3D PRINTING AND ADDITIVE MANUFACTURING – THE IMPLICATIONS FOR OSH

Introduction

This article on 3D printing has been undertaken on behalf of the European Agency for Safety and Health at Work (EU-OSHA). It examines some key questions concerning the opportunities and challenges of the emerging 3D printing industry for employers, workers and the new entrepreneur, who is working from home or informal workspaces. The aim of this discussion paper is to introduce 3D printing and explore its possible impact on both the existing and the new working environment. Finally, some recommendations will be given at European level as to what measures can be taken to ensure that 3D printing benefits a more safe, healthy and fulfilling work environment, in the context of both the existing employer-worker relationship and the new, informal 'self-entrepreneur'.

What is 3D printing?

3D printing is the buzzword in innovation and the creative industry. But what it is, exactly, remains unclear to the general public. Additive manufacturing, desktop producing, rapid prototyping, digital fabrication — there are different names for this new technology.[1] As a result of the fully computerised process of designing and manufacturing products, 3D printing is part of the bigger development of digital fabrication.[2] However, using '3D printing' as an umbrella term for a wide range of new digital production — such as CNC (computer numerical control) milling machines, laser cutters, computerised steel plotters and so on — is misleading. For example, CNC is a traditional technique of milling, but the movements of the machine are controlled digitally. Though they all offer the same amount of freedom in forms and uniqueness, most digital fabrication is based on subtracting material from a solid by milling, sawing or cutting. With 3D printing, a product is built from scratch by adding material. The most concise description, therefore, would be additive manufacturing.[3] In future these two digital techniques (subtracting and adding) will be used flexibly: a CNC machine and robotics can easily be transformed from subtractive to additive production, simply by changing the head.

In this article, the expression '3D printing' will be limited to different techniques in manufacturing products that exist only as a computer file by the use of a machine that adds raw materials in layers until a finished product is shaped.[4] This starts with the design of a product on a computer. The document of this computer-aided design (a CAD file) is basically nothing more than an elaborate print order.

How it works

The computer-generated design is digitally divided into thousands of layers; this slicing is done with software that prepares a design for a print order. Another way a digital printing file of a product can be made is by making a 3D scan of an existing object. This data can be transformed into a print order with special software. These scanners can cost anywhere between €50 and €50,000. A desktop 3D printer will cost around €1,000.

1 https://3dprint.com/82272/what-3d-printing-works/
2 http://www.wired.co.uk/article/digital-fabrication
3 https://3dprint.com/82272/what-3d-printing-works/
4 http://additivemanufacturing.com/basics/

A professional 3D printer for prototyping and limited-edition production will cost anywhere between €2,000 and €20,000. When existing large-scale production is to be replaced by 3D printing, it will require investments in the region of €1 million or even more.

The actual 3D printing technique can be divided into two different technical processes. The impacts they will have on the future of designing, making and distributing goods are also different: the binding technique is used in the highly advanced professional industry whereas the extrusion technique is rougher and is commonly used in the consumer market and bottom-up experiments in 3D printing.[5]

Binding

The binding technique uses a print head (equipped with a laser, an ultraviolet (UV) beamer, a heater, and so on) to bind a synthetic material that is sprayed out. The quality is better and a wider variety of materials can be used. It also demands a higher degree of knowledge and precision, and is more costly. These 3D printers are more expensive and so are the materials used. Binding is therefore mostly used in highly advanced and (semi-)industrial processes.

Extrusion

The extrusion technique involves binding material that is extruded in an exact choreography of time and space. This is the most common process used by open-source and consumer-friendly 3D printers, which usually come as a plywood building kit (for example, Makerbot, Ultimaker, Airwolf). The extruded material can be a liquid, powder, synthetic filament or organic material such as ceramics or rubber. Many of these printers are sold as a do-it-yourself kit. Production is faster and cheaper, but the final product is less refined.

