Chapter 11
How will society adopt 3D printing?

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11.1 Introduction

In this final chapter of the book, 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 the developments of other digital technologies, particularly in media. In that way, we understand consumer 3D printing as the latest addition to these developments. We then undertake to sketch some of the next developments we expect in enterprise 3D printing. Framing 3D printing in the context of 'industrial revolutions' leads us to understanding it as part of broader, socio-technical developments that drive lateral power structures, distributed control and a networked society beyond the Internet in the physical realm. We then investigate some of the business and legal challenges for companies. Looking into these challenges leads us to particularly apparent matters of definition and scope in regard to product liability and consumer protection, and of intellectual property rights. Finally, we ask what governments can do to mollify concerns and let opportunities flourish. We provisionally conclude that an open-minded approach to 3D

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printing and the social-technical developments it represents is most promising.

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

3D printing in their present ways stems from ideas and experiments that have been around longer. The difference is that 3D printing is on the verve of many a break-through and wide acceptance in society. With the timeline below we bring the readers up to speed.

11.2.1 19th and 20th century developments

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.[2] 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'.[3] '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 made use of a characteristic of some specific materials, mainly resins, called photo polymerization: under the influence of lasers, ultra-violet 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,[4] 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

[2] Bourell *et al.* 2009.
[3] Wohlers 2011.
[4] U.S. Patent 4,575,330.

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 harden at room temperature to form the object layer by layer.

Two other additive manufacturing technologies are 'selective laser sintering' 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. The binder glues together the powder to form solid objects. Other approaches deposit wax or photo polymers using inkjet print heads.

11.2.2 3D printing for enterprises

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 technologies. It was in those years that the technology became popular outside specialist industries. Two developments contributed to that popularity, the arrival of open source 3D printers and the appearance of consumer-facing 3D printing services.

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, the 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.[5]

11.2.3 3D printing for consumers

2009 saw the first consumer-facing 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. In 2008, 3D printing became the vernacular equivalent at *Euromold* (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 already went way beyond producing presentation and functional models and visual aids and included assembly aids, tooling, and direct part manufacturing.[6]

11.2.4 Distinction between consumer and enterprise 3D printing

The business consultancy company Gartner started to include 3D printing in their reports on emerging technologies as of 2008 and quickly classified it as 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'.[7] The former remains at the peak of inflated expectations awaiting its "*through of disillusionment*"[8] before (maybe) moving towards productivity while the latter is supposed to reach its plateau of productivity within the next few years. Gartner made a further distinction by marking 3D bio printing as a separate category. 3D printing in medicine is already proving itself valuable in customizing prosthetics and printing living cell material such as for building artificial scaffolds in the shape of an organ.[9]

5 Gartner 2013.
6 Wohlers 2011.
7 Gartner 2013.
8 *Ibid.*
9 Prince 2014.

Today, maintaining a distinction between consumer 3D printing and enterprise 3D printing is useful in at least three ways. First, enterprise 3D printing will be added to current methods available for production. Many developments of 3D printing are relatively close to commercial utilization in a business environment, which is essentially what Gartner argues. A study carried out by IBM showed that within 20 years from now, 3D printing of regular goods such as washing machines, industrial displays, mobile phones, and hearing aids could be possible and commercially viable.[10] The study shows that this development can have a substantial impact on how supply chains currently are structured, transforming them from big, complex, and global, to small, simple, and local. The study recommends that enterprises embrace that transformation, particularly in the electronics industry where these changes are already under way.

Second, consumer technology will be turned into enterprise applications. There is 3D printing as a consumer technology that still lags enterprise applications but could be following their development relatively quickly. This can be seen as a separate development that results in uses in a business environment as well. Such a development from enterprise to consumer applications 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. Consumer 3D printing applications are likely to have their own characteristics, as we will discuss in par. 4 below, and it makes sense to expect that those characteristics will be apparent in the eventual enterprise applications.

Third, consumer 3D printing can be seen as an example of 'democratized innovation'[11]: a trend in society whereby people enable themselves to manufacture custom-made products, introducing manufacturing capability where it did not exist before outside the traditional manufacturing industries. Individual manufacturing has also been called 'user-centered innovation' as opposed to 'manufacturer-based innovation'.[12]

11.2.5 In essence

Enterprise 3D printing will be added to existing production methods. Networked consumer technology for which businesses believe there is a

[10] Brody & Pureswaran 2013.
[11] Von Hippel 2005.
[12] *Ibid.*, 121-124.

market will be developed into enterprise applications. Consumers introduce manufacturing capability where it did not exist before.

11.3 Disruption of business models

Before we discuss the potential consequences of (consumer) 3D printing, we investigate how other industries, the media and content industries in particular, have seen the disruption of business models and the emergence of new products triggered by social developments – for example in music, encyclopedia and news.

11.3.1 Music

In the late 20th century the music 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). At that time, it was common practice for consumers 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 compression formats to store and share music in reasonable quality, 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.[13]

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.[14] Further, there had always been an undercurrent of small bands and labels that would cater for a niche clientele and that were apparently not affected by the alleged piracy.[15]

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

[13] *Cf.* Zentner 2009, 3.
[14] *Cf.* Masnick 2009; Troxler 2009.
[15] *Cf.* Grassmuck 2010.

