



DIRECTORATE-GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT  
ECONOMIC AND SCIENTIFIC POLICY **A**



Economic and Monetary Affairs

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# Open Innovation in Industry, Including 3D Printing

Study for the ITRE Committee



**DIRECTORATE GENERAL FOR INTERNAL POLICIES**  
**POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICY**

# **Open Innovation in Industry, Including 3D Printing**

## **STUDY**

### **Abstract**

New technologies and innovation concepts are important pathways for growth and competitiveness. Open innovation can strengthen innovation ecosystems. 3D printing has the potential to significantly impact the way production and innovation takes place. It is still hard to predict where and how exactly 3D printing will transform our economy and society. This study, provided by Policy Department A at the request of the ITRE committee, describes the mutual reinforcement of open innovation and additive manufacturing and addresses recommendations for different policy levels.

This document was requested by the European Parliament's Committee on Industry, Research and Energy (ITRE).

## **AUTHORS**

Dr. Frans van der Zee (TNO)  
Dr. Dieter Rehfeld (IAT)  
Christine Hamza (METIS)

## **RESPONSIBLE ADMINISTRATOR**

Frédéric Gouardères

## **EDITORIAL ASSISTANT**

Eva Asplund

## **LINGUISTIC VERSIONS**

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## **ABOUT THE EDITOR**

Policy departments provide in-house and external expertise to support EP committees and other parliamentary bodies in shaping legislation and exercising democratic scrutiny over EU internal policies.

To contact the Policy Department or to subscribe to its newsletter please write to:

Policy Department A: Economic and Scientific Policy

European Parliament

B-1047 Brussels

[Poldep-Economy-Science@ep.europa.eu](mailto:Poldep-Economy-Science@ep.europa.eu)

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## LIST OF ABBREVIATIONS

**3D printing** 3-dimensional printing, also known as additive manufacturing

**AM** Additive manufacturing

**CAD** Computer-aided design

**CIS** Community innovation survey

**CNC** Computerised numerical control

**COI** Community of innovation

**COP** Community of practice

**DIY** Do-it-yourself

**EC** European Commission

**EP** European Parliament

**EPO** European patent office

**ERDF** European Regional Development Fund

**EU** European Union

**EURIS** European Collaborative and Open Regional Innovation Strategies

**FP7** 7<sup>th</sup> Framework Programme

**FS** Facility Sharing

**H2020** Horizon 2020

**HEI** Higher education institutes

**ICT** Information and communication technology

**IT** Information technology

**IoT** Internet of Things

**ITRE** Committee on Industry, Research and Energy

**IP** Intellectual property

**JPO** Japan patent office

**KET** Key enabling technology

**KT** Knowledge transfer

**OI** Open innovation

**OIA** Open innovation accelerator

<b>OECD</b>	Organisation for Economic Co-operation and Development
<b>OPR</b>	Open research platform
<b>PRO</b>	Public research organisation
<b>R&amp;D</b>	Research and development
<b>RIS</b>	Regional innovation system
<b>RIS3</b>	Research and Innovation Strategy for Smart Specialisation
<b>ROIR</b>	Regional open innovation road mapping
<b>RTO</b>	Research and technology organisation
<b>S<sup>3</sup></b>	Research and Innovation Strategy for Smart Specialisation
<b>SF</b>	Shared Facilities
<b>SFFS</b>	Shared Facilities (SF) & Facility Sharing (FS)
<b>SMEs</b>	Small and medium-sized enterprises
<b>USPO</b>	United States patent office
<b>VC</b>	Venture capital

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## EXECUTIVE SUMMARY

The 2014 Commission Communications “For a European Industrial Renaissance” and “Research and innovation as sources of renewed growth” set out Europe’s key priorities and provide the background of this study: how to facilitate the renewal of industry and industrial policy in Europe? In this context the European Parliament has contracted the study on open innovation and 3D printing. This study is structured in three parts, starting with an overview of the concepts of open innovation and 3D printing (part 1), where and how the two meet and can reinforce each other (part 2), and ending with conclusions and recommendations (part 3).

**Open innovation** is a relatively recent concept, representing a paradigm shift in how companies commercialise industrial knowledge. The core idea of the open innovation model is the opening up of the innovation process to the outside world. From the very beginning open innovation was understood as a concept with economy-wide potential, as a company innovation strategy and business model, not only related to R&D and high-tech. More generally, open innovation is to be seen as a more distributed, more participatory and more decentralised approach to innovation than the traditional, closed innovation model. The more open innovation is successfully embraced by firms and others, the more this will reshape and alter existing regional innovation systems. As a consequence, policymakers need to seriously rethink the existing innovation policy instruments and the overall policy mix.

After attaining broad public interest in 2008/2009, **3D printing** and additive manufacturing are on the peak of inflated expectations. Rapid reduction in the cost of 3D printers, increase in accuracy, increase in the variety of supporting material, and expiration of critical patents provide a context for accelerating innovation and application of this emergent technology with various sectors using additive manufacturing and 3D printing.

**Industrial 3D printing (additive manufacturing)** is on the way to change production lines and value chains. Functions like tooling and welding became obsolete and small production lines have been replaced. In health and dentistry the dynamic is highest. In the long run, additive manufacturing enables a shift from mass production to mass customisation. Several fields are currently applying additive manufacturing.

**Consumer 3D printing** by private makers is in its infancy. So further development is embedded in the context of a sharing and crowd-based community and new business models have been developed. In the medium term consumer 3D printing in ‘fab labs’ has a promising potential for technical learning, urban development and co-working in craftsmanship and creativity sectors. As can be expected, implications for the labour market and for regional development will take place but the intensity and direction is open depending on application strategies, new business models and regulation.

**Technical innovation** in additive manufacturing and 3D printing is speeding up and supported by European programs. The social aspect, consequences for the labour market and the work flow, new business models need further research and development.

**Additive manufacturing** and consumer 3D printing develop in different contexts. Intellectual property right is the key conflict. The link between 3D printing in industry and ‘fab labs’ is promising for technical learning, customer driven innovation, and urban development but so far there are very few examples that make use of this potential.

**Open innovation and additive manufacturing** should be viewed as parallel and even reinforcing developments. The challenge for European politics is to support the renewal of European industry and at the same time not to miss the potential resulting from bottom-up, user and citizen driven approaches. It is important to emphasize that both additive manufacturing and open innovation, together with open source innovation and 3D printing, are not stand-alone technologies or innovation strategies but are embedded and need to be approached from a broader, comprehensive context of change. This also calls for better and more firmly incorporating social and societal aspects in the innovation process; innovation as such is not sufficient to cope with the big societal challenges successfully.

**Open source innovation and 3D printing** offer ample opportunities for renewing the regional base by creating new potential links between local activities and global production networks. They provide not only the opportunity of starting new business activities but they also give new inspiration for reshaping regional innovation strategies. Combined with the concept of smart specialisation and its underlying concept of entrepreneurial discovery, this provides a strong new impetus to regional strategy renewal.

### **Policy recommendations**

Recommendations for policy-makers need to be addressed to the relevant policy levels: what can be done at EU, Member State and regional level to tackle the most important aspects regarding open innovation and 3D printing?

#### *EU level*

The legislative and regulatory business framework has to be re-examined with specific attention for new technologies and innovation. The EU should avoid regulation that hinders new business activities and the intellectual property legislation should be reconsidered. This is especially important for start-ups and small companies looking at the issue of lowering IP costs and patent grant times. Last but not least the encouragement of coordination between different actors is recommended.

Much more than is already the case, the Horizon 2020 programme should launch projects that focus on so far largely neglected aspects: business models linking social and technological aspects of innovation, environmental issues, workplace innovation and qualification; open innovation in services; open innovation and SMEs. Furthermore it should encourage start-up and SME participation by lowering the administrative burden and the lead time of granting proposals.

The European Cohesion policy should encourage the involvement of fab labs and related facilities in regional innovation policies. The use of open innovation tools in regional strategy development (smart specialisation strategies) could be promoted and good/best practice examples could be collected, communicated and disseminated. Furthermore, it is recommended to check funding rules that fit with the idea of crowd-based activities. Similarly European Territorial Cooperation programmes should encourage European cooperation projects between fab labs on the one hand and fab labs and industrial 3D printing on the other hand.

EU policy-wide actions like launching projects on those issues which have so far been neglected, organising a dialogue between the different groups of actors in the field of additive manufacturing and open innovation, or ensuring that social and technical aspects of innovation work in an integrative way in European projects, should be on the agenda for future development.

*Member State level*

The national legislative and regulatory framework should be rethought and policy makers should avoid regulations that hinder new business activities or could stop or slow down new developments including technological change. Room for regulatory experiments should be provided and one-size-fits-all approaches should be avoided.

The field of innovation policy is covered predominantly at national level and the use of additive manufacturing and open innovation largely depends on the state of development of industry and leading sectors in the Member States. Therefore they should keep an open eye for different developments.

In the education and training policy area, existing approaches regarding the digital economy and societal needs have to be re-examined and new labour requirements related to the digital economy need to be considered.

*Regional level*

The regions should rethink their innovation strategies by making room for and incentivising open innovation approaches. They should be taking an integral, all-embracing approach to regional innovation, preferably based on the *smart specialisation* concept.

# 1. CONTEXT AND METHODOLOGY OF THE STUDY

## 1.1. Context

The European Parliament requested a research study that “should feed into the general debate about the role of an EU coordinated and integrated industrial policy to support economic development and enhance competitiveness of the industries, considering SMEs and the development of innovative solutions. A particular focus should be on the degree of actual implementation of recent policies and the potential of open innovation, including 3D printing”.

In this respect it is important to clarify relevant links of open innovation and 3D printing (3-dimensional printing, also known as additive manufacturing) to the framework of an EU coordinated integrated industrial policy.

The study should feed into the general aim of the European Commission (EC) to improve and adapt the industrial policy of the European Union (EU). In 2014, the communication “For a European Industrial Renaissance” sets out the Commission’s key priorities for industrial policy and aims to facilitate a full and effective implementation of industrial policy in the EU. In the context of industrial modernisation this study highlights the importance of digital technologies and digital transition in the global economy and industrial policy stating, it “*needs to integrate new technological opportunities such as cloud computing, big data and data value chain developments, new industrial applications of internet, smart factories, robotics, 3-D printing and design*” (COM(2014) 14 final, p. 9). Last but not least, the communication “Research and innovation as sources of renewed growth” published in 2014, suggested reforms in research and innovation systems of the EU Member States and showed a clear role of public spending as a leverage for overall spending in research, innovation and development. It also emphasised the importance of strengthening the innovation ecosystem, comprising the Single Market, the public sector, the transformation of the European economy towards sustainable competitiveness and Europe’s citizens, for instance as co-creators, promotion of social innovation and social entrepreneurship (COM(2014) 339 final, pp. 10-11).

## 1.2. Objective of the study

For this purpose the study provides support in understanding the broad concept of open innovation as such and also in relation to key enabling technologies. This enables the involvement of a multiple stakeholder community along the value chain of production. In this respect new technologies and concepts have different impact on innovation.

Significant impact on production as well as innovation comes from 3D printing. The way 3D printing is influencing economy as well as society is yet not predictable but there are strong beliefs that 3D printing can have a revolutionary impact. Industry however is implementing both concepts in different ways and with different intensity. The evolution is marching rapidly and it seems that policy makers are not always able to follow the multi-dimensional and rapid changes in industrial sectors.

While one task of the study is to develop a concept of open innovation and to define 3D printing, the other task is to present – based on existing studies and research – estimates and figures with regard to the actual implementation of related policies and the potential of social innovation and 3D printing for industry and creative people. Thereby, we should keep in mind that the overall potential of smart use of new and upcoming information and communication technologies is much broader.

The study tries to avoid two potential pitfalls: not to underestimate the potential of open innovation and 3D printing and at the same time not to overestimate it.

### **1.3. Methodology**

The methodology of the report is based on three phases: a literature review phase, a second phase which crystallises the literature review to draw a synthesis, and a final phase which includes the conclusions and the recommendations addressed particularly to the European Parliament. The three phases of the study are structured in five chapters (excluding the introduction):

- the first phase includes an overview of open innovation and 3D printing (chapters 2 and 3);
- the second phase provides a synthesis out of the previous two chapters (chapter 4);
- the third phase includes the conclusions and recommendations (chapter 5).

In chapter 2 of the study the concept of open innovation is described and different business models explained. The chapter addresses several examples to show practical implementations of different models in industry. The chapter refers to European approaches and measures of support and how they link to open innovation. Finally the most important aspects to be considered in terms of legal consequences and impact on society and environment are summarised.

Chapter 3 summarises the main aspects of 3D printing. Furthermore the distinction between industry driven 3D printing also called additive manufacturing and the more end-user linked term 3D printing is explained. The 3D printing technology is in its infancy and it is therefore difficult to predict the social-economic impact. The chapter explains different technological aspects and unfolds the different levels of utilisation of 3D printing and the potential future developments.

Chapter 4 serves as a synthesis aiming to link open innovation with 3D printing.

Chapter 5 finally provides distinctive recommendations for the European Parliament (EP), the EC and Member States. However the subject of open innovation as well as 3D printing has such a significant impact on different thematic fields that recommendations regarding policies can never be exhaustive. In this respect the chapter focuses on industrial related policy recommendations and recommendations for small and medium-sized enterprises (SMEs).