Old and new material

The first materials applied in 3D printing were synthetic plastics. The number of materials that can be used with 3D printers have increased a lot in the past 10 years. Now ‘traditional’ materials such as ceramics, steel, glass and even wood are also widely used. Research has shown that desktop 3D printers can pose risks of emitting large numbers of ultrafine particles (UFPs; particles less than 100 nm) and some hazardous volatile organic compounds (VOCs) during printing, although very few filament and 3D printer combinations have been tested to date.[6]

The materials used in 3D printing in an industrial context differ from those used in a home environment. In the latter, the most commonly used materials are the biodegradable polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS), an oil-based plastic and therefore more toxic in use. Ventilation is recommended with PLA and necessary with ABS.[7]

Most commonly used in the industrial 3D printing process is polyamide (e.g. nylon) in liquid as well as in powder form; it is an oil-based plastic. During heating, toxic fumes are released and therefore ventilation is needed. Or, even better enclosing the printer to prevent emissions from spreading to the air in the workplace.

Plastic chemicals, such as epoxy resins, are being utilised in stereolithography as well as for surface treatment of printed objects. These may cause allergic contact dermatitis. Uncured plastic chemicals are not to be touched and contamination of surfaces and clothes must be prevented. Other chemicals

5 http://3dprinting.com/what-is-3d-printing/

6 http://pubs.acs.org/doi/abs/10.1021/acs.est.5b04983

7 https://all3dp.com/pla-abs-3d-printer-filaments-compared/

that are used for post-processing and surface treatment may also be hazardous and should be handled with car

Polyamide in powder form is sometimes mixed with aluminium (alumide); though less toxic, the use of

this material still needs special prevention measures in safety and health. Other industrially applied materials are polysulfon (PSU) and polyfenylsulfon (PPSU), which are both synthetic plastics that require safety measures in terms of ventilation and handling.[8] The fastest-growing segment in 3D printing is the use of metal.[9] This requires measures concerning ventilation, as metal is combined with oil-based synthetics. High temperatures also demand measures in safety and handling. In the case of metal printing, it should be taken into account that metals may be carcinogenic and that the use of respiratory protection is therefore necessary when handling such powders.

New materials are smart materials that react to differences in heat, pressure or light after production. Also new are nano-carbons; these are expected to be used on a large, industrial scale in the near future. The introduction of these high-tech materials requires close investigation of safety, since most of these materials are still experimental.[10]

Another important aspect to look at is the pre- and post-handling of the printing materials and printed objects. In the case of printing material in powder form, it is important to prevent these powders from spreading by using, for example, local exhaust ventilation (LEV) and so safeguarding suitable working methods. There is also a risk of spontaneous combustion of (metal) powders, which should be recognised, e.g. by using EX-devices (detection devices for potentially explosive areas).

The promise of a new industrial revolution

We live in a digital era. Social media is disrupting traditional journalism.[11] Online shopping is causing traditional shops to go out of business and has ripped our vibrant inner cities apart. Even online shopping is changing work circumstances, as it has become highly automated. Robotics will change the way we drive our cars and run our households. In addition, finally, the way we design, manufacture and distribute our consumer goods in this digital era will be changed by the 3D printer. Expectations of 3D printing were so high in recent years that nothing less than a new industrial revolution was imminent. At least, this was the message of the influential, 12-page report in *The Economist* in 2012.

The Economist, April 2012

8 http://www.stratasys.com/materials/material-safety-data-sheets/fdm

9 https://www.3dprintingmaterialsconference.com/3d-printing-materials/metals-are-the-fastest-growing-segment-of-3d-printing-metal-sales-growing-by-32/

10 https://www.sculpteo.com/blog/2016/09/28/top-10-future-3d-printing-materials-that-exist-in-the-present/

11 http://reutersinstitute.politics.ox.ac.uk/news/how-journalism-faces-second-wave-disruption-technology-and-changing-audience-behaviour-0