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 – as singer-songwriter Neil Young put it in an interview: "*Piracy is the new radio*."[16] They had to learn how to handle this new reality in a way that would be profitable over all.

11.3.2 Encyclopedia

The division between production and consumption stayed relatively stable in music. In other content industries, this has been quite different, as the digital revolution empowered consumers to become producers. The best-known example with a very much global reach is in the field of encyclopedia – Wikipedia. Traditionally, encyclopedia were written by a knowing elite with the aim of enlightening and educating the general public.[17] 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. Paid professionals are 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.[18]

11.3.3 The news

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 consumer and a creator of information allowed people to publish content on their own account. A few specific tools intended initially to keep online, web-enabled logbooks of private nature (blogs) led to people publishing their own versions and

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[16] Young 2012.
[17] Diderot 1778.
[18] Okoli *et al.* 2012.

interpretations 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.[19]

11.3.4 In essence

These three examples of music distribution, of creating and curating encyclopedic content, and of 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 only when central control was reduced and individual and even (to a certain extent) idiosyncratic contribution was allowed, change started to affect the business models of incumbent industry. 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. The lesson we draw for change that would occur following 3D printing possibilities, is that when (a) central control is reduced and (b) individual and even idiosyncratic contribution is allowed, change will start to affect existing business models.

11.4 Consumer 3D printing: The latest addition to digital evolution

Consumer 3D printing is so far the latest addition to that digital evolution. As 3D printing technologies become available to consumers, they are changing the way consumers think about producing goods. 3D print shops, web-based service bureaus, shared machine shops and even home

[19] Pew Research Center 2012.

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.[20]

11.4.1 The prosumer

The availability of 3D printing technology is opening up new ways of 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.[21] With digital manufacturing 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 consumer who achieves "*complete customization*" by manufacturing one-of-a-kind products.[22]

We will use the term prosumer to indicate a consumer-producer who may sell or share with anyone or make multiple copies, but who is not a traditional manufacturing company. The prosumer does not necessarily bridge the gap with enterprise 3D printing, which is capital-intensive and conforms to an industrial paradigm of manufacturing. However, the prosumer does show that the picture of who is involved in 3D printing (applications) is fragmented.

11.4.2 Complete customization

The 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. New ways of how people 'consume' goods are supported by web-based '*3D hubs*', intermediary services for people in possession of a 3D printer and people who want objects printed.

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[20] Marsh 2011.
[21] Pine II, 1993.
[22] Toffler 1981, 183.

The most notable player, *3D Hubs*, is a portal to 6,000 printers in Europe and the US (according to their own figures, August 2014). Such interconnections in society show that the public is happy to look after itself, and to commercialize where it sees fit. No central regulation or intervention by the traditional manufacturing industry preceded these services. Consumer 3D printing offers one-of-a-kind products such as scale-models which traditional manufacturing industry currently cannot provide. It is a new market, discovered by explorers in the creative sectors, both professional and home enthusiasts. The fact alone that the audience for '3D hubs' does not buy their desired product from a store and still gets what it wants, means a loss for the industry.

11.4.3 Expected uses

As was the case in the early days of the personal computer, it is hard to foretell all that people would actually do with 3D printing once the technology advances further and becomes more widely available. This is not necessarily assuming that 3D printing machines will be designed to assist generally in people's daily needs at home or in the office, but at least that the technology gives people a choice they did not experience before, and in this way changes their behaviour.

A good guess what people would do with 3D printing is that people would do other things than what manufacturers do. After all, personal use of computers is not normally payroll or inventory management – filing tax returns and electricity meter readings is probably the closest home computers get to be used in an industrial way. Personal use of computers, as illustrated above in the examples on media use (section 11.3), is also more than individual content consumption; it is digital creation and social interaction across time and distance using a variety of digital media. In other words, it is quite likely that people would use personal fabrication not for producing machines or standard components, even though that is what *some* would seek out. It is highly likely, that people would use 3D printing for individual creation and social interaction – as this is what people do.

11.4.4 Social fabrication

The main attraction of 3D printing for people being that it is an exemplary method for producing one-of-a-kind products, 3D printing by consumers is not so much challenging mass manufacturing but forms a counterpoint to the traditional position of manufacturing as a part of (serious) working life. The things shared on *Thingiverse* already paint a picture of consumer 3D printing being hedonistic and playful.

Looking at 3D printing this way, its future is more than just technology for a market of one, producing one-of-a-kind products; it is more than "*personal expression in technology*."[23] It is not only consuming personal fabrication as a commodity provided by a new branch of the entertainment industry in the form of *e.g.*, 'Maker Faires'. The impact is broader than that: the main impact of making will be a social one. Consumer 3D printing would develop into social fabrication, not personal fabrication. The constituents of social fabrication here are participation, collaboration and sharing, made possible – with this much ease and on this scale – by the networked society. 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. This is why 3D printing as a social phenomenon is a truly international development, connecting communities and transgressing borders. Much more than the commercial arena, or government, social fabrication is related to the notion of 'deep play'[24], which can be summarized as the human characteristic to explore and bond and give meaning to life.[25]

In essence

We expect that consumer 3D printing would develop into social fabrication. On a path parallel to traditional manufacturing society will explore, develop and use 3D printing applications through participation, collaboration and sharing. This change represents a possible realisation of a 'third wave'[26] or 'convivial society'[27] in which individual freedom is realized in personal interdependence, not in individual self-interest.