## 2. OPEN INNOVATION – REFRAMING INNOVATION

### KEY FINDINGS

- Open innovation is a relatively new concept that has taken off from the beginning of the 2000s, in firms but also beyond, with notions of user innovation and open source – though not the same - closely tied to it.
- Open innovation is defined as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” (Chesbrough, 2003).
- Open innovation is an appealing and inclusive concept, but the term ‘open’ is easily misunderstood and may give rise to confusion. ‘Open’ is not the same as ‘free’, but means rather in open connection and exchange with the outside world. Behind open innovation there is always a business model.
- There is a difference between open innovation and open source. In (private) open innovation the outcome is closed, with an opened up process. In open source both process and outcome are open and available to others.
- The principle of open innovation has penetrated high-tech industries such as software, electronics, telecom, biotech and pharmaceuticals, but has also spread to medium- and low-tech industries including machinery, tooling, chemicals, food and beverages, logistics, fast moving consumer goods and architecture.
- How companies deal with and apply knowledge and knowledge flows can differ substantially. However, knowledge management and absorptive capacity are crucially important.
- Open innovation is the subject of policy debate, because of its impact on national and regional innovation systems, and because of the levers it provides to incentivise and stimulate positive change by creating new and altering existing innovation ecosystems.

### 2.1. The concept

Open innovation has attracted a great deal of attention over the last decade, in innovation management and business management literature and more recently also in policy-making. The term ‘open innovation’, first coined by Henry Chesbrough in 2003, builds on the idea that firms are better off crossing their boundaries when innovating. In a world of widely distributed knowledge and ideas, firms can no longer afford to be internally focused, and be reliant on just own ideas and resources to innovate and compete. Open innovation in the view of Chesbrough (2003) represents “a ‘paradigm shift’ in how companies commercialise industrial knowledge”. The basic premise of open innovation is the opening up of the innovation process. The open innovation model is typically contrasted to the traditional closed innovation model, in which firms initiate, develop, commercialise, support and finance innovations on their own and do not search for alternative paths to market. In the closed model firms tend to rely primarily on their own research and development (R&D) departments, using inputs from internal and external sources, to invent develop and perfect technologies, and focusing on *internal development* of technologies, products and processes for own commercialisation (OECD 2008). In the closed model, the innovation process follows a rather linear pattern, with a narrowing down of concepts that best fit the firm’s needs and some staying ‘on the shelf’ if not fitting into the company’s strategy.

The open innovation model is dynamic and non-linear in its approach, with an important role for the outside world, in terms of collaboration but also broader, by leveraging external sources of technology and innovation to drive internal growth, including the spin-off and outsourcing of unused intellectual property (Docherty, 2006).

The differences between the closed and the open innovation approach relate to differences in beliefs and attitudes towards innovation (see table 1). Yet the surge of open innovation is also a consequence of a fast changing world around us in which global competition and specialisation are prime, and in which speed and innovation performance are more important than ever.

**Table 1: Contrasting principles of open and closed innovation**

Closed Innovators	Open innovators
The smart people in the field work for us	Not all the smart people in the field work for us. We need to work with smart people inside and outside the company.
To profit from R&D, we must discover it, develop it, and ship it ourselves.	External R&D can create significant value; internal R&D is needed to claim some portion of that value.
If we discover it ourselves, we will get it to the market first.	We don't have to originate the research to profit from it.
The company that gets an innovation to the market first will win.	Building a better business model is better than getting to the market first.
If we create the most and best ideas in the industry, we will win.	If we make the best use of internal and external ideas, we will win.
We should control our IP, so that our competitors don't profit from our ideas.	We should profit from others' use of our IP, and we should buy others' IP whenever it advances our business model.

**Source:** Chesbrough, 2003, p. xxvi

Even though open innovation as a concept has only been around since 2003, its popularity in business and policy circles has taken an enormous surge. Open innovation has rapidly become “one of the hottest topics in innovation management. A search in Google Scholar, open innovation provides over 2 million hits, Henry Chesbrough’s 2003 book has gathered more than 1,800 citations in just seven years (Google Scholar, July 2010), and surprisingly a wide range of disciplines, including economics, psychology, sociology, and even cultural anthropology ... have shown interest in it” (Huizingh, 2011). Its recent rise in policy-making is strongly linked to its potential impact on and contribution to the creation of innovation eco-systems (see also section 2.5).

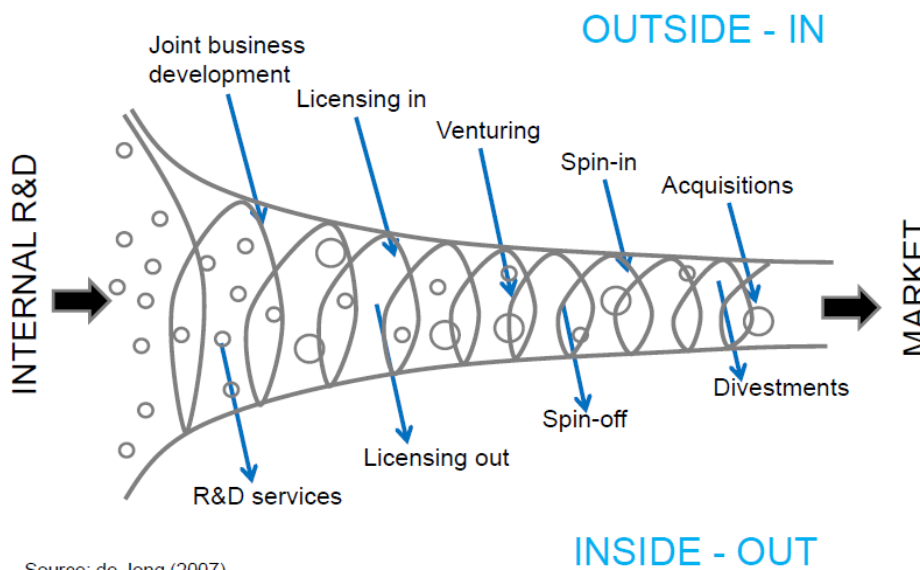
### Open innovation defined

Open innovation refers to “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively”; (Chesbrough et al, 2006). “[This paradigm] assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology.” In a recent, slightly adapted version, by Chesbrough and Bogers (2014), open innovation is defined as “a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization’s business model.”



These flows of knowledge may involve inflows to the focal organisation (*outside-in*), knowledge outflows from the organisation (*inside-out*) or both (coupled) (see Figure 1), sometimes also described as *inbound*, respectively *outbound* activities (Gassmann and Enkel, 2004).

**Figure 1: Open Innovation as outside-in and inside-out knowledge flows**



Inbound activities refer to broadening and enriching the firm's knowledge base through the integration of knowledge, competences, and expertise from external partners such as customers, suppliers, research institutes and others. Inbound activities refer to the sourcing of ideas, expertise, in-licensing, and buying patents, but also to co-creation through alliances, collaborations and joint-ventures. Outbound activities focus on the commercialisation of knowledge and external exploitation of internal knowledge by transferring ideas to the outside environment. Outbound activities include, for example, the selling and licensing of intellectual property (IP), contract research or spin-offs, and enable organisations to commercialise technologies that are 'on the shelf', and to involve better equipped outside parties to commercialise inventions.

### What open innovation is not or not exactly?

Where open innovation is an appealing and inclusive concept, the term 'open' may give rise to confusion and is easily misinterpreted. Sometimes 'open' is used in close connection to *user or user-centric innovation*, such as in 'open, distributed innovation' (Von Hippel, 1976; 1988; 2005) emphasising the public good nature of innovations, or as in 'open collaborative innovation' (Baldwin and Von Hippel, 2011) in which the emphasis is on low-cost or free production of public goods, similar as in *open source*<sup>1</sup> innovation. Open innovation is broader and more-embracing. To quote Chesbrough (2011), "There are other ways some people define open innovation, just as Eskimos have dozens of words for 'snow'. Some claim it works just like open source software: it does not. The business model for innovation is a key part of open innovation.

<sup>1</sup> The term 'open source' dates back to 1998 and was first coined in Palo Alto by the then 'free software' movement, who sought to reframe its discourse to a more commercially-minded position. See: [http://en.wikipedia.org/wiki/Open\\_source](http://en.wikipedia.org/wiki/Open_source)



Others think that it is just supply chain management: it is not. Open innovation involves many other actors that fall far outside traditional supply chains (such as universities or individuals), and these participants in open innovation can be influenced, but often are not actually directed or managed. Some claim it is user innovation: it is not. The user is certainly very important to open innovation, but so are universities, start-ups, corporate R&D and venture capital." In most accounts of open innovation, it is however acknowledged that whereas not the same, the concept of user innovation (Von Hippel, 1986; 1988; 2005) is very near. One important topic area where the two do not coincide but rather disagree is the importance and desirability of appropriability: strong rights for inventors to appropriate the returns of their inventions (West et al., 2014). Open innovation, which can be regarded as a firm-centric theory of innovation, has been strongly associated with strong appropriability. Von Hippel (2005; 2007) and others have criticised strong appropriability in that it i) inhibits collaborative and cumulative processes, and ii) does not support especially individual inventors who are better off by freely revealing than with strong IP protection (West et al. 2014). The following figure provides an insightful way to the different ways of innovation, distinguishing between the openness or closeness of the innovation process and outcome.

**Table 2: Open Innovation: different degrees of openness in process and outcome**

Innovation process	Innovation Outcome	
	Closed	Open
Closed	Closed innovation	Public innovation
Open	Private open innovation	Open source innovation

Source: Huizingh (2011)

The figure clarifies the main difference between open source and open innovation, here termed *private* open innovation. In private open innovation the outcome is closed (a proprietary innovation), whereas the process is opened up. In open source both the process and the outcome are open, and therefore available to others. It also shows another interesting variety of openness, the public innovation. A classic example of the latter is standard setting, where the innovators do not exclude others to use an innovation in order to reap the benefits of the market standard (e.g. the IBM PC in 1981), (Huizingh, 2011).

While initial open innovation studies looked primarily at R&D, new and other perspectives have emerged since Gassman et al. (2010) and distinguish between the following nine different research perspectives on open innovation:

- a *spatial perspective* focusing on the globalisation of R&D innovation, absorptive capacity and access to resources;
- a *structural perspective* highlighting the division of work in innovation, with a strong trend to more R&D outsourcing and alliances;
- a *user perspective* focusing on user needs, the involvement of lead users and the idea of mass customisation;
- a *supplier perspective* concentrating on the early involvement of suppliers in the innovation process;
- a *leveraging perspective* looking at competences and IP to explore and create new markets and new business models;
- a *process perspective* focusing on outside-in, inside-out and coupled processes of opening up the innovation process;

- a *tool perspective* centring on the tools to enable customers to make and configure their own product, or to enable companies to integrate problem solvers or idea creators via websites;
- an *institutional perspective* in which open innovation is seen as a ‘private-collective’ innovation model in which the “free revealing of inventions, findings, discoveries and knowledge is a defining characteristic” and knowledge spill-overs take place;
- a *cultural perspective* focusing on the creation of an innovation mind-set and culture that puts also other values than competences and know-how in the centre of innovation.

*Policy-making* can be regarded as yet another - tenth – perspective, focusing on policy tools and levers to promote and incentivise open innovation and ‘open innovation ecosystems’, using the other perspectives to feed it.

## **2.2. Open innovation as company innovation strategy and business model**

Even though open innovation is frequently cited in close conjunction to R&D and high-tech, its coverage has been much broader and applies to various other sectors. Chesbrough was straightforward right from the launch of the open innovation concept on its economy-wide potential: “Don’t be fooled - the concepts ... are not specific to the high-tech portion of the overall economy. Every company has a technology, that is, a means to convert inputs into goods and services that the company sells” (Chesbrough, 2003: xxvi). While technology is a key aspect, non-technological factors should not be overlooked in getting open innovation work. Product design, new market insights, customer intimacy, and business model innovation are examples of how firms may realise the benefits of open innovation. The increasing importance of information and communication technology (ICT) in doing business, both B2B (business to business) and B2C (business to consumer) have further accelerated open innovation practices. ICT is a major factor behind the emergence of global networks and web-based communities and is an enabler in identifying and establishing contact with external parties. It has also contributed to the rise of third-party innovation intermediaries (‘innomediaries’) and platforms, also referred to as open innovation accelerators (OIAs). The Internet and social software are key to these OIAs and allow them to operate globally and integrate large numbers of participants (e.g. Diener and Piller, 2013).

### **Rapid diffusion of open innovation in various sectors, from large enterprises to SMEs**

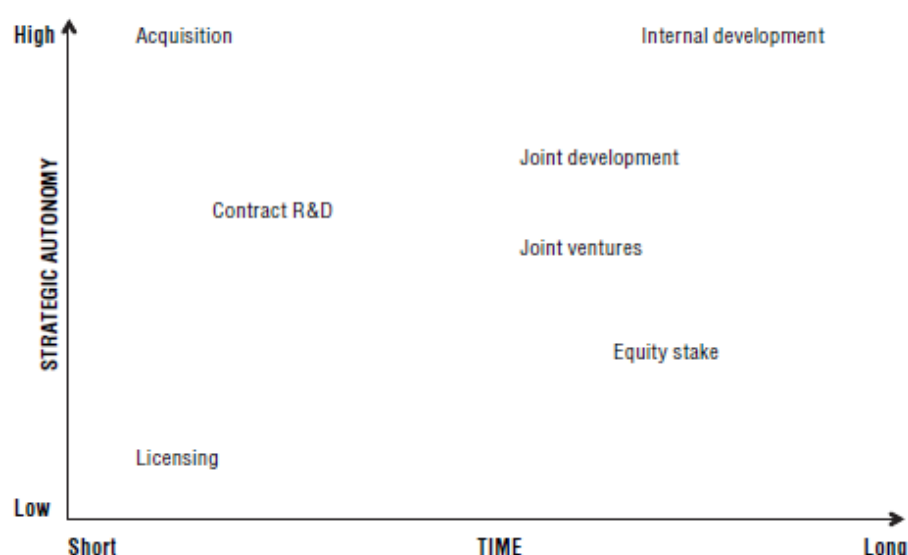
The principle of open innovation has penetrated high-tech industries such as software, electronics, telecom, biotech and pharmaceuticals, but has also spread to medium- and low-tech industries including machinery, tooling and equipment, chemicals, food and beverages, logistics, fast moving consumer goods and architecture. Research on the implementation of open innovation in medium- and low-tech companies, however, is still scarce (e.g. Chesbrough et al, 2014a). Examples include Chesbrough and Crowther (2006) on mature and asset-intensive industries such as chemicals and aerospace; Vanhaverbeke (2006) and Van de Meer (2007) on food and beverages, machinery and equipment, and chemicals, and Saguy and Sirotninskaya (2014) on food.