At that time, the prediction was that the 3D printer was a new digital tool that would soon be found in every household. That would mean the end of mass production. More accurately put, it was a *post*-industrial revolution that *The Economist* predicted. Anyone could download the digital blueprints of a product from the internet and print it at home with just one push of a button. Alterations could be made to the product: for example, people with wide feet could easily print a shoe that is just a little broader. Making this unique, tailor-made product would cost just as much as mass production in a Chinese factory and would thus undermine the existing economic status quo of production. New products would be less in demand; repairing would finally become widespread, because spare parts of broken-down appliances could also be easily reproduced at home with a 3D printer. Since production would move into people's homes, the time and energy spent distributing goods would be limited. Furthermore, supply and demand would be in check, since people would only print what they need. This means no more stock and overproduction; this new industrial revolution could also be green.[12]

The timing of the article in *The Economist* was no coincidence. The technique of 3D printing already existed in the mid-1980s. Stereolithography was patented in 1984 by the French scientist Alain Le Mehaute. Still, it took 10 more years before the term '3D printing' was coined. At that time only highly specialised industries such as medical care, automobile production and aerospace engineering were experimenting with high-tech 3D printers for prototyping and flexible production. However, in the first decade of the 21st century, great strides were finally made. 3D printing on a large scale now became possible not only with plastics, but also with metal, conductive materials, glass, ceramics and even organic tissues. Large companies such as Canon and Siemens began researching the market for consumer-friendly 3D printers. Makerbot, an American company, sold the first desktop 3D printer for just over €1,000 in 2008, making 3D printing technology accessible to a mass public. Around that same time, the research project RepRap (replicating rapid prototyper) developed a rudimentary desktop printer, which consists mostly of plastic parts that can be made with a desktop printer. The mechanical parts of the RepRap can be pre-ordered online. In other words, the RepRap is the first 3D printer that can replicate itself — and that for the cost of just over €200. The software to run a RepRap is open source and freely downloadable.

In short, within a decade, 3D printing shifted from being a futuristic method of producing used only by computer nerds, cutting-edge designers and high-tech industries, to a mainstream, consumer-friendly tool for flexible home production. Or, as *The Economist* put it, "the start of a new industrial revolution". The impact of 3D printing on the economy and on both a societal and a human scale. Foremost are the increases in welfare and the progress resulting from efficient and tailor-made manufacturing, may be significant. 3D printing introduces a local and demand-driven — and therefore a more sustainable — method of production. Because 3D printing is rooted in an open-source structure, it is more open to new businesses and small-scale innovation than to the traditional manufacturing industry. It will therefore be not only a greener but also a more impartial industrial revolution that empowers the consumer.

The impact of 3D printing can be divided into two levels:

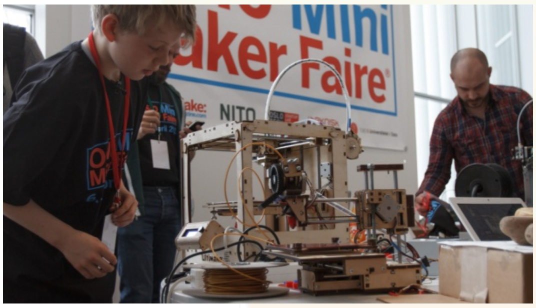
- **Societal**

3D printing will strengthen social inclusiveness. With minimal investment, anyone will be able to start a small business from their own basement. All that is needed is a computer, a 3D printer and a fast Internet connection. The necessary knowledge, ideas and, to a great extent, software are freely exchanged. Digital fabrication has spawned a 'maker movement' of consumers who are manufacturing products. Although the maker movement intersects with hacking, traditional crafts and scientific experiments, the 3D printer is considered to be the heart of this worldwide trend. The impact of the maker movement on an economic and societal level can hardly be overestimated. What Airbnb has done for the hotel business is what 3D printing can do for industrial production: radical democratisation of design, production and distribution. Also, it has the same loss of control of the conditions in which the activities occur.

