3D Printing: Technology and Beyond

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Photo: Victor Flatvad

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3D PRINTING: MANUFACTURING DISRUPTION

Per Strömbäck

The digital revolution has been the domain of intangibles. Instant, cost-free, global distribution of data or perfect copies of anything that can be transformed into data means money, images, audio, video, text, and many other things travel without physical carriers.

Of course, the server computers, switches, routers, and cables that transport the data are still physical, but the ties between content and its distribution format has been cut. It is fair to say this is one of the most significant drivers of change in our society in recent decades. Nicholas Negroponte, the founder of the MIT Media Lab, famously coined the phrase "from atoms to bits" to describe the transformation of how information is distributed. With new manufacturing technologies like 3D printing – the focus of this report – physical objects become involved in this disruption. With 3D scanners, a physical object can be copied to a digital file, distributed via digital networks and replicated in a 3D printer. The copy will not be perfect (like digital images for example) but the quality comes close in many cases, and it is improving. A new object can be designed with 3D software and then printed in the same location, allowing for rapid prototyping, as well as niche, tailored and on-demand objects. 3D printers can print spare parts for themselves, even build themselves by printing some of their own parts. Large-scale printers using concrete can print buildings - these border on industrial robots.

3D printing has been a functioning technology since the 80's, but at the moment we are witnessing a paradigm shift that follows a familiar pattern of lower prices, simpler design, cheaper raw materials and increased volumes. While 3D printing technology has long been the domain of businesses, we are on the threshold of personal 3D printing. MakerBot – a 3D printer company – has a vision of a 3D printer in every home, an updated version of Microsoft's famous slogan of a PC in every home. 3D printers appear to be on a similar trajectory as photo printers. If this pattern is repeated, we are only a few years away from 3D printers in many homes, with low purchase prices (and mark-ups on raw materials), but also specialised services like local 3D print houses, much like the digital print shops that exist in most cities today, offering swift professional print jobs. But the personal photo printers also led to a market disruption where most photo development labs lost their businesses. Manufacturing used to be the domain of large companies with big investments in tools, machines and plants. 3D printing technology promises cheap local manufacturing, an opportunity for businesses, a challenge to certain industries and, in some cases, a threat to society.

Yes, a threat – for example to the issue of gun control. In Europe, there is profound support for strict laws on gun distribution. But there are already designs for 3D printed guns in circulation: Defense Distributed, a not-for profit organisation based in Texas, has made it its mission to "democratize" access to fire arms through 3D printing technology. In May 2013, the first ever gun printed in 3D fired a live round. Other threats include trademark and patent infringement, similar to the copyright challenges in file-sharing that the culture industries has struggled with, but also consumer rights and protection issues: who is responsible if someone is injured by a 3D printed product? The designer? The owner of the printer? The maker of the printer? The trademark system is to a large extent a consumer protection system, but widespread personal 3D printing challenges its current structures and functions.

Beyond the buzzwords are some real policy challenges. This report is Netopia's contribution to the conversation.

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Per Strömbäck
Editor Netopia

3D PRINTING: TECHNOLOGIES AND ISSUES

Mathilde Berchon

In the space of a few years, 3D printing has passed from the status of a tool for rapid industrial prototyping to becoming a superstar in the hopes of the "New Industrial Revolution".

For the first time in the history of manufacturing techniques, a compact and inexpensive machine allows objects to be produced on demand directly from a digital file. Interest from the public is such that platforms for sharing object files are springing up all over the Internet, and the concept is gradually gaining ground in a world where consumers are becoming designers of the world around them.

A 3D printer in every home?

The arrival of open-source personal 3D printers developed by a large international community of enthusiasts has profoundly transformed expectations in relation to this technology, which for a long time was the exclusive province of industry. These new devices take advantage of the progressive expiry of patents filed during the 1980s, and new models are expected to appear in the months ahead.

At the same time, certain industrial players have been profoundly affected by the arrival of 3D printing, which they no longer use only for rapid prototyping but now also for the direct production of everyday objects. These products are made to measure, on demand. 3D printing brings mass customisation to the consumer society, and brings with it new, local and personalised distribution models.

A new order of objects?

This also prompts us to ask questions about the actual status of the objects around us. With 3D printing, objects can be downloaded and adapted, leading to the birth of a new order of open and connected objects.