11.5 An outlook with regard to enterprise 3D printing

The commercial application of 3D printing or enterprise 3D printing is already much more advanced as Gartner's analysis shows.[28] For example, for in-ear hearing aids 3D printing is the technology of choice. The aerospace industry is already making wide use of 3D printing. In casting applications, 3D printing is often more efficient to create single sand cores than

[23] Gershenfeld 2006, minute.
[24] Rifkin, 2011.
[25] Rifkin 2001.
[26] Toffler 1981.
[27] Illich 1973.
[28] Gartner 2013.

conventional methods. All applications combined have created a market worth $3,000,000,000 worldwide in 2013[29], with a further incline expected.[30]

11.5.1 Adoption of the technology

Still 3D printing is far from being a mainstream manufacturing technology across sectors of industry. While prospective enterprise applications of 3D printing keep pushing the boundaries of imagination, the technology is not yet widely accepted and incorporated in operational practices. This fits in with the patterns in the music industry when it was confronted with Internet distribution and more recently in the news industry with newspapers and with televised content.

Industries as a whole are no early adapters; rather, small groups lead and at some point the majority follows. Adoption of new technologies often take decades – for instance the replacement of transmission based drives by electrical motors in manufacturing stretched over a period of forty years.[31] One of the early adapters to 3D printing is the above-mentioned enterprise *Shapeways*, which has made 3D printing its core business by printing products on demand according to customer specifications and allowing external designers to set up a 'store' on the company website. Among other early adapters are moviemakers in Hollywood and retailer IKEA, both of which have started to use life-like 3D models of people for their imagery – real persons doing modelling work need to be hired, have agendas, need to travel and eat. At the moment the bulk of the IKEA catalogue is already computer generated with 3D product imagery.[32] However, the retailer does not yet offer the bulk of its products as 3D printed, or printable objects.

When the point will be reached that the majority follows and to what extent adaptation takes place generally depends on past experiences, choice, and the inevitability of change – for example, technology that everyone has been waiting for is lucrative. At the moment, it is still a possibility that 3D printing will be primarily something for specialized areas governed by science such as the airline industry, space flight or health care, and used for various commercial spin-offs, rather than for the industry as a whole. If the technology is adopted across sectors of manufacturing industry, it will mean that the costs of the machines and the materials are manageable, and that

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[29] Wohlers Report 2014.
[30] Canalys, 2014; MarketsandMarkets, 2014.
[31] Hall 2004, 466-467.
[32] Parkin 2014; Vincent 14.

machine capability (for mass-production or massive small-batch production) is perceived as good.[33]

11.5.2 Which areas of industry

Expectations are that 3D printing applications will indeed be widely accepted and incorporated in operational practices. As a consequence, 3D printing must be seen as having the potential of leading to a massively disruptive transformation of current supply chains. It is expected that typical investment costs for an enterprise 3D printer will fall from $70,000 to $2,000 over the coming years[34] thus lowering the barriers of entry to the market for new manufacturers. These machines allow a high degree of personalization while becoming cost-competitive with traditional mass-manufacturing even if production volumes are up to 98 percent lower. Higher integration in manufacturing will further eliminate tiers in the supply chain.[35] In combination, these developments will set back competitive advantages of mass-production with its requirements of standardization and global markets. This means that probably even before 2025 the manufacturing industry, supply chains included, could become regional or local rather than global.

One particular area affected, is spare parts. As a science article in Newsweek has put it, for cars, computers, factory robots, hot water heaters and every other item ever sold that is even modestly expensive, buyers – both consumers and businesses – need to get replacement parts into perpetuity; this means warehouses everywhere are filled with plastic knobs, metal casings, hoses, connectors, wheels, waiting for something to break somewhere.[36] Advanced 3D printing services seem ideal for getting people those parts either through '3D hubs', local printing facilities capable of doing the job, or enterprises selling the printed parts.

However, the manufacturing industry naturally is not just at the mercy of events. Multinational household names in the food and retail sectors but also airline corporations are already making serious efforts to deploy in-house 3D printing for creating packaging or products or producing spare parts. For others, particularly the multitude of smaller businesses, ordering packaging or parts from another company might be no different to before 3D

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[33] Wohlers Report 2014.
[34] Gartner 2013a.
[35] Brody & Pureswaran 2013, 10-11.
[36] Maney 2014.

printing takes flight – yet the *supplier* might well be another small business making use of 3D printing. 3D printing will be a mainstream reality.

11.5.3 Co-operation adds to the success

Co-operation is expected to contribute hugely to the success of enterprise 3D printing. The combined availability of the Internet, 3D printing technology, and high levels of education, acts as a catalyst for collaboration between people who connect on expert forums and company websites and who wish to work on perfecting 3D appliances. 'Co-design', 'crowd-sourcing' and 'open innovation' all indicate contemporary forms of collaboration whereby individuals gather for a particular goal that they share as a challenge and that they can all work on and benefit from in one way or the other.