12 https://3dprint.com/144928/3d-printing-environmental/

- **Individual**

In short, 3D printing enables individual access to better products. Individual desires and needs can be met more easily. Furthermore, products will be made of replaceable and downloadable components, which makes it easy to repair them. The producing consumer, or *prosumer*, will be empowered and able to improve their everyday life. The most powerful impact that 3D printing will have on the individual will probably be on a psychological level. As the sociologist Richard Sennett pointed out in his book *The Craftsman*, the making of goods is a deep-rooted need of human beings. It enables self-development, self-esteem and self-actualisation. We are what we make, so to speak. In our modern times, a maker movement made possible by accessible digital fabrication such as 3D printing provides the individual with autonomy and offers people possibilities to shape their own lives in both a psychological and a material way. This maker movement also provides new social networks and cohesion, since information and knowledge are freely shared. The worldwide Maker Faires are a gathering of these do-it-yourself producers. It could be said that 3D printing introduces a do-it-*ourselves* movement.



Maker Faire

An evolution instead of a revolution

But now, five years after the feature in *The Economist*, that revolution still has not started. Far from it. 3D printing is not even mainstream.[13] Makerbot almost went bankrupt in 2015 and RepRap has hardly improved since its launch. Because of the unorganised and fragmented nature of the 3D printing industry, there are hardly any figures on its economic contribution on a European scale. However, there are reliable estimates that, in the more highly developed European countries, not more than 1 % of the population actually owns a 3D printer. Nevertheless, the majority of 3D-printed products are manufactured at home and distributed within the sharing economy. Industrial 3D printing is still less than home production. To give an example, the economic contribution of the entire 3D printing industry in the Netherlands in 2015 was estimated at around €45 million; that makes 0.005 % of the country's total gross national product (GNP) of €888 billion. There is no evidence to suggest that this figure is significantly higher in other European Union (EU) countries. The average annual growth of the 3D printing industry over the last five years was 30 %. Even if this figure doubles, it will take at least another five years before 3D printing can compete with an economic sector such as the pop music industry. The impact of 3D printing is hard to predict. However, one thing is sure: it will not replace existing industry, but instead will be an addition to it.

A schism in the use of 3D printing is growing. On the one hand, a new, highly advanced and flexible industry is emerging. These companies work in fields such as medical care and the automotive industry, but also in fashion and everyday consumer products. On the other hand, small-scale and sometimes almost low-tech, do-it-yourself production is growing. These microfactories and start-ups are initiated by designers, cooperatives, small businesses and informal networks. However, what is still missing is the widespread use of 3D printing on a wider level by consumers. The maker movement consists of skilled amateurs and early adopters.

13 http://www.techrepublic.com/article/why-desktop-3d-printing-still-sucks/

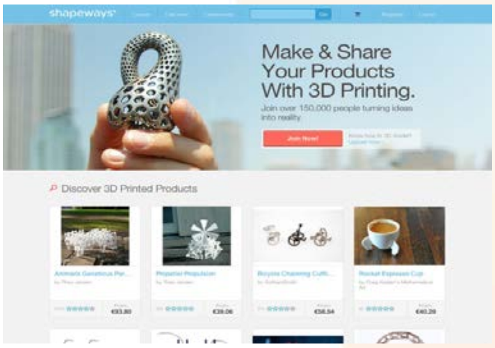
A new industry with 3D printers

Opportunities and risks for employers

3D printing offers new business models. The London-based online platform Open Desk does not even have a production unit. It offers a collection of furniture by designers from all over the world. All furniture is made from wooden boards. When a customer places an order, Open Desk finds the digital fabrication workplace closest to the customer. After production costs are paid to that workplace, the profit is divided between Open Desk and the designer. This way an internationally operating furniture company hardly needs more than a help desk. Shapeways is a global company where people can have their own designs printed. Professional designers can also upload their designs for consumers to order. When an order is made, the designer receives royalties paid by Shapeways. This on-demand production factory is currently only based in New York, but will soon expand to different locations around the world.

New challenges for companies working on such a large scale with 3D printers involve occupational health and safety.[14] This concerns issues such as gas and material exposures, material handling, static electricity, moving parts and pressures.[15]

Also, for reasons of copyright and illegal production, strict monitoring of the workers is needed. When a replica of a Star Wars figure is manufactured, this may infringe copyright. But who is liable: the designer, Shapeways or the buyer? Since 3D printing requires a precise process, the workplace must be clean and organised, and user interfaces must have clear and comprehensible instructions. Errors in programming or the adjusting and calibrating of the printer can occur easily. On top of that, a malfunctioning end product will more easily result in legal actions, since the modern consumer is highly emancipated.