3D-printed objects are taking on forms that it was not possible to achieve in the past. They are more complex, lighter, better optimised and more environment-friendly. Industrial designers and engineers are forced to abandon traditional ways of creating objects and think of new methods that take account of the nature of 3D printing.

Is 3D printing about to disrupt traditional production methods and give rise to a new order of objects?

Many major players in technology and mass distribution are positioning themselves to accept and encourage the arrival of 3D printing. Last August, Microsoft announced the integration of automated processing of 3D printer files into Windows 8. UPS now offers a 3D printing service in some distribution centres in the US. Amazon has added 3D printers and materials to its online catalogue.

3D printing is growing fast

Some governments have decided to give significant support to additive manufacturing (formal terminology for 3D printing in some circles – editor's note) . In his State of the Union address, US President Barack Obama announced that 3D printing had the potential "to revolutionise the way we make almost everything"[1], as he launched the National Additive Manufacturing Innovation Institute with funding of USD 30 million. The UK government is promoting 3D printing with a GBP 14.7 million package for projects by innovative enterprises utilising this technology.[2] Singapore has announced that it will invest USD 500 million over the next five years in the development of 3D printing.[3]

Sales are progressing rapidly. Industry analyst Wohlers Associates reports that sales of personal 3D printers increased by 346% between 2008 and 2011. According to research by Gartner, sales of sub-USD 100 3D printers will increase by 49% in 2013, representing a total of 56,507 units sold. For 2014, continuing growth is estimated at 75%, with more than 98,000 units sold, and this figure is expected to double in 2015. Global expenditure on 3D printing is estimated at USD

412 million in 2013, an increase of 43% over 2012, with approximately USD 325 million spent by companies and USD 87 million by individuals. Expenditure is expected to continue growing in 2014, with an estimated increase of 62%.[4]

3D printing holds a great deal of promise – but all too often this still depends on ignoring the current realities of the state of additive manufacturing technology. The materials available are still limited, the costs remain high, and access to object files is not yet widespread. However, the players are setting in motion numerous initiatives to overcome these limitations, and innovations in this field are exponential.

What can 3D printing be used for today?

Before exploring the changes in society brought about by 3D printing, it is important to have a clear picture of the state of the art in additive manufacturing technology, a world of rich and complex possibilities.

3D printing is not a single technology but a combination of technologies, developed since the mid-1980s. These are known as "additive manufacturing". Unlike traditional manufacturing, which generally involves progressive removal or deformation of material (drilling, cutting, bending), 3D printing works by successively adding material, one layer after another.

The base material can be plastic, metal, sand, etc. It is deposited a little at a time on a horizontal surface called the build bed or build plate. The print head moves on the vertical axis to successively form all the layers of the object. Loss of material is therefore minimal, and innovative shapes – including cavities or gears, for example – are possible.

3D printers are digitally controlled machines. Before anything can be printed, it is therefore necessary to have a 3D file which models the object to be produced. A 3D file can be created using 3D modelling software. It can also be created using a 3D scanner, which copies an object that already exists. In addition, there are many online marketplaces and catalogues where 3D object files can be obtained and modified. The standard file format is .stl.

3D printing is organised around three main families of technologies, each with its own specific advantages and limitations.

Precise technologies that allow mass personalisation

Using light to solidify material

The first family of technologies uses light to solidify a liquid. Stereolithography is the oldest technique and also the most precise. It was patented in 1984 by Chuck Hull, an American engineer who now heads 3D Systems, the largest company in the world specialising in 3D printing. Stereolithography utilises an ultraviolet laser beam that passes incrementally over the build bed and solidifies the liquid polymer layer by layer. The base material used is generally resin.

A number of variants of this technique of exposing a liquid polymer to light have been developed by other manufacturers. Digital Light Processing (DLP) uses the light from a high-definition projector chip. It is used by companies including EnvisionTEC, which is renowned for the great precision of its printing, in the order of 15 µm per layer. And Objet, now part of Stratasys, the other giant of 3D printing, specialises in multi-material 3D printing, having developed its PolyJet technology, capable of printing several plastics with different properties (flexible, transparent, heat-resistant, etc.) for the same object, during the same printing session.

Understanding print quality

There are several important points to take into account when estimating the quality of 3D printing. The resolution corresponds to the density of material on a point on the x and y axes, and sometimes also the z axis, and is expressed in dpi. Layer thickness is calculated in microns or millimetres; this is very important for the final surface rendering and the quality of the detail.