A similar observation holds for SMEs, with most research on open innovation so far been done on large and multinational enterprises (e.g. Van de Vrande et al., 2009; Brunswicker and Van de Vrande, 2014). As SMEs are largely active in medium- and low-tech industries, there is substantial room for further research on successful open innovation practices in both low- and medium-tech sectors, and SMEs. It appears that SMEs in low-tech industries have been successful in applying and integrating knowledge from external partners (e.g. Spithoven, Clarysse & Knockaert, 2010). Strong differences exist between the innovation strategies of small and large firms, with innovation processes of larger firms typically being more structured and professionalised (Van de Vrande et al., 2009). Rather than being interested in open innovation as a 'game changer' or new company strategy/philosophy, which is how large and multinational companies tend to embrace the concept, SMEs appear to engage in open innovation rather as a consequence of their search of changing their existing business model and to adapt to new market realities. Limited technological capabilities and a lack of financial and human resources force SMEs to look outside for innovation partners (Vanhaverbeke et al., 2012). However, SMEs are still much behind large and multinational companies in implementing open innovation. An exception to this are the so-called 'born globals', rapidly growing SMEs active on a global scale early in their existence, many of which appear to depend on the protection and leveraging of their IP (Gassman et al., 2010).

As an illustration of the popularity of open innovation among large and multinational enterprises serves a recent survey on open innovation adoption among large firms in the US and Europe (Chesbrough and Brunswicker, 2013). They find that open innovation is widely adopted in high-tech manufacturing and wholesale and retail trade (90% and 86% respectively) but still far less adopted in low-tech manufacturing (40%), finance, insurance and real estate (56%) and transport, communications and utilities (69%). Yet with an average of 78% most large firms are actively exploring open innovation, up from 30% even before 2003. The intensity with which open innovation is used is increasing, with 82% of all respondents stating practicing open innovation more intensively than three years ago, and only 3% less intensively. Examples of multinational companies actively engaged in open innovation are Philips; Procter and Gamble; General Mills; Unilever; Natura; Fiat; BMW; Heineken; Lego; DSM; BAE Systems; British Telecom; Siemens; IBM; Bayer; Pfizer; SAP and many others. A number of these open innovation examples have been analysed in-depth as case studies, e.g. IBM (Chesbrough, 2007), DSM (Kirschbaum, 2005), Procter and Gamble (Huston and Sakkab, 2006) and Xerox and its Palo Alto Research Centre (Chesbrough, 2003) with which the open innovation paradigm took off more than ten years ago.

### **How companies choose, implement and integrate open innovation**

Firms have a number of different options ('modes') for accessing, sourcing and absorbing external knowledge and technologies, including purchasing (acquisition); licensing; joint venturing and alliances; joint development; contract R&D; collaborations with universities; equity in university spin-offs; and ditto in venture capital investment funds (see OECD, 2008; EIRMA, 2004). How a company chooses between the different available options will strongly affect its resources and strategic directions, with a clear trade-off between strategic autonomy of the company and the time horizon of implementation, the 'make or buy' decision represented at both extremes (see Figure 2).

**Figure 2: Open innovation modes: strategic autonomy and time**

Source: OECD (2008: 38)

In a similar vein Figure 3 shows the different accessing and sourcing options to new knowledge and technologies (*outside-in open innovation*) and for transferring and commercialising them externally (*inside-out open innovation*). How firms will choose them depends on how core technologies and markets relate to them. Joint ventures and venture capital are typically used for both sourcing knowledge from outside and for commercialising 'own' innovations.

**Figure 3: Open innovation modes: technology and markets**

MARKETS	Unfamiliar	Joint venture Contract R&D	Venture capital Internal venture fund	Spin-off Sell
	Non-core	Joint development Acquisition	Licensing Equity stake	Venture capital Internal venture fund
	Core	Acquisition Internal development	Internal development Licensing Acquisition	Joint venture Contract R&D
		Core	Non-core	Unfamiliar
		TECHNOLOGY		

Source: OECD (2008: 39)

Internal development and acquisition (purchasing) are typically used in core technologies for core markets, as open innovation and collaborating with external partners may be too risky. Licensing is more appropriate when dealing with non-core technologies, either in sourcing them externally or in commercialising those developed internally. Open innovation is linked to diversification. If technologies and markets are considered too unfamiliar, companies may want to step out by selling or spinning off activities.

### Knowledge management, absorptive capacity, and dynamic capabilities

Knowledge flows are a prime aspect of open innovation. However, how companies deal with and apply knowledge can differ substantially. Knowledge management and absorptive capacity are crucially important. For example, Dahlander and Gann (2010) conclude that internal R&D is a necessary complement to openness for outside ideas. To be able to unravel knowledge processes in open innovation, Lichtenthaler and Lichtenthaler (2009) distinguish between knowledge exploration, retention, and exploitation. Each of these can be either performed in-house (internally) or sourced externally. Taken together this provides a knowledge capacity framework which describes the company's critical capabilities of managing internal and external knowledge in open innovation processes, as shown in Table 3.

**Table 3: Six knowledge capacities in open innovation**

	Knowledge exploration	Knowledge retention	Knowledge exploitation
Internal (Intra-firm)	Inventive capacity	Transformative capacity	Innovative capacity
External (Inter-firm)	Absorptive capacity	Connective capacity	Desorptive capacity

**Source:** Lichtenthaler & Lichtenthaler (2009)

### Innovation intermediaries and tools to stimulate and accelerate open innovation

Using third-party innovation intermediaries or OIAs in searching for partners and solutions is one of the ways to implement and make open innovation work. Innovation intermediaries include technology intermediaries and technology transfer organisations, but also venture capitalists. Training institutes can also play an important bridging role. These intermediaries can help to accelerate open innovation by providing dedicated tools, methods and access to a community of solvers or participants. Their involvement can range from scanning and collecting information, communication, evaluation and foresight to data and knowledge processing and commercialisation. Their tools and methods range from crowd sourcing, toolkits for user innovation and co-design, to involving lead users, ideation and design contests, technology scouting, social media analysis, and crowd sourcing tournaments ('broadcast search'). OIAs can also provide training and process consulting (e.g. Howells, 2006; Sloane, 2011; Diener and Piller, 2013).

There are basically two types of innovation intermediaries: i) those that run open innovation projects on behalf of their clients and provide solutions, scouting and establish relationships with external partners, and ii) those that help and train companies in building own open innovation competences to engage in direct collaboration with external partners. Examples of third-party innovation intermediaries are NineSigma, InnoCentive, Yet2.com, YourEncore, Presans, InnoCentive, SpecialChem, Daily Grommet, Brainjuicer, Vworker, eYeka and Challenge Post. A recent study by RWTH Aachen identified over 180 active open innovation accelerator (OIA) players.<sup>2</sup>

<sup>2</sup> <http://www.innovationmanagement.se/2013/10/14/brokers-and-intermediaries-for-open-innovation-a-global-market-study/>

Another, more traditional way of open innovation collaboration is with private collective research centres (e.g. Spithoven et al., 2010 on relevant experiences and practices in Belgium) and public research organisations (PROs) or research and technology organisations (RTOs) such as the German Fraunhofer Gesellschaft, the Dutch TNO or, in a new very recent version, the UK Catapults.

### 2.3. Open innovation as regional and ecosystem building strategy

Although open innovation as a concept is first and foremost directed and applied to organisations, and in particular firms, it also has a wider bearing. For the more firms embrace the open innovation concept, the more the innovation ecosystem becomes open innovation-based. It is no surprise therefore that open innovation is also the subject of policy debate, because of its possible effect on national and regional innovation systems and ways to incentivise and stimulate positive change.

The notion of open innovation-driven innovation eco-systems is in the core of what the 2014 EU Independent Expert Group on Open Innovation and Knowledge Transfer has dubbed *Open Innovation 2.0* (Debackere et. 2014). The Expert Group proclaims a “new, advanced Open Innovation paradigm: building and funding ecosystems for co-creation”, where open innovation is taken to the ecosystem level, from “bilateral transactions and collaborations towards networked, multi-collaborative innovation ecosystems.” To make this happen, the Expert Group recommends implementing a European-wide Open Innovation 2.0 policy, with relevant stakeholders in Europe, with academia, business, government and society collaborating along and across industry value chains. According to Expert Group the co-creation approach to open innovation “adds up to more than simply sharing of and transacting on resources, risk and reward. It is about integrating across different value nodes throughout the ecosystem and thereby creating new markets and more effective business models, which wouldn’t exist otherwise.” A precondition for Open Innovation 2.0 is that all parts of the ecosystem are engaged in developing ‘exchange’ and ‘absorptive capacity’, and that ‘forces join at EU, Member State and regional level’. When it comes to policy-making, a bottom-up approach to setting up innovation infrastructures and strategies is favoured, alongside smart incentive mechanisms. Rather than just complementing EU funding with local funding, it is advocated “to leverage local investment with EU funding when dynamic, entrepreneurial actors have joined forces already”. Leveraging can apply to various types of funding mechanisms, including combining regional, national and European funding schemes. Apart from putting open innovation and knowledge transfer in the spotlight (Action 1), the Expert Group proposes three other action lines for Europe, notably to embrace innovative businesses, grow innovative markets, innovation hubs and networks (Action 2), to make universities and public research organisations (PROs) more entrepreneurial (Action 3) and smart integration of capital into the ecosystem (Action 4).

Whereas the Open Innovation 2.0 view is certainly not exclusively regional, it is clear that when it comes to innovation ecosystems and co-creation, the region is an important *locus* of action, with firms, higher education institutes (HEI), research organisations and government (regional and local) in close geographical proximity of each other and forming the base of existing and potential fruitful collaborations and cross-fertilisation.

In a similar vein as the Expert Group Open Innovation 2.0, but even more explicit, the EU Committee of the Regions (CoR) advocates “innovation communities [that] operate as ecosystems through systemic value networking... Regions need new arenas as hotspots for innovation co-creation”. (Markkula, 2014).



Some of the key points in its opinion on *Closing the Innovation Divide* include “i) stress the importance of innovation, of networking and collaboration in a deep sense, of modernising Triple Helix Regional Innovation Ecosystems, ii) encourage bottom-up activities: co-creation, co-design and co-production, working in true ‘know-how’ collaboration instead of just urging governments to develop new ‘solutions’ for citizens, and iii) strive for societal innovation, with living labs, test beds and open innovation methods in regional innovation policy-making, while getting citizens on board” (see Committee of the Regions, 2013; Markkula, 2014).

The concept of *smart specialisation*, one of the major new elements in European Cohesion Policy 2014-2020, engrains a similar philosophy. A Regional Innovation Strategies for Smart Specialisation (RIS3) requires smart, strategic choices and evidence-based policy making, with priorities based on a bottom-up entrepreneurial discovery process supported by strategic intelligence about a region’s assets, its challenges, competitive advantages and potential for excellence. The introduction of regional innovation strategies for smart specialisation as a pre-conditionality for funding, with policy tailored to its regional and local context and based on a process of bottom-up ‘entrepreneurial discovery’, is close to the notion of creating and developing innovation eco-systems. It is also specifically inviting to “exploiting new forms of innovation such as open and user-led innovation, social innovation and service innovation” as possible pathways towards regional innovation and development (European Commission, 2014). Key to RIS3 is the involvement of the *quadruple helix*: firms, research organisations, government (public sector) and civil society. Where the *triple helix* innovation model focuses on university-industry-government relations (Etzkowitz, 1993; Etzkowitz and Leydesdorff, 1995) and their interaction as the source of innovation and economic development in the knowledge economy, the Quadruple Helix model adds a fourth layer focusing on ‘civil society’ and the ‘media-based and culture-based public’, extending the perspective to the knowledge society and the knowledge democracy (Carayannis and Campbell, 2009). Creating ownership and joint responsibility is very much in the heart of the quadruple helix model.

**Figure 4: The Quadruple Helix innovation model**



**Source:** Salmelin, 2014

The notions of innovation eco-systems (e.g. Adner, 2006; Teece, 2007) and regional innovation systems (RIS) (e.g. are conceptually close to the cluster concept (e.g. Porter, 1998), even though the focus on innovation might be less explicit. Clusters can be defined as networks of interconnected companies and institutions, as geographic concentrations of companies, suppliers, service providers, and institutions that provide support such as R&D, education and trade. The relationship between clusters and open innovation has not received a lot of attention so far in the open innovation literature, with a few exceptions, such as Vanhaverbeke (2006) who observes that firms in embedded regional clusters are more inclined to employ open innovation strategies than other firms, and Cooke (2005) who points at open innovation as a factor in strengthening the competitiveness of regional innovation systems.

Huang and Rice (2013), analysing open innovation in relation to proximity and regional clustering based on data on almost 3,500 European firms, find that close geographical proximity tends to increase firm-university linkages, enhance inter-firm explicit and tacit knowledge flows and lead to comparatively less reliance on internal research and development. Schwerdtner et al. (2015) introduce a Regional Open Innovation Road mapping (ROIR) framework for innovation-based regional development.

A strong example of how open innovation is embraced by European regions themselves, in a bottom-up way, is the EURIS programme. In 2010 five European regions joined forces to promote open innovation at regional level, to 'open up EU Regional Innovation ecosystems' and to 'accelerate cooperation rates among innovation stakeholders' both within and between EU regions. EURIS (European Collaborative and Open Regional Innovation Strategies) was co-funded by the Interreg IV C programme and lasted four years, until 2014. The EURIS partnership was composed of the Navarra Government (Spain), the Stuttgart Region Economic Development Corporation (Germany), Brainport Development NV (The Netherlands), the West Transdanubia Regional Development Agency (Hungary) and Lodzkie Region (Poland). Strong emphasis was put on the transferability and dissemination of the programme's findings and lessons to other EU regions and the EU policy community.<sup>3</sup> This includes showcases of ten best company practices, ranging from Google and Netflix to the Arch abbey of Pannonhalma in Hungary and the El Bulli restaurant in Spain. It also covered 40 regional good practices based on both EURIS partner regions and other EU and non-EU region experiences (for a full list, see Annex 2).