Shapeways

Special attention to safety must also be paid where new products are being introduced. An example is 'De Kamermaker', which is a 3D printing unit for architecture developed by the Dutch architectural firm DUS Architects. With this extremely large 3D printer, constructional elements of 50 cm by 50 cm can be printed. But what does this mean for the safety of construction workers? At the Massachusetts Institute of Technology (MIT) in Boston, a research group called Mediated Matters, headed by Neri Oxman, is experimenting with 3D-printed constructions that are based on natural shapes and configurations. Hybrid manufacturing, where only parts of a product are 3D printed, is also becoming widespread.

What is also missing in the 3D printing industry is a universal standard system for use by individuals as well as by the emerging industry. This will enable the sharing of parts, which will benefit sustainability as well as safety.

14 http://www.cmu.edu/ehs/fact-sheets/3D-Printing-Safety.pdf

15 http://www.additivemanufacturing.media/articles/changing-the-rules

The Italian-Japanese design studio Minale Maeda is producing Keystones, a 3D-printed joint that enables you to build your own furniture using standardised wood panels. The strength and tensile strength of these parts must be validated and certified. Often these new products and techniques are developed by specially trained staff within a company. But who controls authorship of these innovations? When not regulated properly, this can cause tensions between employer and worker.

Innovating an existing production facility with 3D printing will require high investments. The advantage is that investments in moulds or special machinery are no longer needed to test prototypes. New products can be released into the market almost immediately and with relatively low costs. New techniques also offer new possibilities. For example, the 3D pen is a printer that looks like a pen and enables you to draw in 3D. For health and safety reasons these new handy 3D printers must be thoroughly tested and strictly regulated because the heating can pose safety threats. More and more of these pens use UV light.

There is a generation of millennials who are drawn to innovative and digital industries such as 3D printing and who have different demands concerning quality of work. In general this means that there will be a rising demand for younger workers who have a different outlook on work: free time and self-development are more appreciated than money and job security. Working on short-term contracts is the new standard. As compensation, young workers demand (creative) participation and a dynamic environment.

Such constant innovations and developments require continuous research and development, as well as investments in highly skilled workers and keeping them up to date through training and education.[16]

The following table shows the changing work conditions between flexible and on-demand production with 3D printing and traditional industrial production.

Table 1: The changing work conditions

Traditional industry	Digital fabrication
Hierarchy	Democratised
Centralised	Open
Regulation	Responsibility
Production-centred	Communication-centred
Promotion	Training
Financial/job security	Freedom and flexibility

The implications for workers and their jobs

Concerning the future of jobs, the key question with 3D printing (as with robotics and other automated production) is, will it replace or change existing work? The answer is yes and no.[17]

Yes, because machines will take over flexible, handmade production. Craft is digitised. With a 3D printer, objects can be made in the complex and elaborate forms that were previously possible only for

16 http://www.pwc.com/us/en/technology-forecast/2014/3d-printing/features/future-3d-printing.html

17 http://www.tandfonline.com/doi/pdf/10.5437/08956308X5606193

skilled craftsmen. With the introduction of 3D printing of materials like metal and wood, traditional crafts are becoming obsolete.

On the other hand, no, this will not inevitably lead to more unemployment. Firstly, 3D printing will also introduce new jobs, for example in the design and production of hardware (e.g. 3D printers) and, more importantly, in creating the software that enables machines to carry out various tasks.[18] Also, 3D printing can easily open up the global market. At the same time, production is increasingly done locally. Therefore, labour that was previously outsourced to low-wage countries may return to Europe. This means that trained workers will be in demand, though the demand for labourers producing simple handicrafts will decline. This means the gap between educated and less-educated workers will increase.

A major change in actual working conditions will be made by the dominant use of plastics in 3D printing. Good regulation and certification of these synthetic materials is essential. Production with 3D printing is expensive and also time-consuming.