Stereolithography, DLP and PolyJet are ideal for producing high-quality prototypes which reproduce the functionality of the object to match the vision of the engineer or designer as closely as possible. They are often used in the design studios and R&D laboratories of large consumer goods companies.

Industrial sectors already transformed by 3D printing

Some industries have already been completely transformed by 3D printing. Manufacturers of dental products, luxury jewellery and hearing aids have seen their financial models profoundly transformed by the use of 3D printing. They generally use stereolithographic or DLP 3D printers which allow extremely high-precision printing. For example, manufacturers have developed specialist 3D printers for the dental industry. The film industry also generally uses Objet's PolyJet technology to produce special effects and accessories.

A young start-up originating from MIT in Boston is now set to revolutionise the world of stereolithography. FormLabs raised almost USD 3 million on the crowdfunding site Kickstarter in October 2012. The company offers a stereolithographic 3D printer for USD 3,300 aimed at designers and businesses.

Versatile powder-based 3D printing

Laser sintering and production of finished objects

A second family of technologies utilises the fusing or progressive binding of powder granules. Known as Selective Laser Sintering (SLS), this is a very widely-used 3D printing technique. These machines use light to fuse powder granules, one layer at a time. SLS is the preferred technique used by architectural firms to produce models, by artists and designers for creating complex sculptures, and in the fashion industry to produce made-to-measure items (e.g. hats, knitwear).

It is also being used increasingly to produce finished items, as it is well suited to the production of boxes, phone casings, mechanisms, connectors, etc. Objects produced using SLS are solid and slightly flexible. They can contain moving, interlaced and embedded parts. The items are white when they come out of the machine. They need to be dusted off, and then different types of finish can be applied, e.g. by painting or spraying.

Laser sintering machines are large and cost hundreds of thousands of euros. They are mainly found in the R&D departments of large companies and at certain manufacturing locations. However, it is possible to have access to this technology through online 3D printing services aimed both at individuals and professional customers: Sculpteo, Shapeways, Ponoko, i.materialise, etc. These services print users' 3D files on demand and then post the object to the user within a period of between three days and several weeks.

Printing metal in 3D

Powder sintering has the advantage of offering a very wide choice of materials that can be printed. Any material that can be reduced to a homogenous powder can be considered for use in printing. Thus, metal can be printed in 3D. Titanium, cobalt-chrome, stainless steel, tool steel, and also gold, silver, bronze and platinum can be printed on special machines which use techniques similar to laser sintering but with much more powerful laser beams. In Direct Metal Laser Sintering (DMLS), the metal powder is exposed to a 200 Watt fibre-optic laser, producing a layer thickness of 20 µm. The E-Beam (Electron Beam Melting) process developed by Arcam in Sweden uses an electron beam which fuses the powder in a vacuum chamber at temperatures of between 700 and 1,000 °C. NASA has developed a variant of this procedure called EBF^3 or EBDM (Electron Beam Direct Manufacturing) to allow 3D printing of metal in zero-gravity environments.

Using these techniques, powder which has not been fused can be partially reused for subsequent printing, which allows a massive reduction in loss of materials – a major advantage, bearing in mind the very high cost of these metals. For example, Boeing uses 3D printing to produce certain turbine parts for its aircraft. In the past, when produced by subtractive manufacturing, these parts required the creation of special tools, and the long and complex assembly of more than ten components. Now they are 3D-printed in titanium, in a single operation. They no longer require tools or assembly, and the loss of material inherent in the previous procedure is now virtually non-existent. 3D printing has allowed a significant reduction in costs at each step of the production chain. The part has also been redesigned, taking into account the possibilities offered by 3D printing. It is more ergonomic and thus enables a reduction in fuel costs on each flight. General Electric is investing in 3D printing for the production of parts to be incorporated in its LEAP jet engines by the end of 2015 or early 2016.[5]

Often used by architects to create models, laser-sintering 3D printing can also be used when it comes to actual construction. The Italian engineer Enrico Dini invented the D-Shape technique, which allows printing using coral, sand or concrete. His system uses a procedure similar to laser sintering, fusing the particles of the material on a large scale.