OPINET, one of the EURIS's projects, created a network of Open Innovation Contact Points in Navarra, Stuttgart and West-Transdanubia aimed at promoting and facilitating Open Innovation strategies in SMEs, through disseminating open innovation SME best practice / success cases, practical guides, e.g. on how to deal with Intellectual Property right issues when collaborating, and identifying real open innovation opportunities for SMEs. Likewise, the ORP (Open Research Platform) project, aimed at enhancing technology transfer between academic institutions and companies in translating scientific achievements, developed an electronic tool to facilitate communication and exchange information between universities, companies, young and experienced entrepreneurs, and to act as a forum for exchange of good practices. Another EURIS project, HYBRISECTORS, developed a method for regional authorities and agencies to identify potential business opportunities at the intersection of sectors, markets and knowledge fields, termed 'hybridation', and to identify and stimulate hybridation projects. The method has been tested in pilot projects in the area of renewable energy and new materials (Navarra), in technology materials (Stuttgart) and in electro mobility (West-Transdanubia). The EURIS SFFS project assessed the potential impact of Shared Facilities (SF) & Facility Sharing (FS) schemes as a driver for open innovation in the automotive sector. The interest for SF initiatives is growing as they enable actors to work together on a pre-competitive basis. The role of government in realisation of new SF is essential, especially when it comes to financing. Sharing existing facilities (labelled FS) provides the owner the opportunity to increase the usage and lower his operational costs, with third parties getting access without having to invest. By opening up, new business relations and collaborations can be established, stimulating knowledge sharing and competence development. Findings show that rather than acting as a driver, in automotive SFFS function as an enabler, with high maturity of the ecosystem being a precondition for the development of SF and FS.

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<sup>3</sup> <http://www.euris-programme.eu/en/documents>



The most successful facility sharing initiatives appeared to be fully commercial and financed by private funds. The BMOI (Business Models for Open Innovation) projects explored ten company cases in three European regions with the aim of “generating actionable insights to help firms transform their business model(s) to profit from open innovation.” An overview of the 10 cases can be found in Annex 3.

EURIS, although focused and broad as a programme initiative is certainly not the only one to link regional initiative to open innovation. Another good example is the CLIQ network. CLIQ (Creating Local Innovation through a Quadruple Helix) that operates as a live open innovation system and disseminates processes and results during the project lifetime. The CLIQ network focuses on the role of local authorities in medium sized cities. One of its tools is the ‘CLIQ-o-Meter’, a self-evaluation tool developed to allow local government and innovation agencies to assess their current system and effectiveness in supporting innovation. CLIQ also aims to engage civil society through social media as a way to generate new ideas (see e.g. Deléarde, 2013). Other examples funded by the European Regional Development Fund (ERDF) include, among many: INNOPOLIS (European Collaborative and Open Regional Innovation Strategies) aimed at developing an open innovation environment; Open-Alps supporting SMEs in their innovation processes with external partners, as part of EU’s Alpine Space Programme; *Rapid Open Innovation*, a project aiming to improve the competitiveness of SMEs active in the field of eco-building, woodworking and mechanics in the Italian-Austrian border region; and the Open Innovation Project (IOIT) with various activities across the UK, France, Germany, Ireland and Belgium.<sup>4</sup> Last, but certainly not least, as already mentioned, open innovation is one of the pathways towards smart specialisation, having found its way in many of the strategic programming documents (i.e. Operational Programmes) of the 274 European regions covered by regional policy for the period 2014–2020.

#### 2.4. Open innovation as a participatory and grass-roots activity

Opening up the innovation process is the basic underlying idea of open innovation. Open innovation is a more distributed, more participatory and more decentralised approach to innovation than the traditional closed innovation model. Whereas firms have a key role to play in the open innovation concept (Chesbrough, 2003), the opening up of innovation to the outside world also involves users and citizens as innovation practitioners, going beyond the collaborating with other firms, external R&D labs or professional innovation intermediaries (e.g. Laursen and Salter, 2006). The user innovation concept (Von Hippel, 1988; 2005), which actually precedes the open innovation notion, has already underlined the importance and active involvement of users in the innovation process. User involvement can take various forms, from involving lead users, ideation and design contests to social media analysis, hackathons and crowd sourcing tournaments (‘broadcast search’). Howe (2009) defines crowd sourcing as “the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call.” Crowd sourcing can be used to generate ideas, services, or content from a large group of people, usually an online community.

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<sup>4</sup> See, e.g. <http://openinnovationproject.co.uk/>

The surge of digital technologies and sophisticated software, open source or proprietary, has further enabled the user and citizen involvement and hence the 'democratisation' of innovation, from idea generation to customised design and fabrication. 3D printing techniques can be regarded as the last addition to this set of user innovation tools. The price of computers, software, 3D printers and energy have gone down substantially in recent years, and their power and availability have increased likewise. Together they can form a powerful alternative, according to some, to traditional enterprise and the prevalence of market capitalism (e.g. Rifkin, 2014) and give rise to the birth of the 'prosumer'. The importance of customer involvement, however, is also acknowledged by established firms who proactively use it, also as a tool to attract and bind customers. Customer involvement in innovation is thus part of new business models which serve to out compete rivals by tying in consumers. Proctor & Gamble's 'Connect and Develop (C&D)' programme, for example, is said to have increased R&D productivity by nearly 60% and have doubled the innovation success rate (Huston and Sakkab, 2006). Firms can also establish communities to enable individuals to start using their products (Jeppesen and Frederiksen, 2006).

User communities, or generally more open innovation communities, have increasingly become influential drivers of innovation (Dahlander and Gann, 2010). Communities of innovation (COI) can be seen as a subset of communities of practice (COP), with a strong focus on innovation. Communities of practice are "groups of people who share a concern, a set of problems, or passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wenger et al., 2002). There is, however, a strong diversity in conceptual notions that go under the heading of community (e.g. West and Lakhani, 2008). For example, Fleming and Waguespack (2007) define an open innovation community as "a group of unpaid volunteers who work informally, attempt to keep their processes of innovation public and available to any qualified contributor, and seek to distribute their work at no charge", resembling very much the spirit of the open source concept. However, Fichter (2009) takes a rather different view, when he defines an innovation community as "an informal network of likeminded individuals, acting as universal or specialised promoters, often from more than one company and different organisations that team up in a project related fashion, and commonly promote a specific innovation, either on one or across different levels of an innovation system." Another, again different, notion of open innovation communities is online communities, which includes social networking sites such as Facebook and Twitter, which with their multi-million membership allow individuals to share experiences and socialise with each other (e.g. Dahlander et al., 2008).

Open innovation communities can form an important external source of innovation, especially for those who are able to implement a constructive enduring relationship with those communities (Dahlander and Magnusson, 2005). Users or citizens that are part of these communities not only are able to develop innovations, but also help to develop new user perspectives, create a shared understanding of the innovation and its features, and can even build product or firm loyalty and create a sense of belonging and meaning among its members (Dahlander et al. 2008; Rindova and Petkova, 2007). Not only functional aspects and features of products matter, but also symbolic and aesthetic value (ibidem).

As Fleming and Waguespack (2007) point out "(o)pen innovation communities typically lack financial or corporate backing, forgo personal ownership rights to their members' work, rely on volunteers, and eschew formal planning and management structures.... Despite their bazaar like, egalitarian, argumentative, unplanned, chaotic appearance, open innovation communities rely heavily on strong leadership to function effectively and to resist splintering, forking, and balkanization". Governance of innovation communities is an important issue (Von Hippel and Von Krogh, 2003; Fleming and Waguespack, 2007).

The open innovation community concept bears a strong resemblance to the notion of *grassroots innovation movement*. Like in open innovation communities, innovation is also here bottom-up driven. However, grassroots innovation movements are, however, ideologically inspired, seeking innovation processes and outcomes that are socially inclusive towards local communities, responding to the local situation and the interests and values of the communities involved. Grassroots innovation movements typically arise in reaction to perceived social injustice or environmental problems or ideals such as independence in terms of energy supply (energy autonomy), being healthy or striving for other ideals. Grassroots innovation can be found in a wide range of applications, from alternative food networks, community energy projects, furniture-recycling schemes, eco-villages to low-impact development (e.g. Church and Elster, 2002; Seyfang and Smith, 2007)<sup>5</sup>.

Grassroots innovations should be distinguished from *frugal innovations*. Frugal innovation, also known as minimalist- or reverse innovation, goes back to 'frugal engineering', a term first used by Carlos Ghosn, CEO of Renault (Rao, 2013). Frugal engineering refers to of reducing the complexity and cost of a product, often by leaving out nonessential features, to make a product attractive and affordable in other markets. Frugal innovations are foremost aimed at developing and emerging economies and are typically intended for low-income consumers at the base of the pyramid. A frugal innovation is cheap, tough, easy to use and developed with minimal amounts of raw materials (The Economist, 2010). A prime example of frugal innovation is *Jugaad*, a concept that has been adopted in management philosophy (Krishnan, 2010; Radjiou et al., 2010). The Jugaad signifies a makeshift cart assembled in north India, under scarce resources, for handling routine chores.

## 2.5. Key issues in open innovation – a future perspective

Whereas various key issues of open innovation have been reviewed so far, this section takes a more forward-looking perspective. What are the issues that require attention, need to be pursued, and are high on the agenda in the coming years? This section cannot be more than, and necessarily is, a selection of relevant topics and arbitrary therefore by its very nature. However, to provide a balanced overview of topics, a number of recent articles on the future of open innovation were taken as point of departure, notably Gassman et al., 2010; West et al., 2014; Chesbrough et al., 2014a; Huizingh (2011) and others.

### Intellectual property, Open Innovation, and behaviour towards risk

Intellectual property (IP) has become increasingly important in today's knowledge economy. An efficient IP system is key for the further development of R&D collaboration and technology transfer as one of the core elements in open innovation. Crucial is finding a right balance between protection of ideas based on exclusive and proprietary rights on the one hand and the right to freely use and to commercialise on the other. Clearly this involves making delicate decision about risk and who and what is to be trusted or not. Or, stated differently, balancing between risk-taking and promoting cumulative innovation (Gassmann et al., 2010). As Chesbrough and Vanhaverbeke (2011), Veugelers (2009), Vallat (2009) and others have pointed out the current IP system in Europe needs serious reconsideration, for a number of reasons.

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<sup>5</sup> Seyfang and Smith (2007) define grassroots innovations as "innovative networks of activists and organisations that lead bottom-up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved... Grassroots initiatives tend to operate in civil society arenas and involve committed activists who experiment with social innovations as well as using greener technologies and techniques".

The relative costs of a European patent is still substantially higher than our major competitors such as the US, with a high level of fragmentation, and a serious financial burden for start-ups and small companies.

Van Pottelsberghe de la Potterie (2010) suggests a substantial reduction in entry fees for young innovative companies. Furthermore, the time to grant a patent by the European Patent office (EPO) is still considerably higher than the grant time required by the Japan Patent Office (JPO) or the US Patent Office (USPTO). Although the European IP regime is currently in a phase of reform and improvements are under way, there is still room for additional action.

Activating unused IP is another major challenge, although important progress has been made over the last years. An interesting development in this respect is the emergence of IP auctions, with Europe's largest auctioneer Ocean Tomo<sup>6</sup> starting in 2007 (Gassman et al., 2010), and global IP marketplaces such as 'yet2'. The establishment of patent funds (such as those by Deutsche Bank and Credit Suisse) which buy IP from universities and high-tech ventures and leverage its value through professional management is another development; this also holds for the emergence of IP integrators, IP insurers and even intellectual commons where IP is pooled and shared (ibidem). Also some large companies have opened up to activate unused IP. For example, IP ventures established by and as part of Microsoft actively partner with start-ups, venture capitalists and government agencies to take Microsoft Research inventions further (Chesbrough and Vanhaverbeke, 2011). Another example is IBM's IP Collaborative Innovation Initiative pledging 500 patents to open source communities and launching an open innovation network (ibidem). Recently, European RTOs, notably Dutch TNO, has started to more actively manage and open up its IP portfolio to start-ups and SMEs. Another development worth mentioning is the emergence of large scale pre-competitive technology collaborations in which predefined IP-models are used to deal with IP ownership of jointly developed technologies (Chesbrough and Vanhaverbeke, 2011). An example is the so-called fingerprint IP-model used by IMEC or CTMM (Odusanya et al., 2008).

### **Open Innovation management, risk management and trust**

One of the main challenges in open innovation is open innovation management. This requires not only managing decentralised innovation processes inside and outside the company, but also the challenge of managing virtual R&D teams (Gassmann et al., 2010) and more broadly the governance of online communities. Especially the latter, with individuals participating in these communities and who are beyond the firms' hierarchical realms (Dahlander et al., 2008) can make it difficult for firms to steer the direction of development (Dahlander and Wallin, 2006). This also includes the perception of and the way in which risk is tackled, e.g. how to deal with intellectual property such as the copying of good ideas in an early phase. Or, related, the ways in which relations come about and trust is found and built.

A large number of players with different goals, capabilities and diverse degrees of involvement, raises the importance of governance which increases the resources firms have to spend as well as the risk of such investments (ibidem). Due to their small size and inherent lack of resources, open innovation management is in particular an issue for SMEs. Open innovation is appealing to SMEs and interest has been growing in recent years and the 'liability of smallness' can sometimes be overcome by opening up (Gassmann et al., 2010). Liability of smallness is another form of risk that is faced in open innovation.

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<sup>6</sup> Since 2009 ICAP Ocean Tomo, later renamed ICAP Patent Brokerage.