Such collaboration has not usually been a part of product development of technology-intensive enterprises, which tend to shroud their R&D in secrecy for fear of the competition. The availability of the Internet and 3D printing technology and the potentially endless possibilities for manufacturing will tempt some companies to adopt an outward approach and consult the people hitherto unknown to the company – the audience of the worldwide web – that want to take on the challenge.

In the aircraft industry, after *General Electric* had invited anyone to come up with a lighter jet engine bracket design according to its specifications, the company was reportedly perplexed by not only the number of designs it received (close to 700) from people it said it would likely otherwise not have found, but also the percentage of weight-reduction the winning design offered – nearly 84 percent instead of the 30 percent the company had aimed for in its call.[37] The bracket of choice was then downloaded and 3D printed out of titanium and steel, essentially using a laser beam to fuse layers of metal powder into the final shape.[38]

It is highly unlikely that a company that has experienced such advantages with collaboration will want to do without in the years to come. Successes with 3D printing are greater and are achieved sooner.

[37] Newsweek 2014.
[38] GE Reports 2013.

11.5.4 In essence

In part made possible by contemporary forms of co-operation between enterprise and non-enterprise partners, 3D printing will become a mainstream reality in the industry. When the point will be reached that the majority of enterprises adopts the technology for mass-production or massive small-batch production and to what extent depends mostly on past experiences, choice, and the inevitability of change.

11.6 The third industrial revolution: 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 private and industrial manufacturing, as discussed in the two sections above. Various authors have framed 'industrial revolutions' slightly differently; a common denominator often being the means of production and core materials used. Marsh counts four industrial revolutions based on technological changes before the current one,[39] while other sources count one[40] or two[41].

11.6.1 How industrial revolutions occur

Rifkin suggests an interesting way of identifying 'industrial revolutions' and their driving forces.[42] The premise of his analysis is that fundamental economic change occurs when new communication technologies coincide with new energy regimes, and we shall briefly paraphrase this approach as a basis to further discuss the socio-technical implications of the changes 3D printing is likely to bring about. This is explained further. The core energy source of the first industrial revolution was coal and the steam engine. The driving energy source for the second industrial revolution was oil and electricity. For the third industrial revolution, Rifkin foresees renewables such as wave, wind, solar, and geothermal energy as the main energy sources.

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

[39] Marsh 2011.
[40] Beniger 1986.
[41] For an overview see Wikipedia.
[42] Rifkin 2011.

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'[43]. As Liebling remarked, the "*freedom of the press is guaranteed only to those who own one.*"[44] 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 does not.

The primary communication channels 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 paralleled the production and distribution structures of the newspaper – centralized editorial and distribution facilities, single ownership – the telephone was somewhat different as it allowed broader access to the communication infrastructure: anyone who could afford a subscription and received access to one of the somewhat limited endpoints of the wired telecommunication network was able to participate. Yet the network itself was still controlled centrally and in fact relied on centralized switchboards for proper operation.

The communication medium intricately tied to the third industrial revolution (and according to Rifkin one of its triggers)[45] 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 a hierarchical model of central nodes for control.[46] 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.

11.6.2 Third industrial revolution

Rifkin argues that at the core of the 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

[43] Carlyle 1840.
[44] Liebling 1960, page.
[45] Rifkin 2011.
[46] Lougheed & Rekhter 1989; Rekhter *et al.* 2006.

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. It also lead to massive and largely uncontrolled breaches of privacy by surveillance and data collection programmes. Already those information exchange practices pose unprecedented challenges to today's legal system and the moral values underpinning it. Furthermore, the development of consumer facing applications such as search and social networking lead to the emergence of new monopolies; a technical infrastructure that is networked and requires no hierarchical control this does not necessarily and inevitably translate in networked and non-hierarchical practices – contrary to romantic beliefs in early Internet times. We maintain that it is vital not to fall for similar deceptions with the technical possibilities of 3D printing.

According to the European Commission, Europe is on the verge of a 'third industrial revolution'.[47] This third industrial revolution is supposed to fundamentally change industry. It is supposed to bring the fundamentals of the Internet – being lateral, networked, and without any requirement for hierarchical, 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 (see the previous section).

11.6.3 Delegated manufacturing

One possible effect is a change of where manufacturing actually takes place, as shown by Brody & Pureswaran.[48] 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 what has become current practice today when IKEA delegates the final steps of furniture assembly to its customers. A less fundamental way of distributed manufacturing would consist of corner shop style local 3D printing facilities, as illustrated above. Both scenarios, however, would have a major impact on logistics and on current retail practices.

As items could be produced from widely available, standardized raw materials, the downstream supply chain would change considerably. Retail

[47] European Commission 2012.
[48] Brody & Pureswaran 2013.

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.

11.6.4 Change of ownership structures

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, or ‘manufacturing commons’. Ownership in such mutual and co-operative models is ambiguous[49] as is profit-making as the ultimate purpose of the enterprise: co-ops have to take into account ‘social externalities’ – for example knowledge. The way knowledge is handled in commons today is also ambiguous. Morally it is attached to its source. But technically it is available publicly – albeit sometimes to a limited audience. The current legal system and the licenses that facilitate the commons “*seek to restrict uses of knowledge for public purposes*.”[50]

The energy industry, for example, is supposed to shift from today’s centralized structures – three of the world’s four largest companies are energy companies – to lateral structures in which “[it is] *possible for virtually everyone to become a potential entrepreneur and collaborator, creating and sharing information and energy in open commons*.”[51] Similarly, in manufacturing lateral structures could develop in which everybody will have the possibility to manufacture small batches or single items, as we highlighted above. This ties in with the characteristics of a ‘sharing economy’.