Colour 3D printing and its applications

In the same family of powder bonding techniques, 3DP is a technique developed at MIT; the exploitation rights were sold to several companies in 1995. The 3D printers made by Z Corporation, today owned by 3D Systems, use this technique, which consists of bonding the powder granules of a composite material, layer by layer, by depositing minuscule drops of glue. The advantages of 3DP are the speed of printing – one of the fastest on the market – and the ability to print in colour. The print head on the most advanced model, ProJet X60, is capable of injecting more than 390,000 colours. The texture obtained is rough and slightly sandy. 3DP printed objects are brittle and fragile. They are ideal for scientific presentations, showing a visual prototype, creating models or figurines, but it would be difficult to consider using 3DP for the production of finished articles for everyday use.

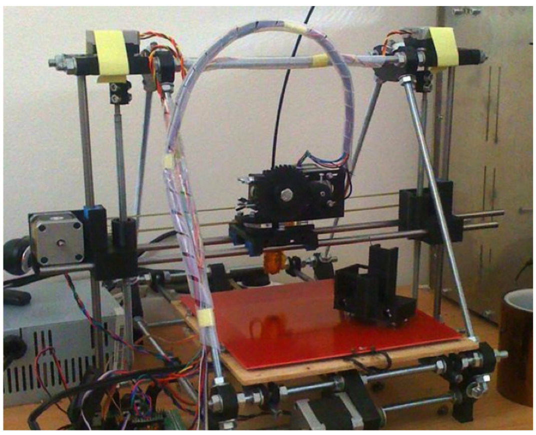
Fused deposition modelling – the advent of personal 3D printing

The success of 3D printing has brought one technique in particular to the forefront: fused deposition modelling (FDM). This technique is used in the majority of personal 3D printers, which are still often supplied in kit form for self-assembly. It uses a plastic filament – ABS or PLA – in a heated extrusion nozzle. The nozzle moves horizontally and draws the desired object on the build bed. It then rises on the vertical axis and deposits the second layer of the object, and so on until the whole object has been produced. FDM is one of the least precise 3D printing techniques, but it does have many advantages: low cost, ease of use, very compact machines, ease of repair. This technique, originally patented by Stratasys, has become the emblem of mass 3D printing; this is primarily due to the arrival of open source hardware.

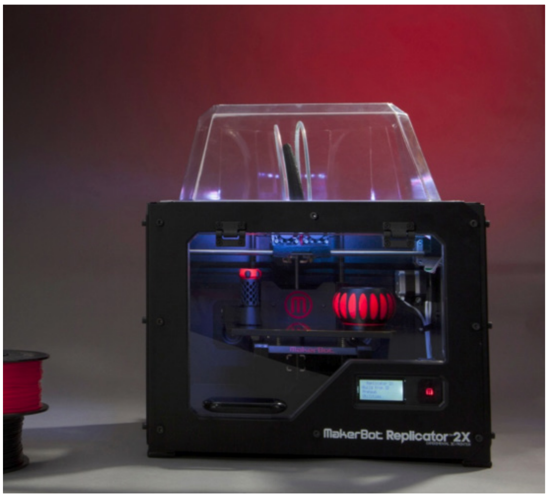
The RepRap project – the arrival of personal 3D printing

In 2005, Adrian Bowyer, a researcher at the University of Bath in the UK, had the idea of imagining a machine capable of replicating itself by 3D-printing many of its own parts. He developed RepRap Darwin, the first open source 3D printer: all the documentation is shared online (diagrams, components, configuration), released under a GNU/GPL licence, like open source software. All users are free to reproduce, adapt and even sell it. A large international community of enthusiasts is growing rapidly around this project, and hundreds of variants have already been created.

The RepRap Prusa Mendel, named after its contributor Josef Prusa, is one of the most popular. Users meet at production locations like “hackerspaces” – places where IT enthusiasts meet to learn and create together – and build their own 3D printers. In 2009, at the NYC Resistor hackerspace in New York, a group of friends adapted and improved their RepRap to create a new variant, which they called MakerBot Cupcake. They decided to sell their model in the form of a self-assembly kit. The MakerBot has proved very popular with designers, engineers and experienced DIY enthusiasts. A company called MakerBot Industries has been set up, and its vision is for a 3D printer in every home. Many other commercial projects have been derived from the RepRap project, including Ultimaker, Printrbot, Solidoodle, Bits from Bytes and Cube.