As a result the adoption and implementation of open innovation by SMEs still is behind that of large multinational corporations. As Brunswicker and Van de Vrande (2014) and others have pointed out knowledge management and innovation management capacities, which are important facilitators for open innovation, are regularly lacking in SMEs.

This applies to both internally and externally, as open innovation requires sufficient capability for managing network relationships.

### **Increasing importance of innomediaries in building trust and reducing risk**

Over the last decade a new type of innovation service providers has emerged, innovation intermediaries, alternately termed 'innomediaries' (Chesbrough and Vanhaverbeke, 2011) open innovation accelerators (OIA) (Diener and Piller, 2013), 'OI solution brokerage houses' (Saguy and Sirotinskaya, 2014) or 'solver brokerages' (Feller et al., 2009). What these innovation intermediaries do is to aggregate demand for innovation capabilities (firms seeking innovators capable of meeting specific challenges) and ditto supply (the population of innovators). What exemplifies the new generation innomediaries is the strong use of software platforms and software solutions. According to recent research by the RWTH Aachen there are currently more than 180 mature OIAs, each having a pool of participants ('community') of 20,000 members on average (Diener and Piller, 2013). But large differences exist, with OIAs specialising in ideation and contests often having communities of over a 100,000 members. OIAs that offer search services such as technology scouting have in general access to high level expert communities. OIAs hence form an important bridge function, in establishing trust and in lowering the perceived risk of entering the open innovation scene. The membership of OIAs focusing on ideation and concept generation is broader and more heterogeneous, and is also perceived as the most promising open innovation format by OIAs themselves, covering about 80% of the market (ibidem). The global OIA market was estimated to have EUR 2.7 billion in 2013 and was expected to double within two years (based on self-assessment of the companies surveyed). The OIA market is highly dynamic, with 20% of the 2010 OIA players non-existent by 2013 and numerous mergers and acquisitions have taken place. The way OIA work is that prospective participants have to accept general terms and conditions, but generally do not sign a formal contract, which differentiated OIA from more traditional forms of R&D networks or alliances. About a third offer their clients the opportunity to select participants based on matching certain socio-demographic criteria (ibidem).

### **Measuring open innovation activities, costs and benefits and performance**

An important challenge is new and better approaches to measuring innovation (see e.g. West et al., 2014; Gassmann et al., 2010; Brunswicker and Van de Vrande, 2014). Most research on open innovation so far has taken the form of case studies. Case studies are typically qualitative and descriptive in nature. They are rich in detail and well-suited for identifying existing industry practices, cooperative patterns and relationships and the contextual characteristics of open innovation. But what has only marginally been explored so far is large scale quantitative studies. Large scale quantitative studies allow greater generalisability and a better understanding of what can be expected from open innovation deployment in terms of its costs (see for an example Faems et al., 2010), benefits (see for an example Spithoven et al., 2013) or innovation results and performance at large. Large quantitative studies are also better able to reveal differences in open innovation implementation and performance between different sectors and between different countries, and to quantify the relative importance of practices and factors, causalities, and test for context dependencies (e.g. Huizingh, 2011).



Large scale quantitative studies require the use of large open innovation data samples, such as survey data, patent data (e.g. Love et al., 2011), financial data and other evidence such as company reports, press releases, news articles (by means of content analysis). Existing data sources offer an appropriate stepping stone for such research, such as the EU Community Innovation Survey (CIS) which has in some cases been used for open innovation research, starting with Laursen and Salter (2006).

The current rise of big data and data analytics offers another new interesting alley for further research (Brunswick et al., 2015). However, large scale empirical data research comes with significant challenges, most importantly as relevant firm-level data are neither easily available nor accessible.

On top of this large scale research does not only need to involve cross-sectional data analysis but would also need to involve time-series - longitudinal - analysis to investigate change and transition processes as a result of open innovation over time.

### **Building innovation eco-systems**

As highlighted in section 2.3, the idea of open innovation and building innovation eco-systems is inextricably linked to the *Open Innovation 2.0* concept promoted by the 2014 independent EU Expert Group on Open Innovation. Inter-organisational networks are crucial to the development of open innovation (Gassmann et al., 2010). As West et al. (2014) point out different innovation networks each have their own distinct forms of governance: alliance networks differ from open innovation communities and platforms (see above). In building innovation eco-systems financing is an important issue. At the end of the 1990s the increasing importance of venture capital was one of the 'erosion factors' that led to the decline of closed innovation (Chesbrough, 2003). Venture capital (VC) has over time played an important role in supporting start-ups (seed capital) and in leveraging young companies and bridging the valley of death. However, the great recession of 2008 and beyond led to a strong decline in available VC funding, especially in Europe which traditionally has a substantially smaller VC market than the USA. Funding is especially important for innovative start-ups and small enterprises, which encounter several 'valleys of death' along their development path. Vanhaverbeke et al., (2014) point at the possible link between the penetration of venture capitalists in a country, the perception of open innovation and how open innovation works, and differences between northern and southern Europe. The Expert Group on Open Innovation advocates (Debackere et al., 2014) advocates to build more innovation-friendly financial instruments and institutions, in particular a smart funding system, in which various players work together. It also calls on the EC to stimulate the emergence and development of online collaborative funding platforms, including crowd funding.

### **Spreading Open Innovation and beyond: the Future of Open Innovation**

In the future years the further opening up of innovation will be a main topic. Challenges are the so far 'untouched' sectors, such as the automotive sector but also the service sector at large (Gassmann et al., 2010; Chesbrough, 2010; Mina et al, 2014). Spreading also applies to introducing open innovation to new contexts, e.g. to non-profit organisations and more to small firms (West et al., 2014). Important from a value added and innovation performance perspective is also cross-industry open innovation (Gassmann et al., 2010). For spreading open innovation, the dissemination of best practices, new targeted policy initiatives (smart funding) but also the surge of innomediaries is important. Open innovation is likely to stay on the agenda of companies, governments but also, and naturally, in fast growing open innovation communities and platforms. Since the early 2000s open innovation has spread already substantially. What will be its future?

The mainstreaming of open innovation will most likely continue, which may lead to a point where open innovation becomes 'business as usual'. This brings Huizingh (2011) to conclude that "... that we should not be surprised to learn that within a decade, the term will fade away. Not because the concept has lost its usefulness, but, on the contrary, because it has been fully integrated in innovation management practices."

### 3. 3D PRINTING – REFRAMING THE VALUE CHAIN

#### KEY FINDINGS

- 3D printing and additive manufacturing are on the peak of inflated expectations. Rapid reduction in cost of 3D printers, increase in accuracy, increase in the variety of supporting material, and expiration of critical patents provide a context for accelerating innovation and application of this emergent technology.
- Industrial 3D printing (additive manufacturing) is on the way to change production lines and value chains. Functions like tooling and welding became obsolete and first small production lines have been replaced. In health and dentistry the dynamic is highest. In the long run, additive manufacturing enables a shift from mass production to mass customisation.
- Consumer 3D printing is in its infancy, so far. So further development is embedded in the context of a sharing and crowd based community and new business models have been developed. In the medium term consumer 3D printing in 'fab labs' have a promising potential for technical learning, urban development and co-working in craftsmanship and creativity sectors.
- There are implications for the labour market and for regional development but the intensity and direction is open depending on application strategies, new business models and regulation.
- Technical innovation in additive manufacturing and 3D printing is speeding up and supported by European programmes. The social aspect, consequences for the labour market and the work flow and new business models need further research and development.

Additive manufacturing and consumer 3D printing develop in different contexts. Intellectual property right is the key conflict. The link between 3D printing in industry and fab labs is promising for technical learning, customer driven innovation, and urban development but so far there are very few examples that make use of this potential.

This chapter examines 3D printing and additive manufacturing. It starts with a first look at the history and the technology. The second section presents the key actors and networks in the field of 3D printing and additive manufacturing. The following sections discuss the state of the art and trends in industrial 3D printing (additive manufacturing, originally labelled as rapid prototyping) and two approaches of personal 3D printing (makers and fab labs). The following section summarises the way 3D printing and additive manufacturing has been part of European projects. The concluding section compares the different phases in 3D printing and additive manufacturing and looks for societal implications (education and qualification, re-regionalisation) of this emergent technology.



### 3.1. 3D printing and additive manufacturing - a first overview

In 2008/2009 3D printing gained broad public interest. Gardner, a business consulting company well known with reports on emerging technologies included 3D printing in their reports and soon raised 3D printing to “the peak of inflated expectations” where it stays until today. In 2009 The Economist published a case history “A factory on your desk” and headlined the “ability of 3-D printers to speed up the design process will have big impact on industry” (The Economist 2009). From then on nearly weekly new examples of up-coming 3D printing came into the media: a Finnish band performed a concert with 3D printed instruments, a ‘Stradivarius’ violin has been printed, the first house and the first car became constructed by 3D printing, a toucan in Costa Rica which lost the upper part of its beak after being attacked by youths looks set to be fitted with a 3D printed prosthetic replacement, and so on.

In industry the roots of 3D printing go back to the 1980s. In the beginning it was implemented as ‘rapid manufacturing’ and in the middle of the 2000s the notion ‘additive manufacturing’ gained acceptance.

Additive manufacturing or 3D printing stands for a group of technologies that build physical objects directly from 3D (Computer-Aided Design – CAD) data. In contrast with established subtractive manufacturing technologies (cutting, lathing, tuning, milling or machining) in additive manufacturing the object is built up by the consecutive addition of liquids, sheet or powdered materials in ultra-thin layers (DMRC 2013: 13).<sup>7</sup>

**Box 1: Additive Manufacturing Definitions by the ASTM International Committee F42**

Additive manufacturing is the “process of joining materials to make objects from 3D model data, usually layer by layer, as opposed to subtractive manufacturing methods. Synonyms include additive fabrication, additive processes, additive techniques, additive layer manufacturing, and additive fabrication.”

3D printing is the “fabrication of objects through the deposition of a material using a print head, nozzle, or other printer technology. However, the term is often used synonymously with additive manufacturing. It particular it is associated with machines that are lower in price and overall functional capability.”

(Quoted by Wohler Report 2014: 13)

The virtual model (CAD, programmed or scanned) stands at the beginning of the process. In a second step it has to be segmented in single layers and programs a sliced model. This model bases the core process, the construction (or printing). The object is printed layer by layer. In parallel, supporting material is generated in order to stabilize out sticking or overhanging material. Once the printing is finished the model is identical with the virtual one and the supporting material can be extracted in a mechanical way (Pickert/Wirth 2013). In certain cases some postproduction work is needed after printing (sintering, heat treating) to achieve desired quality (strength or hardness, sanding or polishing) (Hornick/Roland 2013).

<sup>7</sup> Additive manufacturing is not the only way to make a solid object from a digital model. Early CNC machines based on computer aided manufacturing (CAM) and had been invented in 1952 and spread in manufacturing since the 1970ies. They work in a subtractive way (Bohne 2013, Gershenfeld 2012).

DMRC (2013) distinguishes between two groups of additive manufacturing technologies. Laser-based processes based on layer-wise solidification by applying energy via laser. Nozzle-based processes make use of wire-shaped thermoplastics that are partly melted and extruded in the nozzle.

There are some roots in topography and photo sculpture of the 19<sup>th</sup> century but modern additive manufacturing started in the 1980s with first experiments in the Battelle Memorial Institute.<sup>8</sup> The milestones in the development of 3D printing are:

- the patent of Charles Hull in 1986 led to the commercialisation and industrial application of 3D systems;
- at this early stage additive manufacturing (AM) technologies have been used for creating prototypes using resins and polymers (rapid prototyping);
- in 1995 the first commercial metal based additive manufacturing system was introduced (rapid manufacturing);
- in 1996 ZCorp introduced the term 3D printing;
- in 2002 Gershenfeld set up the first fab lab in Boston and started an outreach programme;
- in 2007 the RepRap Project started at the University of Bath by Adrian Bowyer and aimed at 3D Printers that could re-print most of its own components;
- in 2009 MakerBots Industry was founded which brought the first consumer-friendly open-source based 3D printer on the market and launched; in parallel Thingiverse recently the most popular 3D printing repository was launched;
- in 2009 the ASTM international Committee on additive manufacturing was set up to standardise terminology and lay the foundations for product, processes and material certification around 3D printing;
- in 2009 was the year when the first consumer-directed 3D printing service came online (Shapeways).

Additive manufacturing is based on a complex combination of different technologies. Zhao et.al. (2014) analysed publications related to 3D printing and worked out five leading fields of technology: multidisciplinary material science, applied physics, engineering/electrical/electronic, optics, and nanoscience/nanotechnology. Further technologies involved are engineering (manufacturing, mechanical, biological), chemistry (multidisciplinary and physical), or instruments/instrumentation.

Today, most studies present six or seven different basic types (Table 4). The basic materials are polymers and metals; biological material is of rising importance for health. The most advanced 3D printers in industry combine different materials and modes of fixing whereas printers for private households and small creative industries are single material printers (polymers), so far.