11.6.5 In essence

3D printing as key enabler for distributed manufacturing – together with other digital manufacturing technologies such as computer-controlled

[49] Davies 2009.
[50] Davis 2010, 13.
[51] Rifkin 2012, page.

laser cutting and milling – is able to turn information into products. As a manufacturing technology it can easily be 'mutualised', it fits the collective models of ownership well. It is an essential ingredient for socio-technical development that forms the basis for lateral power structures, distributed control and networked society beyond the Internet and into the physical realm of manufacturing and the production of objects.

11.7 Governing 3D printing for enterprises

Even if one considers enterprise 3D printing just 'a different way of making things', things change for manufacturing companies. We investigate some of the business and legal challenges that manufacturing companies await.

11.7.1 Design-build-deliver

The introduction of 3D printing affects production, storage, and supply within manufacturing industries (see above, sections 11.5 and 11.6). Paraphrasing Petrick & Simpson, traditional mass-manufacturing works on the principle of 'design-build-deliver', whereby designers translate customer needs into viable products, and producers emphasize production that is low-cost and efficient and distribution through an extended supply chain.[52] In this model, keeping the cost as low as possible is central, which explains the quest for ever-reduced variation to enable repetitive production of interchangeable parts.[53] The roles of the participants in this process are well established.

This is different in areas where 3D printing takes hold: who is involved can vary from product to product. Rather than a more or less linear supply chain there is a network of contributing partners. In addition, for designers and engineers who have been taught on the principle of 'design-build-deliver', creativity lies in optimizing efficient and low-cost production.[54] Although a similar model could emerge for 3D printing as one of its attractions surely is that products will be easier to make and therefore cheaper, at the moment 3D print enthusiasts exploring its potential in every way, still make the biggest waves.

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[52] Petrick & Simpson 2013.
[53] *Ibid.*, 12-13 with further references.
[54] *Ibid.*, 13.

11.7.2 Re-define 'consumer'

The fragmentation of roles and production lines leads to change, including in how a company deals with the law: who can be presumed a consumer who is to be protected under European consumer laws? In the EU, contract law demands that not only a legal person such as a company but also a natural person who, under a contract, sells consumer goods in the course of his trade, business or profession must deliver goods to the consumer which are in conformity with the contract of sale.[55] This rule of conformity has become a cornerstone of consumer protection and is likely to apply to any consumer – prosumer – who sells, at a certain price, a 3D printed product to a customer, even though he himself may not see his printing activities as those of a company. European consumer laws[56] and their national counterparts will need scrutiny by the corporate legal departments in light of 3D print developments. Naturally, matters of definition and scope also call for involvement of the judiciary for interpretation and the (European) legislator for possible amendments.

11.7.3 Re-think 'producer'

Other matters await a business either using 3D print technology for its own products, or getting its supplies from another business that incorporates 3D print technology in its supply products. The main question here is who is to be regarded a producer who faces legal obligations and legal liability.

In case of companies using 3D print technology for creating their own products, or 3D printing the products, the companies concerned are *producers* who will be aware that they bear a legal responsibility for bringing a product of a certain quality to the market and allowing consumers to purchase it and use it for what it is for. In the EU, this responsibility requires a business to ensure that the product it delivers to the consumer is in conformity with the contract of sale.[57] In addition, producers can be held liable for defective products.[58] Due to the novelties in 3D printing – think of new raw materials used for printing – the expected quality needs to be determined first, before products can be measured against it. Or else to an extent the unexpected, emerging qualities of the novel product might be considered part of the contract. Other questions concern product safety – in

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[55] Directive 1999/44/EG, Art. 1,2,c jo Art. 2.1.
[56] Directive 2011/83/EU.
[57] Directive 1999/44/EG, Art. 2.
[58] Directive 1985/374/EEC, Art. 1; Directive 1999/34/EC.

particular, health, reliability, and durability are at stake (*e.g.*, children should not get sick from the materials that are used to create a 3D printed toy; a printed spare part for a car should not break under normal stress) – and about who takes care of oversight (e.g. certification norms).

All of this shows that the legal obligations of manufacturing companies need broader consideration than 'just' defining who is a producer and when. Moreover, in case a business receives its *supplies* from another business that incorporates 3D print technology in its supply products, it may either be using those supplies in its own products – which then brings to the foreground the issue of product conformity and product quality – or rely on the functionality and the reliability of the supplies in its own company (its office for example) – which makes the company the customer – or both.

For 'prosumers', i.e. the self-producing private individual or independent entrepreneur who shares some of the characteristics of a manufacturing company, it can be argued that if they act like a professional manufacturer they join the professionals in the legal sense too. Meaning that the laws of conformity and product safety in principle stretch out to the prosumer enters the 3D print market as well. When considering this more profoundly, especially at the legislative level, the downsides for socio-technical developments will need to be looked into.