RepRap Prusa Mendel. Source: RepRap.



MakerMakerBot Replicator 2X, with two reels of plastic filament. Source: MakerBot Industries.

3D-printed kidney, ear and finger. Source: Wake Forest Institute for Regenerative Medicine.

Robohand, an open-source robotic hand that can be downloaded and adapted. Source: Robohand on Thingiverse.

Advanced uses of 3D printing

3D printing by depositing successive layers of material is not limited to plastic. Using the same principle of a print head which extrudes the material and deposits it on a plate, researchers have developed 3D printers capable of printing living cells. The 3D printers made by Organovo can print human tissue for use in pharmaceutical research. The cells are contained in a syringe which moves along the horizontal axis and deposits the cells in a gel which is printed simultaneously.

The Wake Forest Institute for Regenerative Medicine, headed by Professor Anthony Atala, has gained a reputation for its work on the 3D printing of human organs for regenerative medical applications. The prototypes presented so far show the realisation of a kidney, an ear, and the bone of a hand. However, these organs are not viable in their present state, so they are not yet suitable for transplants. One of the major challenges is the degree of precision required of the printing to enable reproduction of the networks of veins, arteries and capillaries that make the organ live. The principle of syringe depositing is also used with foodstuffs. Cheese, pizza dough and chocolate, for example, can be deposited layer by layer to produce an edible product. There are also alternative 3D printing techniques, such as Laminated Object Manufacturing (LOM), which uses layers of paper successively glued together and cut to shape.

A new order of objects

Technological progress and easier access to 3D printing are bringing about a change in consumer behaviour. New applications are being discovered, along with new challenges.

3D printing holds a great deal of promise, encouraged by the media and certain players in the industry. It is heralded as the solution to industrial decline – the way forward to a world where mass production can be replaced by objects produced locally on demand by the end-user. Individuals would create and directly produce the objects around them, fully customised according to their particular needs.

Power to the consumer

Individual users would then be capable of producing their own objects on demand, and of improving and transforming the objects around them. Sometimes called "artisan 2.0", the owner of a 3D printer is viewed as a consumer-actor in his or her physical environment. We are seeing more and more co-creation – collaboration between designers and users, the idea being to guide the end-user by means of a customisation tool devised by the designer.

The modelling stage still remains the main obstacle to mass adoption of 3D printing. Today there are several different ways of obtaining a 3D file: create a model using 3D modelling software, scan an object with a 3D scanner, or download and adapt an existing 3D file from

Demonstration of the 3D Structure Sensor scanner connected to an iPad. Source: Occipital.

a catalogue. The first method offers the most freedom, but it is also the most complex. Users who are not already familiar with a professional modelling application like Catia, Solidworks or Blender can now turn to simpler tools which can be used directly online and free of charge, like SketchUp, Tinkercad and 123D. Scanning your environment to model objects in 3D, modify them and then reproduce them with your 3D printer is possible today, subject to availability of the material and the printing capacity of the machine. Microsoft's Kinect motion sensor is used in many home 3D scanner projects. Others are based on devices for smartphones and tablets, like the Structure Sensor project of Californian start-up Occipital, which raised almost one million US dollars on the Kickstarter funding platform in October 2013.

The number of online catalogues of 3D files is growing. The most popular site, Thingiverse, created by MakerBot–Stratasys, has hundreds of thousands of objects available for download. There are more than 40 marketplaces dedicated to 3D printer files. Some are offered by online 3D printing services (Shapeways, i.materialise, Ponoko, Sculpteo), others by the manufacturers themselves (Thingiverse, Cube), others again by the online modelling solution providers (Autodesk 123D, Tinkercad, etc.), while still others are independent (CubeHero, Layer by Layer, 3D Burrito, Azavy, Modelyst). On these sites, designers can offer their designs free of charge or for sale; the site will typically retain a commission of between 5 and 7%.[6] The rapid drop in the cost of the devices is one of the most important factors in the adoption of 3D printing by individual users. It is now possible for an individual to buy a personal 3D printer for about EUR 300. These models, although basic, make it possible to rapidly produce small-sized plastic objects. Collaborative funding sites like Kickstarter and IndieGoGo in the US make it easier to launch new printers with direct backing from the public. One of the most recent projects, Peachy, is a 3D printer priced at USD 100 that transforms 3D files into sounds generated by the computer, which are then used to solidify a liquid polymer.