As with other digital technologies (robots, artificial intelligence, and so on), the consequences for those who perform these routine tasks can be profound. The work can be boring and highly uncreative, similar to watching paint dry. At the same time, the 3D printing technique is still relatively complex and demands a high degree of concentration. Mistakes are easily made and the smallest errors will lead to major failures in the final product.

With all the innovative buzz surrounding it, 3D printing is an alluring industry. As with many start-ups, workers are tempted to put in long hours; also, the line between work and non-work activities can easily become blurred. Most of the companies working in 3D printing are young and fast growing, and are therefore less organised. With a variable staff, organisation among workers is difficult. This raises concerns about reasonable pay, working hours, and safe and clean working conditions.

Starting your own business at home

A new, informal chain of production is introduced with 3D printing. This democratic ‘maker movement’ enables people to start their own business from home. Just like Steve Jobs, who was an experienced computer entrepreneur when he started a company from his garage, most of the small companies and start-ups in 3D printing are run by semi-professionals. Together they form a highly disorganised industry that is hard to regulate. An individual 3D printing entrepreneur can be working from home or from an informal office space (e.g. a garage) that is unfit for a professional environment. Ergonomics, clean air, working hours and a healthy balance between the home and the workplace are under tension.

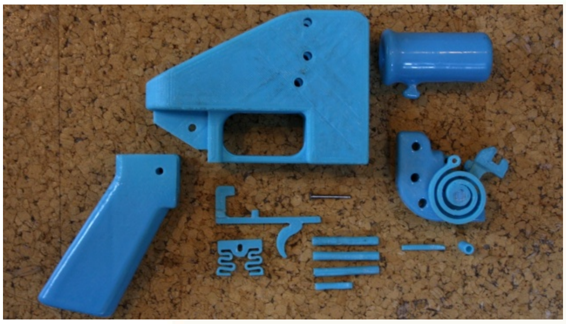
By far the biggest challenge of 3D printing for the self-employed worker is insecurity. When everybody can become a 3D printing manufacturer, the competition between these *crowdworkers* can lead to high pressure. The market has shown tremendous difficulties in regulating the price of these 3D printing services. This economic stress is further enhanced by the lack of social rights and financial regulation. What seems to be a creative forefront can in fact become a new digital proletariat. In this *gig economy*, as it is called in the United States, self-employed 3D printworkers hop from one commission to another. There is a serious risk of a new class of modern-day journeymen emerging. Even the home manufacturer who keeps control of sales and distribution by offering their product on online platforms such as Etsy or eBay is not safe. The old-fashioned “ work timing” clock is replaced by the pressure of online ratings. The promise of a post-capitalist economy can become a form of hypercapitalism where many people control the production but nobody controls the lower limit of social and economic security.

These new types of small enterprises offer dynamic but highly insecure job opportunities. In this fast-developing industry, today’s innovation can be tomorrow’s obsolescence. In companies where the legal division between the designer, the manufacturer and the entrepreneur is vague, liability in case of malfunction or inferior quality is unclear. This creates uncertainty in liability. With all sorts of products having become freely available by (illegal) downloading from the internet, piracy and copyright infringement are imminent.[19] Regulations and reliable worker contracts are needed. Apart from these

18 http://www.forbes.com/forbes/welcome/?toURL=http://www.forbes.com/sites/louiscolumbus/2014/09/15/demand-for-3d-printing-skills-is-accelerating-globally/&refURL=https://www.google.nl/&referrer=https://www.google.nl/

19 https://www.technologyslegaledge.com/2015/09/top-3-legal-issues-of-3d-printing/

legal issues, this also poses the problem of new ethical dilemmas. The Liberator Gun is a handgun that can be printed on a desktop 3D printer after downloading free print instructions from the internet.[20].