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<sup>8</sup> Information about the history of technical and industrial aspects is available in the appendix of the annual Wohlers Report (Wohlers/Gornet 2014). Bourell et. al (2009) introduce the prehistory in the 19<sup>th</sup> century. Troxler/van Woensel (2014) and Troxler (2015) give an overview from the open source point of view. The Wohlers Report is the most comprehensive Report about the state of additive manufacturing in industry. The first report came out in 1993 and was about rapid prototyping. In 2007 the focus was called 'additive fabrication' and in 2011 it was about additive manufacturing and 3D printing.  
<http://www.wohlersassociates.com/state-of-the-industry-reports.html>

**Table 4: Basic types of 3D printing**

TECHNOLOGY	MATERIALS	TYPICAL MARKETS
<b>Powder bed fusion –</b> Thermal energy selectively fuses regions of a powder bed	Metals, polymers	Prototyping, direct part
<b>Directed energy deposition –</b> Focused thermal energy is used to fuse materials by melting as the material is deposited	Metals	Direct part, repair
<b>Sheet lamination –</b> Sheets of material are bonded to form an object	Metals, paper	Prototyping, direct part
<b>Binder jetting –</b> Liquid bonding agent is selectively deposited to join powder material	Metals, polymers, foundry sand	Prototyping, direct part, casting moulds
<b>Material jetting –</b> Droplets of build material are selectively deposited	Polymers, waxes	Prototyping, casting patterns
<b>Material extrusion –</b> Material are selectively dispensed through a nozzle or orifice	Polymers	Prototyping
<b>Vat photopolymerisation –</b> Liquid photopolymer in a vat is selectively cured by light-activated polymerisation	Photopolymers	Prototyping

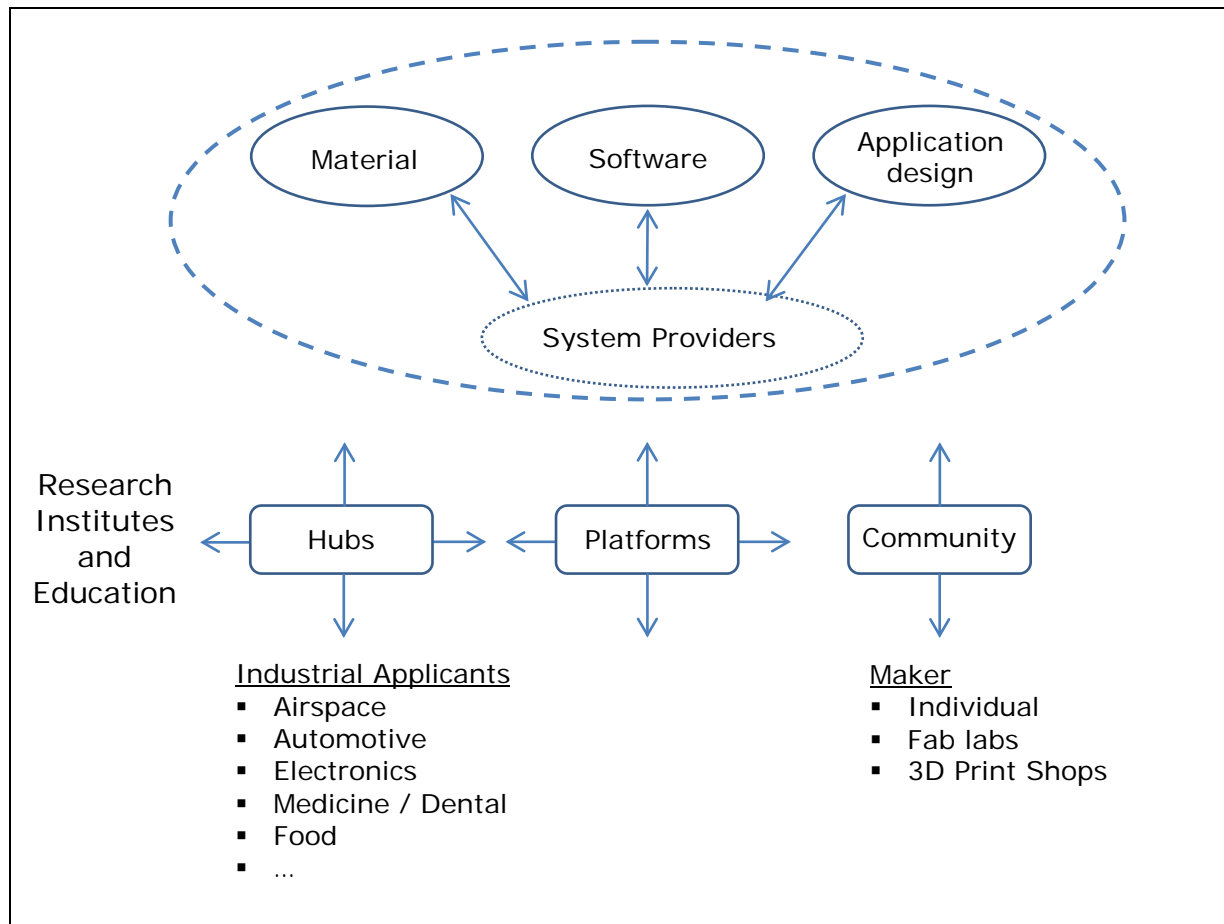
**Source:** Roland Berger 2013: slide 14.

Accordingly to the common language usage (see Box 1) in this chapter ‘additive manufacturing’ refers to the application in industrial processes whereas ‘3D printing’ addresses 3D printing in fab labs or by private makers. ‘3D printing’ is also used when both aspects are mentioned.

### 3.2. The value chain – actors and interactions

The value chain in the case of additive manufacturing is at its infancy phase and still very heterogeneous. Several small players are involved, specialised SMEs, as well as leading multinational companies. Four groups of actors or actor networks are present in the broader field of additive manufacturing (Figure 5).<sup>9</sup>

**Figure 5: Key actors in the additive manufacturing value chain**

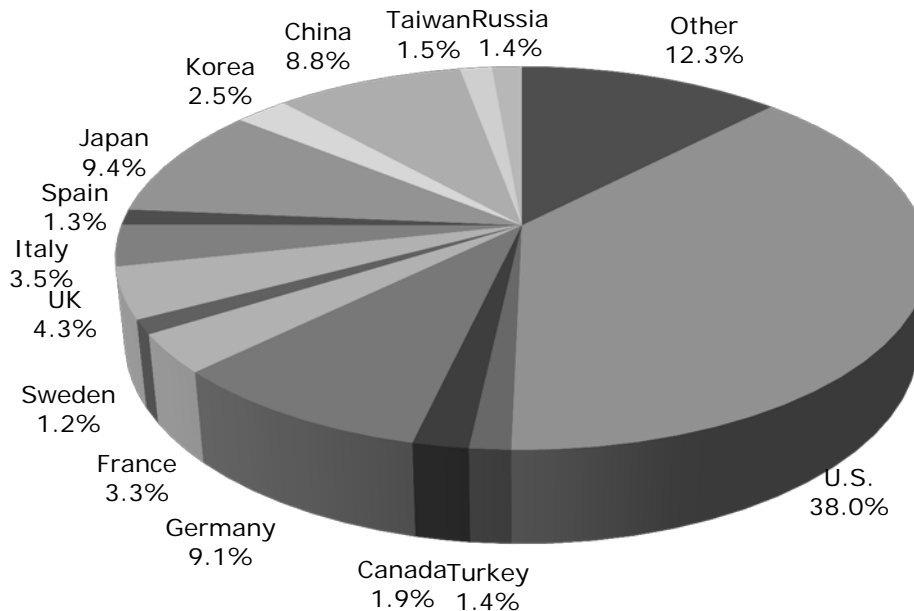


**Source:** IAT, own compilation

The first group includes those companies that are directly involved in the development and production of additive manufacturing systems and related materials and components (cf. Berger 2013, slide 20). The system providers usually based on a stand-alone powder bed fusion system. Most of them have of low level of vertical integration and source standard components by contract manufactures. They integrate components and software. Software providers are active in different fields of process control and enhancement software. Specialist companies develop add-on software like automatic support generation, design optimisation. Further companies are material providers. They deliver powder with high purity and a very narrow distribution of the granular size.

<sup>9</sup> The actors in personal 3D Printing are discussed in 3.3 and 3.4.

**Figure 6: Regional distribution of producers of additive manufacturing and 3D printers**



**Source:** Wohlers 2014:26.

Figure 6 shows that 38% of the producers are located in the USA. Germany, Japan and China count for approximately 9% of the market share each. Companies from countries all over the world are involved. This shows that there is an ongoing fragmented and growing market and a lot of possibilities to join. Box 2 presents an example from Eastern Europe: Zortax, a very young Polish company that came on the scene since it acquired the largest contract for 3D printers, so far.

**Box 2: Zordax - a successful start-up from Eastern Europe**

Zortrax was founded in 2011 and is a Polish manufacturer for professional 3D solutions. Zortrax gathered some interesting publicity when they were launched and they have built a few solid 3D printers after creating a burgeoning 3D printer part business in Central Europe.

The roots of the company go back to 2001 when Rafal Tomasiak and Michal Olchanowski from the Masuria region met and became interested in the potentials of the internet. They studied marketing at the School of Finances and Management in Elk, Poland and after this they worked on apps for mobile phones. In between they moved to Hongkong but Rafal Tomasiak returned to Poland.

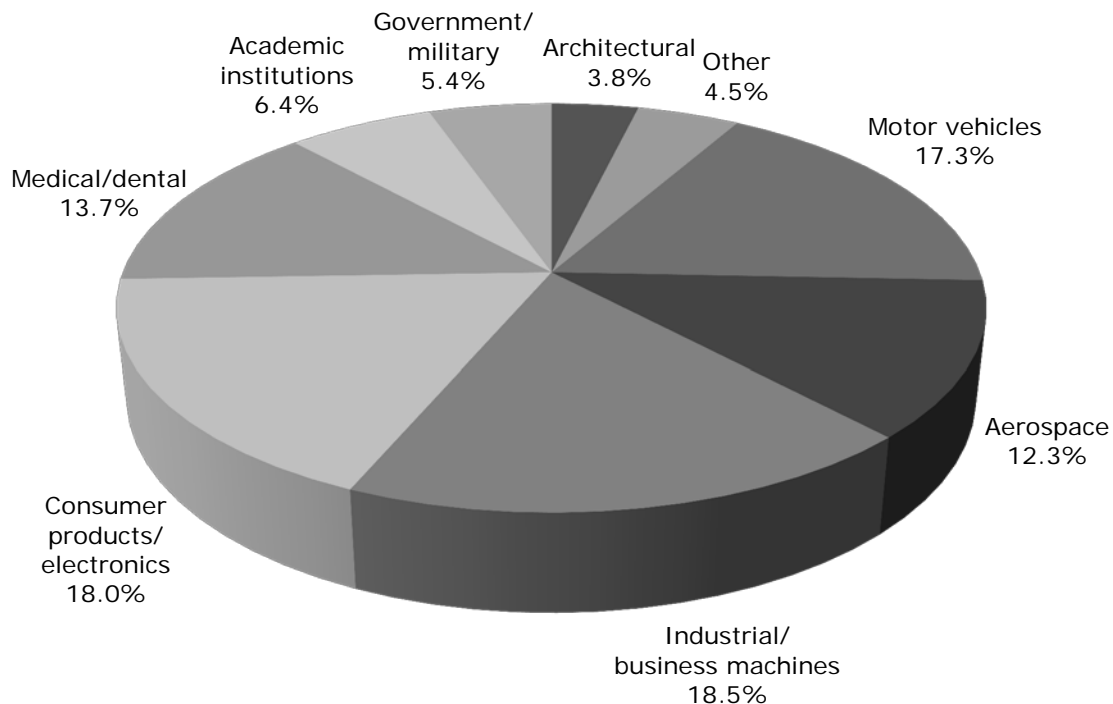
Around 2010 they started developing a 3D printer. The initial idea was to develop and to produce a smaller 3D printer than earlier models. At the first stage single elements of a 3D printer were developed. With these experiments, developments and proofs took place as long as the prototype could be created. From this stage it took 2.5 years for the first prototype of a 3D printer to be developed. In 2013 the 3D printer Zortrax M-200 was ready to be marketed. Further members joined the team, especially among them Karolina Boladz responsible for marketing and promotion issues. In 2014 a Zordax Retail Store in Krakow was opened. The financing of the 3D printer was accomplished through a crowd founding (kickstarter.com) platform where the printer also was launched. They collected \$180.000 but in the end the crowd founding platform was even used for the promotion of the product. Dell has been attracted through this platform and in 2004 ordered 5 000 units, the biggest deal in this new industry, so far. Further information:

<https://zortrax.com/>

<http://techcrunch.com/2014/01/22/polish-3d-printer-zortrax-sells-5000-units-to-dell/>

The second group entails companies that apply 3D printing (Figure 7). Companies from aerospace, automotive and electronics are lead users. In medical and especially dental the share of 3D printed objects is fast growing.

**Figure 7: Users of additive manufacturing and 3D printing by sectors**



**Source:** Wohlers 2014:18.

The third group covers knowledge and education institutions. Topics of basic and applied research projects are designing for additive manufacturing, rapid product development, metal casting, high-performance tooling, medical modelling, tissue engineering, architectural modelling, and 3D scanning (Wohlers 2014: 214). Certificate and degree programmes aiming at additive manufacturing have been launched in the last years in several universities. The Wohlers Report (2014: 215ff) lists 84 institutions all over the world that are active in research and education in the field of additive manufacturing.

Despite of differentiated and growing academic research, the key players in patenting come from the industrial sector. In 2013, three fourths of the patents issued came from companies, 10% from universities as well as from individual actors, 6% from non-profit laboratories (Wohlers 2014: 197). The key applicants for patents are located in the USA (3D systems, Stratasys, Hewlett Packard, Boeing), in Japan (Matsushita, Seiko-Epson, Panasonic, Sony, JSR, CMET), and Germany (EOS, MTU, Fraunhofer, Degussa, Siemens, cf. Economica 2014: slide 18).

The fourth group includes different platforms and networks that bring together actors from the heterogeneous fields of additive manufacturing.

Firstly, there are platforms dealing with standardisation. On the global level the **ASTM Committee F42 on Additive Manufacturing Technologies** was formed in 2009. F42 meets twice a year with about 70 members attending two days of technical meetings. The Committee, with a current membership of approximately 215, has four technical subcommittees. All standards developed by F42 are published in the Annual Book of ASTM Standards, Volume 10.04<sup>10</sup>.

In 2011, ISO (International Organization for Standardization) established a technical committee ISO/TC 261 additive manufacturing. Standardisation institutes from 19 countries are involved. Standards concerning additive manufacturing processes, terms and definitions, process chains (hard- and software), test procedures, quality parameters, supply agreements and all kinds of fundamentals are on the agenda<sup>11</sup>.