11.7.4 Not at the mercy of events

Enterprises can take matters into their hands by introducing various measures. One such measure would be to adopt a system of certificates comparable with the 'appellation d'origine contrôlée' (AOC) or controlled designation of origin. The comparison here with a certification granted to French geographical indications and agricultural products may seem frivolous but it is not a bad idea, when we consider that 3D printing is on the verge of a massive break-through, to look into a system of certificates that enables companies to show the customer that they are a registered business selling a product that originated in their production facility. Even though certificates can be forged, and guaranteed products can be defective, the market for 3D printed appliances would be more transparent, especially if (an existing) transnational authority were to take care of supervision.

Companies who have trademark rights can of course place a visible and recognizable sign on the printed product as an indication of its origin. There are complications here, too. It would be able to print such signs with any high-quality copy of the trademarked product, which would make it hard to tell which is fake – meaning the product looks real enough but the right holder has not been asked for permission to print and sell. Once 3D printing would take flight, the legal battles could go on without end. We are not saying there is no point at all in having trademarks for your print products and going after infringers. But for companies there would need to be more than a single measure if they want to signal to their consumers that what they offer is the genuine product. Even several measures combined would not stop unauthorized copying. Another measure would be setting up a system for collecting mandatory fees for 3D prints similar to the copying levy for 2D print copies. This a company cannot achieve alone though it can lobby for it. However, such measures are unpopular as the downsides are serious – more regulation, and life would be yet a bit more expensive for the consumer.

Furthermore, companies engaging in international trade would need to inform themselves of the state of the law in the countries where they have a customer base. However, governments need time to identify and address the implications of 3D printing on national law, so obtaining legal certainty first may be an illusion.

11.7.5 Intellectual property rights

As Bojanova puts it, mass adoption of 3D printing would provide a more widely accessible way of producing digital models and physical goods.[59] Mass adoption of 3D printing will help reduce costs through improved designs and streamlined prototyping, but the ease of use will cause loss in intellectual property, which might increase economic conflicts and raise political debate.[60] Intellectual property rights – temporary monopolies with regard to the use of a brand name, image, design, or patented technology – can apply to 3D printed objects and associated processes.[61] Such a temporary monopoly does not come without certain responsibilities: the law grants a legally enforceable right that has a certain definition and scope and that has to be balanced, in specific cases, against the rights of others, *e.g.*, the freedom of commercial expression of competitors. Nevertheless, intellectual property rights can be powerful instruments to have in a corporate portfolio.

History suggests that battles of intellectual property are brewing in 'the world of 3D printing technology'[62]. There is the quest for (patentable) technology. In addition, the handling of digital files and manufacturing may involve acts of infringement of a legal right. 3D printing and the way people use the technology will no doubt be assessed in detail from a legal point of view in the years to come. This is bread and butter for lawyers, and the

[59] Bojanova 2014.
[60] *Ibid.*, 11.
[61] *Cf.* Mendis 2013.
[62] Hornick & Roland 2013, 14.

resulting clarity may be satisfactory for enterprises, but confronting adversaries does not necessarily help enterprises to move on to conducting (3D print) business in a successful manner. Moreover, since intellectual property rights are territorial, the outcome in one country does not necessarily determine what is allowed in another.

There is not a singular approach to corporate intellectual property interests that would be affected by massive 3D printing involving society in many shapes and forms. For one, trademarks, copyrights, patents, and other IP rights are hard to compare. For another, there are good reasons to exercise rights, though not always. In the case of (suspected, alleged) 3D print infringement there would be those corporations who have their legal team dispatched in the blink of an eye. There would be others who refrain from taking legal action, perhaps because of the perception that their market is changing and that they themselves should change with it. Enforcing intellectual property rights when society – and first of all, the industry – is in the process of exploring and adopting 3D printing, involves certain risks of its own: alienating the people a company views as its customers or as its wider community of developers, and missing out on future possibilities of the technology as the threat of fines or legal action stifles social experiments and innovation.

There is a strong precedent to show restraint when it comes to combatting acts of unauthorized use of copies or unauthorized prints. 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’.

The point of the parallel being that for a corporation much might be gained by allowing, or at least not going against, a broad introduction and acceptance – and therefore: use – of 3D printing technology in society. There is no easy answer to how to deal with rights enforcement – there is hardly a point of having rights and not enforcing them. The answer seems to lie in alternative approaches, such as rigorously adapting business approaches to customer behavior and choosing the use of open source software over exclusive rights for reasons of technological advancement.

11.7.6 Managing an ‘ecosystem’ of outside developers

At the moment, it is still an open question what the traditional manufacturing industry will do towards reconciling their relative position of monopoly power that they get from intellectual property rights, on the one hand, and their growing belief in the advantages of co-operation with a wider community outside the company, on the other. Would such co-operation lead to a continuous conversation that does justice to the collaborative nature of science and innovation in 3D printing?

Owen, Bessant & Heintz have made the case for 'responsible innovation'.[63] This concept has different dimensions but one is a requirement for responsible companies to create a 'conversational space' where the company shares its expertise and some of its secrets with others in the community for mutual, or social benefit.[64] For example, a company may invite a community of designers and engineers outside the company to develop a solution to a particular problem, with mean of 3D printing. In turn it can share all necessary information about earlier tests it conducted, and allow the outside community to join the testing phase of the proposed solutions. The manufacturing industry can thus experience the value of a 'conversational space'. However, this would probably do little to change their hearts about claiming the resulting technology and designs as their intellectual property. In other words, others are allowed to join in, and they may get a reward, but only the company gets to benefit from the intellectual property.

