 2010, p. 339, emphasis in the original). Companies, often right holders, are part of society and, of course, need to behave accordingly. They communicate and interact with other 'stakeholders' in society such as local government, pressure groups and citizens. Irrespective of 3D print technology, but very much as a result of the new lateral structures in society, business will move in a direction where they widen their overall objective from profit making and shareholder value to a permanent contribution to society (Visser 2011, p. 320). The power and influence of business will change as it will be subject to numerous checks and balances with regard to social concerns, the environment and ethics (Visser 2011, p. 320) – Corporate Social Responsibility regulation is a good example. Business models can be developed embracing 3D printing, either for use in production or for use by users and consumers in hassle-free ways. Here, an important choice has to be made: will companies develop business models in response to 3D printing technology that presuppose competition or will companies choose a model that embraces cooperation with others? Companies can only make this choice in a certain context: supported by laws and regulations, and knowing what position other companies in the market take.

8. Framing the social changes: what governments can do

Collaborative, lateral design and production do not sit well with the classic view of (single) authorship and intellectual property rights. As with the music industry, people (consumers) focus on easy ways of use at small fees and have a mind to share and exchange because that fits with their preferred way of using (protected) material. Hampering socio-technical progress by deploying defensive strategies is not fruitful in the long run nor is it the socially responsible thing to do. As we have argued above, there should be room for experimenting, particularly in areas that are of common concern, such as global warming and problems that developing countries are dealing with, without anyone having to fear legal threats.

These concerns should be addressed at a legislative and policy level. It needs to be ensured that the legal system for the protection of software, inventions and designs fosters progress, not impedes it. But already patents are being secured by manufacturers of 3D printers who used to work in cooperation with a community of developers and designers in the past. Experimenting and collaborating should take priority in order to allow for continued lateral collaboration in society. Ideally, governments establish a haven, a playground, and a field of study, for designers, researchers, and innovative companies who work alongside each other and with each other towards more and more sophisticated 3D printing technology and devices. Why not agree that such work on 3D printing, whereby people use designs and knowledge and expand on it, does not constitute an infringement of rights if used for 3D print-modifications, and evaluate after a certain period? There are downsides to this approach, which goes against certain legal interests and may be cause for concern in itself. But on the other hand, society does not gain from (fears for) temporary monopolies in regard to 3D printing either. We believe open minded developments are most promising.

In lateral design and production, the socio-technical developments do not demand national, or international, coordination. Instead, framing by authorities or self-governance is desirable. Governments can use their authority and public funds to signal out priority areas – as there are many fields that are, or may become, impacted by the possibilities of 3D printing, it is important to invest in certain fields (medical, food, safety, global problems such as pollution) with research money and private enterprise involvement. Think for example of efforts aimed at solving particular needs in developing countries or disaster relief, starting with the idea that sending raw materials and 3D printing machines instead of the actual products could provide a quicker and cost-effective alternative. Innovate without aiming for patents. Is that even possible? This is for society to find out, with willing governments who understand the point. Framing 3D printing developments by the government has a further advantage: keeping an eye on safety aspects of (tradable, distributed) products (for car repair, distribution of injection needles etc.) and setting standards where necessary.

It should be possible to work on common, international goals, while also taking time to consider the implications of 3D printing for the national economy. How can national industry benefit from international developments in 3D printing, and what would it mean if national industry does not become a front-runner in the market for 3D printing? What will happen to large ports such as Antwerp and Rotterdam if overseas container shipping declines due to the development of continental 3D print production? These are policy questions that are best answered in conjunction with the interests of the lateral structures in design, development and production.

Many governments have already thought about 3D printing, when the subject of weapon part fabrication came up (printing entire handguns that work is not yet possible). This is a serious, but minor (and distracting) issue compared to the potential in many other fields. Efforts could be put into developing software that can recognize and filter printing files with content considered dangerous, even though this would be an intrusion of digital freedoms and the right to privacy. Where would authorities want to filter digital traffic: on transmission or on printing? On transmission will mean through internet providers (topic of deep packet inspection); on printing will imply regulating the 3D printers market, similar to the 'old' colour printer market where every colour printer prints an invisible 'mark' identifying the individual machine[1]. Which approach to use is a matter of choice.

9. Conclusion

Writing about the changes that the arrival of 3D printing will bring is akin to philosophizing about living on Mars. It will happen, but how and when and on what scale is yet unclear. This is not to say that we cannot frame the topic. For enterprises, for designers and developers, and for consumers, noticeable changes are to be expected. Some anticipate those changes with fear of losing current positions, but others want to take part in new developments, and to collaborate. For enterprises, the true answer is in being socially responsible which in the first instance translates to allow and embrace collaboration. A collaborative approach, however, creates difficult questions about competitive advantage and about competition in general. These difficult questions not only relate to 3D printing in its core technolo-

1 See https://www.eff.org/issues/printers

gical sense, but also to the socio-technical developments that 3D printing enables in a networked society. For governments, the challenge lies in creating (legal) frameworks that allow for innovation, and that put cooperation and competition at comparable levels. 3D printing technology deserves every chance and with the involvement of all stakeholders: a true form of open innovation that encounters the least resistance possible from either rights holders or legislators.

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