Liberator Gun

A special mention must be made of the 'fablab' (an abbreviation of 'fabrication laboratory'), which is a cooperative workspace with digital and analogue devices. The fablab plays an important role in the empowerment of individuals, enabling them to create smart devices for themselves. It is, one could say, the missing link between home 3D printing for personal use and new businesses. A fablab is open to the general public under the condition that the production process is documented. With more than 250 fablabs worldwide (over 100 in Europe), one of the largest open-source databases on 3D printing and other digital fabrication has been created. The number of fablabs is still growing. Most are non-profit and offer free services for individuals, such as courses and workshops; the number of commercial fablabs has also increased. Since these workspaces run on an informal basis, the required working conditions are not always met. With sensitive devices such as laser cutters and computerised milling machines, special consideration must be given to safety in these workplaces. Also, a minimum age and maximum working hours are easy not to comply with.

Fablab

20 http://www.3ders.org/articles/20151130-what-are-the-legal-aspects-of-3d-printing-a-european-law-firm-weighs-in.html

Future signs

New innovations will have a profound impact on 3D printing and the working environment. The five most important innovations that will be introduced are:

Food

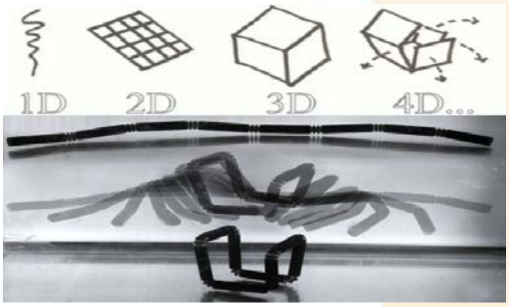
Flexible production and freedom in creation offer great opportunities in the food industry. Currently, mostly liquid foods, such as chocolate and pancake batter, are used with 3D printing. In the near future, 3D printing will be used for raw food that will later undergo treatment such as heating, or will be processed by natural processes such as fermentation or germination. This will pose new challenges to hygiene, safety and general working conditions (clean air, ergonomics, and so on).

3D food printing

4D printing and smart materials

Smart materials have one or more properties that can be changed significantly in a controlled way by external stimuli, such as temperature, force, light, moisture, pH, and electric or magnetic fields. When manufactured with a 3D printer, these smart materials can form objects that respond to their environment by changing shape, tactility or hardness. This process is referred to as 4D printing, as the objects will change again over time. These changes can result from sensitivity to light, pressure or temperature. Some of these materials may have a 'memory'; this means they will change back to their original shape when the circumstances change again. Many of these materials are highly experimental and the risks they pose to health and hygiene are uncertain. There have been calls for regulation.[21]

4D printing



4D printing

21 http://journal.georgetown.edu/programmable-matter-4d-printings-promises-and-risks/

Bioprinting

The 3D printing of organic and/or living tissue is referred to as bioprinting. Bioprinters output cells from a bioprint head that moves left and right, back and forth, and up and down to place the cells exactly where required. Over a period, this permits an organic object to be built up in many very thin layers.[22] In addition to outputting cells, bioprinters can also extrude a soluble gel to support and protect cells during or after printing. There have been numerous successful experiments of printing 'living' materials containing fungus or algae. As with smart materials, this technique poses risks to health and hygiene. Furthermore, it raises ethical issues.[23]

Bioprinting

Nano-printing

By combining 3D printing with nanotechnology, it will be possible to shape objects at a nano- or molecular level. In theory this means that through additive manufacturing it will be possible to manufacture any form of object of any kind of material, in any shape or volume. This technique, however, is still theoretical; no predictions can be made about the impact of nano-printing on the work environment.

Conclusions

The everyday impact of the 3D printer on physical safety in the workplace is likely to be limited. There will be risks, but it is hardly to be expected that there will be new risks related to physical safety. After all, it is just a machine that demands relatively little manual involvement. Also, most materials used in 3D printing are known and so are their effects on health by emission of gas, material exposures, material handling and static electricity.

The impact on the well-being of the worker may be considerable, however. It poses new risks in terms of job insecurity, working hours, liability, monotony and routine on the job, keeping up with new developments by training and education, and, finally, security risks arising from the introduction of experimental machinery. It is highly recommended that a response to these changes in the work environment be made at the European rather than national level, since 3D printing is a global economy. This involvement should manifest at three levels:

1. Monitoring and verification

What innovations are upcoming? How likely is it that this innovation will be implemented on a large scale? Is this technique patented or otherwise protected? Who is liable in case of malfunctions? Can the used materials be traced?