New materials, new challenges

3D printing is moving progressively from prototyping to manufacturing in some industrial sectors, but the technical limitations are a restraining factor. The materials are one of the main areas of research in additive manufacturing, in particular the capacity of the devices to print using more durable or more innovative materials like resin and ABS.
Metal 3D printing is one of the most advanced fields of experimentation, but some laboratories are also focusing on the development of machines that can print electronics in 3D. For example, at Stanford, a group of students have developed a RepRap capable of printing conductive ink using conventional plastic 3D printing. At the MIT Media Lab, the Mediated Matter research group[7] headed by Neri Oxman is experimenting, among other things, with "4D" materials. These are "intelligent" materials which, like skin, for example, are capable of adapting to their environment. An object printed in this type of material could, for example, reinforce itself or become more flexible or more resistant in places, depending on the physical constraints around it.

Mediated Matter is also experimenting with large-scale 3D printing, which is still one of the weak points in 3D printing technology. Most of the objects around us cannot be produced as a single piece by 3D printing, as the printing volume of existing machines is very limited. The German manufacturer Voxeljet specialises in large-format industrial 3D printers. Its VX4000 model has a print volume of 4 x 2 x 1 m, which represents about eight times the average volume of other machines. This is still one of the exceptions. Falling device prices, a wider variety of available materials and increasingly easy access to 3D object files are the three influential factors leading to the increasingly widespread adoption of 3D printing by individual consumers. For companies, growth is primarily due to the new possibilities for shapes, reduced production costs, and the possibility of moving towards mass customisation. Techniques are being improved, and 3D-printed objects are increasingly being optimised and made more complex.

LEGAL ASPECTS OF 3D PRINTING

Christina Wainikka

Abstract
The use of 3D printing technology may challenge several sets of legal rules since these rules are based on paradigms that 3D printing throws overboard. It is important for policymakers to discuss these issues as soon as possible since the legal framework may otherwise become obsolete.

This text highlights several issues, namely: legal rules on copying; legal rules on quality; and legal rules on marketing and sales. Our conclusion is that a first step for policymakers should be to compile an inventory of legal rules that are, or could be, affected by the use of 3D printers.

Technological development calls for legal development
Technological development tends to change the paradigms on which legal rules are based. This has been seen several times in history, from Gutenberg to the IT revolution. 3D printing may challenge the status quo, like the spinning jenny once did. The new possibilities created by 3D printing may challenge various sets of legal rules, in the same way the digital revolution challenged copyright.

3D printers as a challenge to legal paradigms
Legal rules are created based on a certain view of reality, including what is technologically possible. 3D printers create new possibilities. As a consequence, the foundation of the legal rules is altered.

These challenges can be dealt with in different ways. Throughout history, we have seen legislators handle challenges by prohibiting the use of new technology - a strategy that has often failed. We have also seen policymakers and legislators claim that new technology does not actually call for changes in legislation[8]. That strategy may function for a while, but sooner or later legislators have to face the need for adaptation.

Call for an "inventory"
In this text, I highlight some of the challenges that the law faces from the use of 3D printers. This should not be regarded as an inventory of all challenges - the aim is just to provide some examples of what policymakers and legislators could/should be aware of.

Our focus is on three different sets of legal rules: legal rules on copying; legal rules on quality; and legal rules on marketing and sales. These rules all deal with questions regarding rights and origin, something that the use of 3D printers may challenge.

The main conclusion is that the challenges to different legal rules from the use of 3D printing will soon become reality[9]. The use of 3D printers is already here, and different users may soon see the need to sidestep the law to make the most of its technological potential[10].

3D printers may lead to innovations that are greatly needed to achieve the aims of Horizon 2020, the EU Framework Programme for Research and Innovation[11]. It is important to eliminate legal obstacles to this development. The first crucial step should be to compile a proper inventory of the legal rules that are challenged by the use of 3D printers. This document only presents a short overview.

It is important that policymakers and legislators start to discuss the changes that are necessary.

A need to change rules on copying

The different intellectual property rights (IPRs) contain several rules on copying. One right even has the name "copyright". It is interesting that these rules on copying were created in a time when copying was difficult and when copies did not have the same quality as the original.