When General Electric (GE) awarded prize money with the goal of having a light-weight jet engine bracket designed for 3D printing, it chose ten winning designs stipulating in the rules of the contest that those winners transfer all intellectual property that their design may contain or embody including all rights to any copyrights, design rights, and inventions.[65] GE thus claims the right to exploit the winning jet engine bracket designs, and yet they believe in the power of collaboration.[66] As Michael Idelchik, who runs advanced technologies research, says on the company website:

> "You need almost an artistic approach to design, the ability to model and analyze structures, and also the knowledge to pick the right materials and the correct manufacturing equipment. There is a lot that goes into the mix, and collaboration is the perfect tool for finding the best solution."[67]

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[63] Owen *et al.* 2013.
[64] *Cf. ibid.*, 260.
[65] See http://blog.grabcad.com/ge-terms-of-service/ and http://grabcad.com/challenges/general-electric-additive-manufacturing-engine-bracket-challenge. Last accessed on 20 February 2015.
[66] GE Reports 2013.
[67] Reference.

He also meant that his own colleagues within the company would not have found the winning solution in this short amount of time.

The question is what approach would be durable and rewarding both for GE and the collaborative ‘ecosystem’. What is a true ‘conversational space’? The spirit of co-operation between hundreds of engineers outside the company towards mutual goals of learning (about the 3D printing challenges and finding ways and solutions) and earning a living, is not best captured by a trade-off between prize money and a company’s exclusive control of the resulting designs and technology.

GE has already understood that 3D printing is more than just ‘a different way of making things’; it has experienced that 3D printing is a part of broader developments. It will likely involve the wider community more often. What it seemingly has yet to do is translating this insight in an inclusive approach that allows those who consider themselves part of the 3D printing community to remain partners of, and have access to, the designs and the technology for various purposes.

11.7.7 In essence

Several considerations regarding consumer protection and claims to ownership of collaborative design and technology demand the attention of in-house counsels and corporate management. We have not investigated appropriate business models, but we have argued that adapting one’s business approach to socio-technical change is to be preferred over heavy-handed enforcement of legal rights.

11.8 Framing the socio-technical changes: what governments can do

We now discuss actions governments can take to foster both consumer and enterprise 3D printing.

11.8.1 No need to be strongly involved…

Improving 3D printing technology and finding new applications requires little central control. Rather, they allow for lateral participation across society and collaboration across countries. As a result, possibilities for governments to steer developments are more limited. Society can explore, develop, and benefit, on its own accord; the government’s most important role is to try and mitigate, and where possible avoid, any adverse effects that get in the way of developments.

It has a duty to not just take the upsides of technology as the focal point, which tends to serve vested interests in the industry in the end, but also take into account the weakest players, which are, in this case, the new arrivals in the form of the many people, shops, networks, communities who explore the potential of the technology. Put differently, the unclassified, less organised, 'non-traditional' contributors to 3D printing technology and appliances, who participate in designing and engineering and who enjoy creative processes and entertainment, to the point that they share and exchange what they create, not necessarily showing their passports at the borders of intellectual property.

Some comparison can be made between how 3D print appliances are currently developed in society and the way in which encyclopaedia were democratized by Wikipedia not long ago (see section 11.3). Given a certain technology, people look for ways of using it for their own good. This is great from a democratic point of view but difficult to respect for governments, who fundamentally do not like the sense of disorder that arises from these developments and want to regulate instead, in the interests of one group of stakeholders or the other.

11.8.2 …Save for safeguarding and removing barriers

Another parallel has to be drawn with the developments of Internet technology and applications – and here we shift to a need for governments to actually be involved. In the realm of data generation and collection by multinational corporates, governments have been shockingly lax and late in regulating the uncontrolled commercialisation of private data. In the case of 3D printing, governments need to find ways to detect analogous exploitation of individuals early and will have to react swiftly in countering such exploitation.

Governments can also be expected to follow up on challenges with regard to the quality – particularly: safety – of 3D print products that reach the market. This principally regulatory issue was already elaborated in the previous section (11.7).

Lawmakers, scholars, and the judiciary are already considering the implications on the legal system. For example, patent laws may be unprepared for the fundamental shift in physical product sales and distribution that will likely occur as 3D printing by consumers (prosumers) becomes more widespread.[68] If so, increasing interest may be seen in keeping technology a 'trade secret' rather than making the technology public in exchange for the patent. This is a development that is not altogether positive or society, as trade secrets are by nature undisclosed.

[68] Brean 2013, 813.

Furthermore, though we have tended to stick to a continental European legal perspective in this chapter, we would like to mention here the expectation in the US that the flexibility of CAD designs may make it easy to produce a 'design-around' without changing the product's function, leading to a possible resurgence in (US) 'design patents'.[69] Relying on copyright protection in courts may therefore be on the increase with regard to aesthetically driven products.[70] This shift might have a negative impact on the development of creativity and innovation due to the long term of protection that copyright implies. In fact, it might actually warrant a significant shortening of that term of protection – the stakes are bound to be raised.