22 http://www.explainingthefuture.com/bioprinting.html

23 http://www.computerworld.com/article/2486998/emerging-technology/bio-printing-human-parts-will-spark-ethical--regulatory-debate.html

These are just a few of the questions that will emerge. Monitoring changes in 3D printing requires a constant dialogue with the industry. This can be done most easily and cheaply by establishing an online platform that both workers and employers can participate in. For contacting and monitoring individuals such as the prosumer (self-producing consumer) the vast network of fablabs in Europe can be used.

2. Regulating and certification

As a result of the dynamic, bottom-up and sometimes experimental nature of 3D printing, there is a lack of regulation. Certification can be a strong instrument. Currently, this certification has been done only by high-tech companies that are very protective of production techniques developed with large investments. Their secrecy and patenting does not contribute to the regulation of 3D printing in general. The regulation of 3D printing in the working environment must be done for the following reasons:

- **Quality and safety control**

3D printing is under constant influence from the development of new techniques and materials. This poses risks to safety in relation to the 3D printers as well as the manufactured goods.

- **Liability**

The introduction of new techniques and materials can lead to conflicts of intellectual property and creative ownership between employer and worker. Also, with designs being (mostly) freely available online, there are new risks of copyright infringements and liability in the case of malfunctioning or inferior products. Standard contracts and legal advice may be needed.

- **Workers' well-being**

The global economy and dynamic start-up atmosphere surrounding 3D printing can be stressful to workers who are faced with higher demands in working hours, flexibility and responsibility. Since the 3D printing industry mostly consists of start-ups and new types of microfactories, the organisation of workers in traditional unions is limited.

- **Health and safety**

Material use and emissions may pose health risks.

- **Job insecurity**

In an industry that is highly innovative, job insecurity can be high. This can be reduced by training opportunities to keep workers up to date.

- **Involvement**

Working with automated machinery such as 3D printers can be boring and stressful. Training can have a positive influence on workers' motivation. Workers in 3D printing are usually relatively young. Employers should also take extra measures to keep them motivated by sharing responsibility and offering flexible working conditions.

3. Training and education

Apart from challenges concerning the individual working environment, 3D printing also offers incredible opportunities for improving equality in the labour market in general. We live in a knowledge society based on networking and technology. The division between people who have access to and knowledge of technology and those who do not, is growing. However, with 3D printing and the underlying maker movement, access to knowledge is cheap and relatively easy via the internet. The most important networks in this maker movement are the fablabs. By collaborating with fablabs in offering education and training, the growing ‘tech gap’ can be bridged, which will lead to a more equal labour market. This is especially relevant in the economic context of Europe, where individuality, openness and innovation are main targets.

For further reading

- Printing Things. Visions and Essentials for 3D Printing. Dries Verbruggen (editor). ISBN 9783899555165. Gestalten, 2015
- Open Design Now: Why Design Cannot Remain Exclusive. Lucas Evers & Bas van Abel (editors). ISBN 9789063692599. BIS Publishers, 2011
- The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World. Jeremy Rifkin. ISBN 9780230341975. St. Martin's Griffin, 2013
- Fabricated: The New World of 3D Printing. Hod Lipson & Melba Kurman. . ISBN 9781118350638. Abe Books, 2013
- *Makers: The New Industrial Revolution.* Chris Anderson. ISBN 9780307720962*.* Crown Business Publishers, 2012
- *The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers.* Mark Hatch. *.* ISBN 9780071821124*.* MacGraw-Hill Education, 2013
- *3D Printing: The Next Industrial Revolution.* Christopher Barnatt. *.* ISBN 9781484181768. Create Space Independent Publishers, 2013
- *Postcapitalism: A Guide to our Future.* Paul Mason. ISBN 9781846147388 Allen Lane Publishers, 2011

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