The ability to make digital copies has led to new rules of copyright. For example, the INFOSOC directive contains rules intended to harmonise rules on private copying[12]. The implementation of these rules has created new tasks for collecting societies, which collect money to distribute to rights holders in order to compensate for copying. The European Commission has also concerned itself with easier licensing of copyright-protected works[13].

3D printing makes it possible to create new kinds of copies[14]. Traditionally, we have seen that digital technology makes it possible to produce very high quality copies of two-dimensional works, as well as of, for example, musical works. 3D printing makes it possible to produce copies of three-dimensional works, such as sculptures or other works of applied art. The system for collecting money to share with the rights holders may also function very well for these works, but the systems are not yet developed. This should be a concern for policymakers.

An IPR copyright is concerned with all types of copying, whereas other IPRs are concerned mainly with industrial copying. IPRs such as trademarks, patents and designs focus on professional use, and copying done at home has not been considered a concern[15]. The belief is that this kind of copying does not significantly affect the rights holder's ability to commercialise and generate income to compensate for investment made in R&D and/or a design process.
However, 3D printing may make it necessary to reconsider this type of copying. 3D printing may make it possible for consumers to copy products that are protected by IPR, enabling them to do so without paying anything to the rights holder. In, for example, the rules on community design, this copying is explicitly permitted under art. 20 of the Regulation.

The consequences of this kind of copying are something that should be considered by policymakers. On the one hand, a solution could be to prohibit all private copying, as has been done in some countries when it comes to copyright. On the other hand, this could lead to other consequences, as we have seen in the field of copyright.

A solution could perhaps be to have a system whereby vendors of 3D printers pay a fee for each printer. This solution does, however, require collecting societies and there are no real collecting societies in the field of industrial rights.

These are just some examples of what could be considered when it comes to legal rules on copying and 3D printing.

A need to discuss rules on quality

There are several sets of rules concerning the quality of goods, and the use of 3D printers may challenge some of these. Two sets of rules on quality that could be considered are trademark law and the rules on product safety.

Trademark protection within the European Union has been harmonised through directives, and there is also a community trademark[16]. Trademarks can consist of several things, including three-dimensional designs.

Trademark protection has several motives, with one being that a trademark functions as a warranty for the customer; the customer can rely on the trademark and know what to expect. The rights holder of a trademark has the exclusive right to use that trademark. That right, however, does not hinder the resale of a product, as long as it is sold with the permission of the rights holder.

A 3D printer could create "sort of" originals that are protected as trademarks. If these copies are made with the permission of the rights holder it would probably be possible to resell them, due to the rules on exhaustion of rights[17].

However, if the rights holder has not given permission, a privately made copy would probably still be allowed, but could not be sold to someone else. This would not be a problem as long as the item is still owned by people aware of the fact that it is printed on a 3D printer. A secondary issue is whether this sale only applies to the person making the copy. Could a chair printed by a grandmother be inherited? And if so, could the grandchild sell it?
Policymakers should consider whether existing rules are suited for the future. Printing will happen; the sale of printed goods will happen. Policymakers should set up a reasonable framework. A reasonable framework will, of course, have to balance the interests of the rights holders, competitors and consumers. It is important to have a framework that allows new markets to grow. If printed goods become common then it would be harmful if they were not permitted to circulate on a market.

Product safety is important. It is crucial that consumers can rely on the safety of the products they buy, and there are both directives and standards in this area[18]. These rules concern not only the safety itself, but also the responsibilities if something happens. The distribution of responsibilities is a key issue in the General Principle Directive.

The use of 3D printers may challenge these rules. Imagine, for example, that somebody prints a product. This product could be a toy. If this toy is not safe and a child is hurt then someone has to be responsible. The directive's definitions in art. 2 and the responsibilities in art. 3 are not aligned with the possibilities of 3D printing. Who should be responsible? Should it be the designer? The company selling the materials? The company selling the 3D printer? Should it be the consumer who made the actual toy by using the 3D printer? This is not evident and should be discussed by policymakers. It could challenge how the rules on product safety currently distribute responsibility.

A need to develop legal rules on marketing and sales

Rules on marketing have been harmonised within the European Union[19]. These harmonised rules include rules on commercial origin, art. 6. A customer who is given the impression that a product has a certain commercial origin should be able to rely on that impression.

The use of 3D printers may make it possible to print and sell something that has a different commercial origin. Consumers may be misled into buying products that they think have a certain commercial origin but that are, in fact, printed.