Further on, the **European Committee for Standardisation (CEN)** covers topics related to additive manufacturing and first steps to coordinate the different standardisation activities are on the way (SASAM 2014).

Secondly platforms have been launched to organise and structure the new field of additive manufacturing. The **European Additive Manufacturing Group (EAMG)** was launched in May 2013. Members are companies and organisations across the supply chain. Four objectives are addressed:

- "to increase the awareness of the Additive Manufacturing technology, with a special focus on metal powder based products;
- to enable the benefits of joint action, for example through research programmes, workshops, benchmarking and exchange of knowledge;
- to improve the understanding of the benefits of metal based AM technology by end users, designers, mechanical engineers, metallurgists and students;
- to assist in the development of international standards for the AM Sector.<sup>12"</sup>

The European **AM-platform** (formerly Rapid Manufacturing platform) is active since 2007 and aims at organising this fragmented sector. The objective of the AM-platform is to contribute to a coherent strategy, understanding, development, dissemination and exploitation of AM and it is committed to the strategic targets of the EU<sup>13</sup>.

In the USA **America Makes** (founded in 2012 and opened in 2013) is the National Additive Manufacturing Innovation Institute. They claim to help "the United States grow capabilities and strength in 3D printing, also known as additive manufacturing, by fostering collaboration in design, materials, technology, workforce and more." America Makes aims at facilitating collaboration among leaders from business, academia, non-profit organisations and government agencies and focus on areas that include design, materials, technology, workforce and more.<sup>14</sup>

<sup>10</sup> <http://www.astm.org/COMMITTEE/F42.htm>

<sup>11</sup> See:

[http://www.iso.org/iso/standards\\_development/technical\\_committees/other\\_bodies/iso\\_technical\\_committee.htm?commid=629086](http://www.iso.org/iso/standards_development/technical_committees/other_bodies/iso_technical_committee.htm?commid=629086)

<sup>12</sup> <http://www.epma.com/european-additive-manufacturing-group>

<sup>13</sup> <http://www.rm-platform.com>

<sup>14</sup> <http://americamakes.us/>



Thirdly, there are research institutes based on networks of academics and industry. One of the leading European institutes is the **EPSRC Centre for Innovative Manufacturing in Additive Manufacturing** based at the university in Nottingham. The centre works closely with businesses to tackle major research challenges “ensuring that the UK remains at the forefront of AM and its application in industry”<sup>15</sup>. A further prominent European example is the DMRC in Paderborn (cf. Box 3).

**Box 3: DMRC Paderborn, Germany**

Direct Manufacturing Research Center (DMRC) was founded in 2008/9 in Paderborn by Boeing, EOS Electro Optical Systems, Evonik Industries und SLM Solutions GmbH in cooperation with the University Paderborn. Further partners joined: Stratasys, Blue Production, Stükerjürgen, Aerospace Composites, Phoenix Contact, HuH, Liebherr, the LEGO Group, Siemens, and Baker Hughes. The institutes of the University Paderborn cover research in lightweight construction, mechatronics, modelling and simulation, particle technology, polymer materials, and product engineering. All projects under the umbrella of DMRC are university – industry joint projects.

DMRC is funded by the North Rhine Westphalia state government and has strong ties with ‘its OWL’ the German flagship cluster on Industry 4.0 (in East Westphalia Lippe)

The DMRC aims at:

- further development of technological innovation applied in direct manufacturing in serial production;
- transfer and implementation of AM-technologies in new and established companies;
- promoting the corresponding paradigm change from product based design to function based design;
- training and qualification of a new generation of engineers;
- realisation of independent market studies and assessment of methods and processes;
- realisation of scenario-projections modelling the future of direct manufacturing;
- international well-known platform for exchange of best practice and optimal processes. Further information: <https://dmrc.uni-paderborn.de>

### 3.3. Industrial 3D printing: additive manufacturing

Industrial 3D printing or additive manufacturing is seen as a disruptive technology that is on the way to transform methods of production, especially of mass production and of mass customisation. The role, speed and impact of the implementation of additive manufacturing differ and depend on the industrial context and/or the company’s strategy. All approaches have in common the future challenge that lies in the IT-based integration of manufacturing systems aiming at flexible and custom specific production. Further on, there is a widespread consensus that the productive sectors will be of ongoing if not rising importance for economic competitiveness.

Sabo (2015) compares the implementation of additive manufacturing in Europe and in the USA and concludes that there is a difference in the focus: the European approach aims at integrating the different functions of the production process. It uses the connection to the cloud and sensors to actively adjust a physical thing to a current cyber physical system. In

<sup>15</sup> <http://www.3dp-research.com/About-EPSRC-additive-manufacturing>



contrast, the US approach sees the Internet of Things (IoT) as an infrastructure, which collects information and controls itself and other things in the physical space (Sabo 2015, 8f).

But further differentiation is needed because there are more contexts that frame the mode of implementation, especially the sectoral one. Therefore, the following discussion is structured by the depth of implementation. It starts with a look at the state of the art and concludes with the most far reaching vision.

### **Integrating additive manufacturing in the production line – state of the art**

The German discussion as well as large parts of the European discussion on industry 4.0<sup>16</sup> sees additive manufacturing as one element in of the up-coming cyber-physical system in manufacturing. Recent reports about industry 4.0 discuss additive manufacturing occasionally or ignore it (acatech 2013, bitcom/Fraunhofer 2014) but focus on the overall process of system integration. This does not mean that additive manufacturing is completely ignored but the key question is what function will be given for additive manufacturing in the reconfiguration of the manufacturing system.

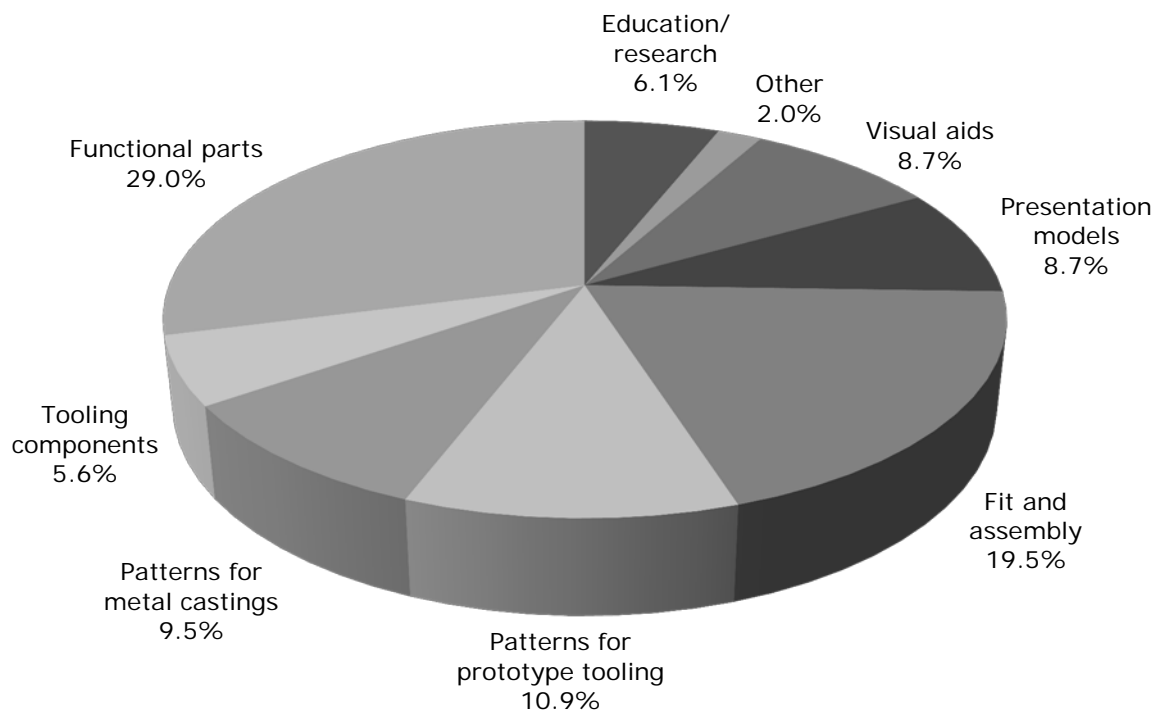
As shown in Figure 7 above largest users are companies from aerospace, automotive, mechanical engineering, and electronics. In electronics the take-off in large scale manufacturing lines (chip production) is ahead. Architecture, jewellery, design have adapted additive manufacturing for models and prototypes. Medical and dental is the sector with the fastest replacement of given production technologies by additive manufacturing and in health biomaterial based technologies are expected to speed up.

Figure 8 shows how companies currently make use of additive manufacturing. Prototyping for fit and assembly counts for approximately 20% and is no longer dominating. Nearly 30% of the companies use additive manufacturing for functional parts (short run, series production, prototyping etc.). Patterns for metal castings and for prototype tooling count for approximately 10% each. Use for education, visual aids and presentation models sums up for approximately one fifth.

Despite rapid growth, the use of additive manufacturing in industry is marginal so far (if measured by the share of total production values). Nevertheless, the current application gives a hint where additive manufacturing could play an important role.

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<sup>16</sup> Industry 4.0 is the German flagship project on the future of industrial production.

**Figure 8: Current fields of application in additive manufacturing**

**Source:** Wohlers 2014: 20.

Table 2 shows the most important fields of application and gives a first impression of the consequences of additive manufacturing. So far, printing complex and functional integrated parts replaced some small scale production lines. Tooling and welding became obsolete in several cases. Stock reduction is on the way and in consequence there is an upcoming discussion about the consequences for transport and logistics.

**Table 5: Fields of application and the consequences of additive manufacturing**

	SHARE OF AM MARKET in %	FIELDS OF APPLICATION	CONSEQUENCES
Aerospace	9.6	Small quantities of geometrically complex and lightweight parts, i.e.: reparation and remanufacture of worn components parts	Fewer stocks Reduce or even eliminate tooling, welding, inventory, and entire assembling lines
Armament	6.5	Any kind of geometry and processing soft and hard materials, modification and repair of components	Re-tooling becomes obsolete, and reparation and re-manufacturing becomes easier
Automotive	17.5	Functional prototypes, small and complex parts for luxury and antique parts	Design and manufacturing tools become dispensable

Dental	14.7	Digital prostheses, dental aligners and invisible dental braces, dental restoration	Digitalising the manufacture process, high reproducibility of production properties, reduced processing times
Electronics	n/a	Radio-frequency identification (RFID) devices inside solid metallic objects, polymer based, three-dimensional micro-electromechanical systems, microwave circuits fabricated on paper substrates, grippers	Easier adaption to domain specific development processes, acceleration of design process, functional integration of a number of different electronic devices in just one product, functional prototypes, spare parts produced on demand

**Source:** Compiled from DMRC 2011: 12ff.

### Additive manufacturing: Challenging mass production

Facing the future of manufacturing, the key question is as to how far additive manufacturing replaces the assembly lines in given modes of production.

In a study by Berger (2013, slide 18) advantages and disadvantages of additive manufacturing and given modes of manufacturing are compared. The advantages are seen as followed:

- additive manufacturing enables freedom of design because complexity no longer limits production;
- tooling is on the way to become eliminated and related costs and time will be saved. Topological optimisation enables lightweight design;
- because parts can be consolidated in a single component (part consolidation) assembly requirements are reduced and related production steps will be eliminated.

In contrast, the study points out several disadvantages.

Inefficiencies caused by prototyping heritage result in slow building rates:

- slow building rates and high cost of material powder;
- application design and process parameters are not as simple as often assumed: in complex processes around 180 materials.
- process and other parameters need considerable effort in preparing and programming;
- the manufacturing process does not end with printing. Post-processing often is needed because of component anisotropy, surface finish and dimensional accuracy;
- further on, the size of the chamber limits the size of components and the discontinuous production process prevents economies of scale.

So far, comparing advantages and disadvantages gives a first impression about the potential. More detailed methods of calculation are needed to evaluate the effectiveness of additive manufacturing compared with given production technologies.

Lindemann et.al. (2013: 999) work on a systematic methodology for calculating lifecycle costs of a product in order to understand the costs of additive manufacturing in industrial production. Their life cycle costing model covers six stages:

- conception & definition (design analysis, tender specifications, performance specifications)
- design & development (on the one hand technical drawing (CAD), component design and Quality Management Planning, on the other hand machine preparation prototype and test phase)
- production (on the one hand material costs, machine costs, energy costs, on the other hand post processing, quality assurance and personal costs)
- installation (assembly, transportation)
- usage & maintenance (running costs, storage costs, warranty costs)
- disposal (disassembly, material residual value)

The model is a theoretical one so far and as the authors say more empirical experience is needed. But the model shows that additive manufacturing is much more than simply printing and it is part of a complex development, planning, construction, and disposal process.

### **The disruptive potential of additive manufacturing**

Facing this complexity leads to the question as to how far additive manufacturing is on the way to transform manufacturing. Some studies focus on the disruptive potential of additive manufacturing. In its fast reaching version additive manufacturing based industry delegates all or at least large parts of manufacturing to the customer.

Such a comprehensive prospect is given by the IBM study on the new software-defined supply chain (Brody/Pureswaran 2013: 5). They focus on four key issues:

Economies of scale:

- ideally, cost of producing one unit = cost of producing a million units;
- while industries never will reach an economy of scale of one, 3D manufacturing will lower the minimum economic scale of volume production.

On demand manufacturing:

- rapid prototyping will allow for shorter product design cycles;
- stockless inventory models will result in smarter supply chains and lower risk in manufacturing.

Customisation:

- 3D printing will enable product customization to personal and demographic needs;
- new retail models will emerge, engaging the consumer in the product design process.

Location elasticity:

- supply chains will become more location elastic, bringing manufacturing closer to consumer.
- transportation of fewer finished goods will alter global trade flows and the logistic industry.