11.8.3 Restraint

Peacock warns against a hasty move towards 'artificial suppression' of 3D printing and labelling all 'unofficial' 3D printing as piracy.[71] As Peacock argues, the 'democratization of manufacturing' involves the creation of a new market for the dissemination and exploitation of ideas. It would be regrettable if legislators and the judiciary were to ignore the emergence of a new market force capable of, among others, recalibrating the costs of manufacturing.[72]

In other words, social developments that involve technological innovation have their benefits – the 'democratization of manufacturing' is an important one – but come at a price. The challenge is to allow change in society to run its course without interfering too much. The price, therefore, is restraint – both on the part of the authorities, who would perhaps normally be inclined to 'restore order' more swiftly, and on the part of the industry, where generally the right holders are who wish to protect their intellectual property.

That said, governments are typically in a position where they have the power to influence or at least respond to developments in society. They have various instruments at their disposal to meet these ends. Inform the public, facilitate networks, sponsor research, chair multi-stakeholder meetings, seek co-operation on this international topic with other governments and the European institutions, erect frameworks, nudge or direct the market towards

[69] Hornick & Roland 2013, 15.
[70] *Cf.* Brean 2013, 813.
[71] Peacock 2014.
[72] *Ibid.*, 1960.

standard-setting, if necessary adjust legal terminology in applicable laws. And then, or possible sooner, let developments run their course.

11.8.4 In essence

Governments are in a position where they can respond to market failure but when it comes to fostering both enterprise and consumer 3D printing they need to treat carefully in order not to stifle social developments all too soon. They have ample (policy) instruments at their disposal and they are not alone in crafting solutions for dilemmas that would occur.

11.9 Conclusion

Writing about the changes that the arrival of 3D printing will bring is somewhat akin to philosophizing about living on Mars. It will happen, but the how and when and the magnitude are not yet clear. This is not to say that we cannot frame the topic. For enterprises, for designers, engineers and developers, and for consumers, noticeable changes are expected. Some may anticipate those changes with a fear of losing market power, while others would want to take the changes as a starting point, and adjust their business approach.

Enterprises can capitalize on the realization that 3D printing produces the fruits of a networked society, where people – enterprises and the wider 3D print community – collaborate. A spirit of co-operation, however, raises difficult questions about competitive advantage and competition in general. Questions that do not only relate to 3D printing in its core technological sense but also to social developments related to the technological possibilities. For governments, the challenge lies in helping to create frameworks that allow for innovation in a broad, 'non-traditional' sense.

11.9.1 Summary of findings (sections 11.2-11.8)

When trying to conceive what a 3D print breakthrough would look like, we have argued that enterprise 3D printing is very likely to be added to existing production methods, and that in fact this development is underway. In addition, networked consumer technology for which businesses believe there is a market will be developed into enterprise applications. And finally, consumers introduce manufacturing capability where it did not exist before (section 11.2).

Experiences with music distribution, creating and curating encyclopedic content, and the production of fast-paced and well-informed news in our perception depict a social development that builds on the possibilities of digital and Internet technology. However, only when central control was reduced and individual and even (to an extent) idiosyncratic contribution was allowed, change started to affect the business models of incumbent industry. 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. The lesson we draw for change that would occur following 3D printing possibilities, is that when central control is reduced and individual and even idiosyncratic contribution is allowed, change will start to affect existing business models (section 11.3).

In addition, we expect that consumer 3D printing would develop into social fabrication. On a path parallel to traditional manufacturing society will explore, develop and use 3D printing applications through participation, collaboration and sharing. This change represents a possible realisation of a 'third wave' (section 11.4).

In part made possible by contemporary forms of co-operation between enterprise and non-enterprise partners, 3D printing will become a mainstream reality in the industry. When the point will be reached that the majority of enterprises adopts the technology for mass-production or massive small-batch production and to what extent depends mostly on past experiences, choice, and the inevitability of change (section 11.5).

3D printing as key enabler for distributed manufacturing – and other digital manufacturing technologies such as computer-controlled laser cutting and milling – is able to turn information into products. As a manufacturing technology it can easily be 'mutualised'. Therefore 3D printing fits well the mutual models of ownership. It is an essential ingredient for socio-technical developments that form the basis for lateral power structures, distributed control and networked society beyond the Internet in the physical realm (section 11.6).

Looking into the implications of a massive adoption of 3D printing in society – including, importantly, the industry – we have noted several considerations regarding consumer protection and claims to ownership of collaborative design and technology. As the parallel with changes in the digital music industry shows, adapting business to socio-technical change is to be preferred over heavy-handed enforcement of legal rights (section 11.7).

Finally, governments are in a position where they can respond to market failure but when it comes to fostering both enterprise and consumer 3D printing they need to treat carefully in order not to stifle social developments all too soon. They have ample policy instruments at their disposal and they are not alone in crafting solutions for dilemmas that would occur (section 11.8).

11.9.2 The new logic

We conclude our contribution to framing the outlook of 3D printing by expressing the new logic in keywords: social, distributed, lateral, coexistence of intellectual property rights and open source, and experimental-friendly framing.

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