The current legislation could be used to handle this kind of misrepresentation. However, if it is considered that this kind of sale should be allowed, policymakers must make sure that 3D printed goods can also be sold.

The time to act is now!

The examples presented in this text are just some of the challenges that may be created as a consequence of the expanding use of 3D printers. Since the use of 3D printers is still quite limited, its consequences remain, to a large extent, unknown. However, they are rapidly growing in popularity. It is time that policymakers - and legislators - are made aware of this issue.

Challenges will probably first develop in intellectual property rights. The use of 3D printers may shake several of the industrial rights in a way similar to how copyright law has been challenged in recent decades.

Policymakers and legislators must realise that it is their responsibility to study any potential legal challenges. They should not take it lightly.

THE PHILOSOPHY OF 3D PRINTING

Waldemar Ingdahl

The promise of abundance

The promise of the internet revolution was to provide all people with all knowledge. The promise of the 3D printer revolution is to provide all people with all material goods. Visions abound of limitless replication – printed machine components, clothes, musical instruments and even body parts.

A 3D printer can be programmed to make multiple versions of a basic product. It is not necessary to retool an entire line of machines to change production. Complex designs can be made while wasting less material. Chris Anderson, former editor at Wired magazine, sees printers democratising innovation. It is easier to invent something new when using powerful software, sharing designs over the internet and producing wherever convenient.

Nicholas Negroponte discussed the blurring of bits and atoms in his 1995 book Being Digital. All forms of information made up of atoms would eventually be transformed into bits, he claimed. With information being fully transferrable, specialised devices would converge into multipurpose tools. The smartphone is a good example of Negroponte's scenario since it functions as a computer, a video player, an MP3 player, a camera, a calculator, a notebook and, of course, as a telephone. Negroponte also foresaw that bytes would bridge the divide to biology, with a convergence of the synthetic and the natural. Printing flesh. Will we be able to print living human beings?

Technological determinism

German philosopher Martin Heidegger stressed that humanity is not in charge of technology, but that technology shapes humanity through forming our world view. The essence of technology is to frame the world and to it make quantifiable, rationalised and destructively instrumental, he believed. It might seem strange that the thoughts of such an anti-humanist philosopher, filled with agrarian nostalgia, have had such an impact on the philosophy of technology, but his technological determinism has remained.

3D printing is becoming increasingly productive, affordable and accessible, but it is not a particularly new line of technology. Computer Numerical Control (CNC) systems have been used in manufacturing since the 1950s, controlling lathes, milling machines and laser cutters. In modern CNC systems, end-to-end component design is highly automated, using computer-aided design and computer-aided manufacturing programs. The 3D printer works on the same principle. The capability of 3D printing that stands out is its ability to make anything, regardless of the complexity of form. Whereas 3D printers can print the most intricate or simple shapes with equal ease, traditional techniques struggle with geometrical complexity.

Before the Apple II was introduced, a PC was just an expensive calculator. The Apple II was simpler to use, and added games. Nice, but computing still needed a 'killer app'. VisiCalc was the first spread-sheet computer program, and turned home computing from a hobby into a business tool.

Although 3D printing may be unhindered by complexity, volume and speed are a constraint in manufacturing. Cost, time and the materials required increase exponentially to the third power. The most important progress so far has been in reducing the cost of building prototypes for engineers. Now the technology needs to shift from printing prototypes to limited production.

Technology is not neutral

Philosopher Michael Polanyi saw knowledge, creativity and technology as charged with strong personal sentiments and ideas. He argued against the position that technology is value-free. The use of technology is best seen as a process of negotiations, a "marketplace of ideas". In fact, tacit knowledge such as guesses, hunches and personal visions are as decisive as informed, committed actions in determining how a specific technology will be applied.

When microwave ovens became popular in the 1980s, they were predicted to replace all forms of cooking. A similar adoption of 3D printing would not replace industrial manufacturing, but would rather be a complement. The choice of how a technology will work is ours to make.

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16. Regulation EC No 40/94 on the Community trademark.
17. For the community trademark, see art. 13 of the Regulation.
18. See the General Product Safety Directive, 2001/95/EC. The Directive itself gives reference to the use of standards to handle questions of product safety, see http://ec.europa.eu/consumers/safety/prod_legis/
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