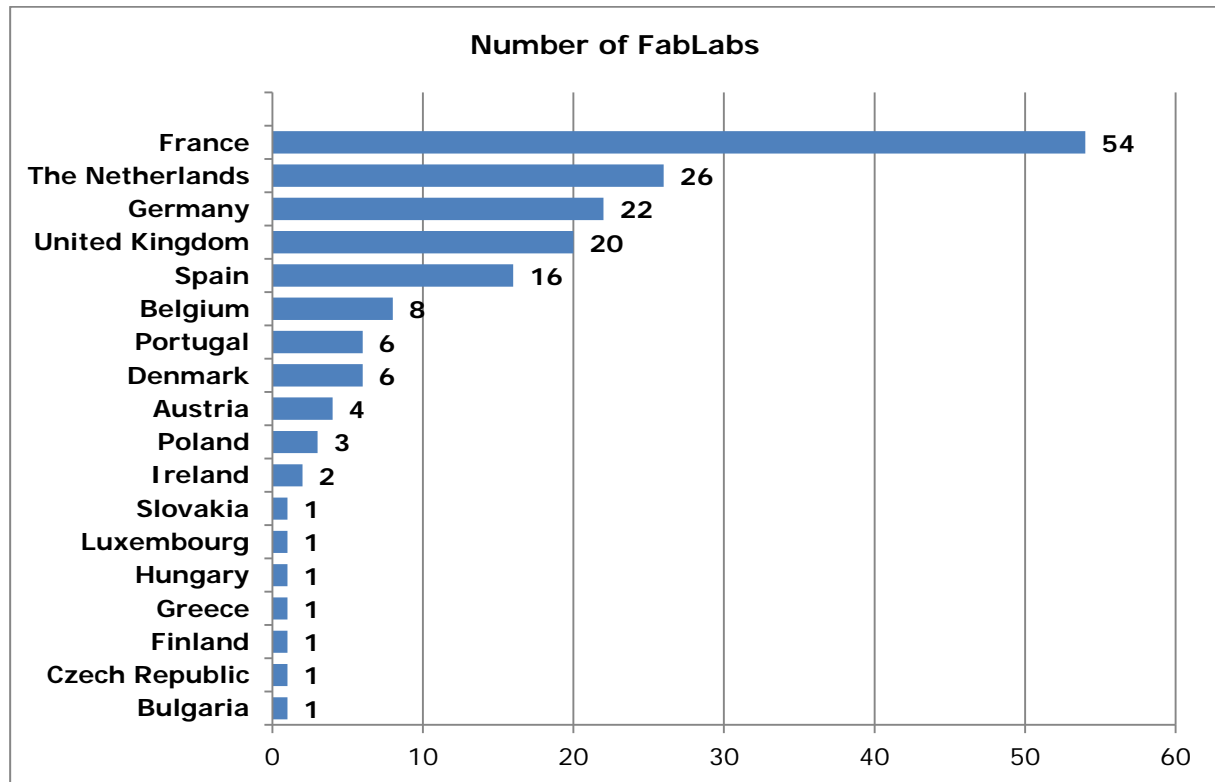
In methodological terms studies like this have to be handled carefully because they base the outline on one specific technology. Much more research is needed about the context. At national level the variety of production systems has to be taken into account. In sectoral terms different modes of governance within the value chain and within the production process frame the way of implementation. Further on, the activities based on 3D printing outside the given industrial context have to be taken into account.

### **3.4. Consumer 3D printing – Fab labs**

#### **Fab labs – state of the art**

Fab labs are located in community resource centres like schools, universities, local hubs, or creative projects and they aggregate different printers and related machinery in most cases. They work as repository for a diverse array of materials, user-generated designs and resources. They often combine education, learning by doing, contract printing and are linked to the global community. In Europe most fab labs can be found in France (Figure 9), followed by the Netherlands and Germany. But this does not say much about the real impact because fab labs recently are growing like mushrooms after heavy rain and they are quite different in function and equipment.

The 'Fab Lab' movement has its origins in the Center of Bits and Atoms at the MIT in Boston. Gershenfeld (2005, 2012) started with seminar courses and set up the first fab lab (fabrication lab or fabulous lab) at the South End Technology Center in Boston in 2003 and supported by the US National Science Foundation. The Center was committed to the introduction of new technologies in urban communities and contributed actively to the global diffusion of the fab lab idea. Driven by a student's community in the centre further Fab Labs were installed in Sekondi-Takoradi in Ghana, in Costa Rica, and in Vigyan Ashram in India. In 2006 a Dutch website for Fab Labs was launched and supported by Gershenfeld and contributed to the rise of Amsterdam as one of the leading Fab Labs hubs in Europe (Troxler 2005).

**Figure 9: Number of Fab Labs in Europe (April 2015)**

Source: <http://www.fablabs.io/labs>

Naboni/Paolette (2015) refer to Milano as a leading European Fab Lab hot spot when they describe the typical equipment of a fab lab. A typical Fab Lab “is supplied with an array of flexible computer controlled tools that work with different length, scales and materials. The fab labs core shared capabilities include computerised numerical control (CNC) laser cutting machines for press-fit assembly of 3D structure from 2D components; a larger scale milling machine for furniture and house-sized elements; a sign cutter for printing masks, flexible circuits and antennas; a high precision (micron resolution) milling machine for three dimensional moulds and circuit boards; programming tools for low-cost high-speed embedded processors, and design, assembly and test stations.” (Naboni/Paoletti 2015: 12f)

In 2009 the **Fab Foundation** (<http://www.fabfoundation.org>) was formed to facilitate and support the growth of the international fab lab network through the development of regional Fab Foundations and organisations and works as the most important umbrella for the heterogeneous local fab lab initiatives. In spring 2015, the list of Fab Labs covers nearly 500 members (<https://www.fablabs.io/labs>) all around the world.

The Fab Charter defines the social base of the fab lab movement: “Fab labs are a global network of local labs, enabling invention by providing access to tools for digital fabrication.” The charter highlights the idea of sharing and Fab Foundation claims to provide operational, educational, technical, financial, and logistical assistance beyond what is available within one lab. According to the idea of sharing fab labs are seen as community resource and the innovations should be available for everybody aiming at using and learning<sup>17</sup>.

<sup>17</sup> <http://fab.cba.mit.edu/about/charter/>

**Box 4: Vigyan Ashram, India**

The Fat Lab at Vigyan Ashram in Pabal/India was founded in 2002 and is one of the first outlays of Gershenfeld's Center of Bits and Atoms in Boston. The centre is part of the Indian Institute of Education in Pune. Learning in the centre is based on the Vigyan Ashram's Introduction to Basic Technology and is dedicated to treat problems as opportunities.

The teaching programme focuses on daily life problems in rural India: inconsistency in supply of electricity, housing problems, modes of transportation, means of communication, issues of employment, agriculture, sanitation and so on.

Facing the problem of electricity for instance engineers in the fab lab developed basic circuits and the design for LED light units. A local electronic component supplier helped to make kits for electronic components. A specific focus of innovation is to make better use of local material like coconut shells, broken shells, old PC mice and so on. In some cases the students earned some money by selling self-made units to the villagers.

Experimentation in the fab lab and learning are consequently linked. The preparation of the circuit printing for instance is based on the survey that covers soldering, testing, and installation. The related curriculum covers Ohm's law, electric circuits, solar energy, calculating energy requirement, or art and design.

The problems and the equipment are basic. The fab lab provides the 3D printer but conventional machines and tools are used in the fab lab too. The manager of the fab lab says that "...with the introduction of the Fab Lab and tools for digital fabrication, a sense of empowerment, setting aspiration for sophistication, precision and quality achieved. The glamour of the Fab Lab machines motivated the youth to become creative and come up with possible things that can be done with these machines." (Kulkarni 2013: 237).

**Upcoming: Fab Labs as focus for renewing industry**

Nearly all studies expect a re-regionalisation trend caused by the implementation of 3D printing. Re-regionalisation does not necessarily mean that production will come back from overseas large scale plants. The key interest is in creating local hubs as a base of technical learning and industrial renewing. This idea is not limited to European or North American locations but spreads all over the globe.

For instance, in 2013 the Asian Manufacturing association announced the establishment of ten 3D Printing innovation Centres in ten Chinese cities (Groth et.al. 2015: 68.) and the Shanghai Coworking-Office Lohaus (Loft of Health and Urban Sustainability) offers members the possibility to make use of 3D printers to work on product innovation and to strengthen cooperation between start-ups (Groth et.al. 2015:68).

Countries like France, the USA or South Africa developed national wide programmes for local hubs in additive manufacturing or 3D printing. But the discourse about fab labs has a strong bottom-up approach. In some cities especially in the Netherlands a dynamic took place initiated by the impulse of Gershenfeld. In Milan it is a business related dynamic based on designers and architects as 'early birds'. In cities like Hamburg or Berlin fab labs are linked with community development activities. In countries like India or Ghana fab Labs combine learning, qualification and production to overcome local bottlenecks. In Barcelona one of the most ambitious projects – the Fab City project was launched (cf. Box 5).



### **Box 5: Fab City Barcelona, Spain**

The Fab City Project in Barcelona was initiated by the architect Vincente Guallart. He planned to install and develop hand in hand fab labs in every district of the city as part of the civic infrastructure. The organisational focus is the Institute for Advanced Architecture of Catalonia, founded in 2008. The key idea is to transform the city into a factory of goods, knowledge, collaboration, exchange and innovation. Architecture and urban planning, a local network of globally connected Fab Labs and new business models are expected to work and improve hand in hand.

So far, Fab City as a brand was developed, launched and the first events and conference have been organised. A foundation has been established and support is expected by the public and the private sector.

Barcelona 5.0 is planned to be based on a mixed model of Fab Labs. Tomaz Diez explains the key assets:

"- education and research: by developing its own programmes and collaborating with schools, universities and research institutions and centres;

- social sustainability: by generating solutions for local needs and engaging all the sectors of the society to the digital fabrication revolution and its implications;

- business platform and entrepreneurship: by giving the means and the tools to take ideas to the next level, and to think about new models of collaboration, and project development, like crowd sourcing and crowd funding."

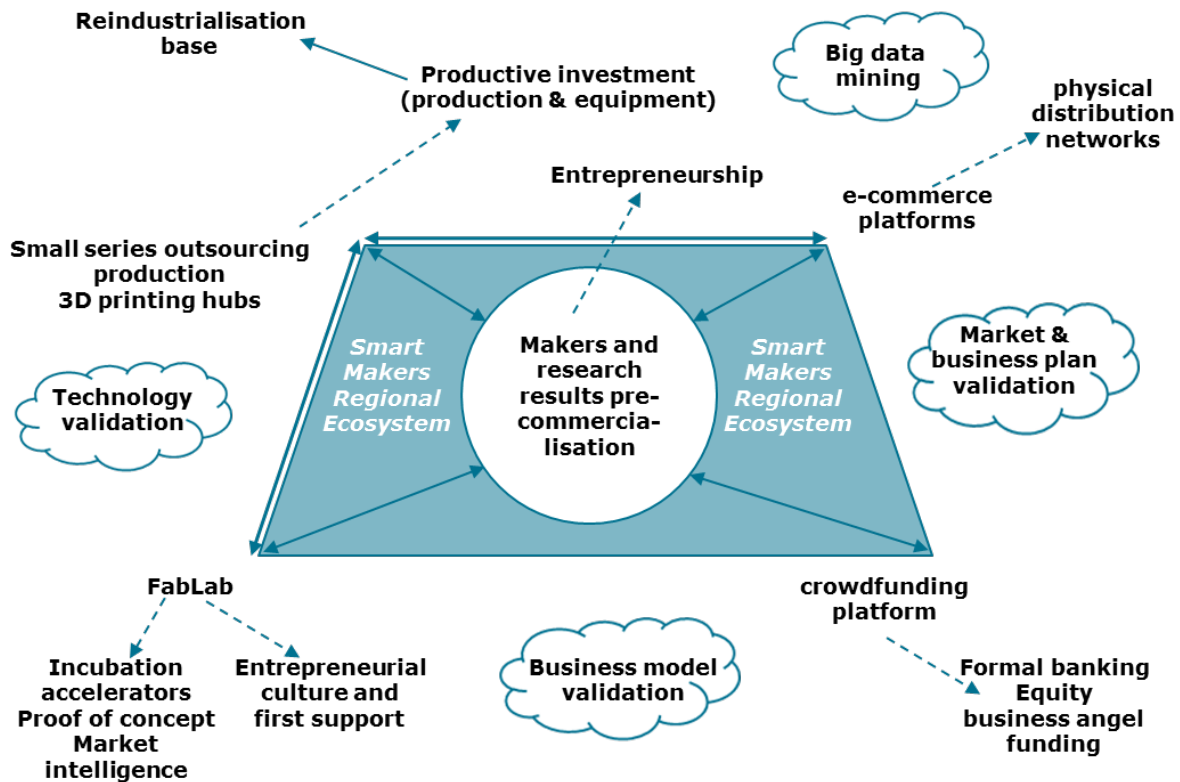
[http://p2pfoundation.net/Fab\\_Cities](http://p2pfoundation.net/Fab_Cities)

### **The vision: Fab Labs as nodes in a 3D printing eco-system**

Fab labs are on the way to become regional nodes of a global 3D printing eco-system.

Saublens (2014) presents six pillars that this eco-system is based on (Figure 9):

- Fab labs are equipped with a set of sophisticated machine tools (laser cutting, 3D printing, robots et. al.) and combine different functions like learning, qualification, printing (private or contracted) etc.
- E-sourcing platforms link makers, fab labs, service providers and producers of 3D printers (the Chinese alibaba.com is an example, the Israeli company ARAN another one).
- 3D printing hubs refer to a business model that enables makers to print small series (for example Sculpteo in France, Materialise in Belgium, or Shapeways in the Netherlands).
- Crowdfunding platforms enable seed funding, presales and prototyping (for instance the French, KisskissBank the German Seedmatch, Sedre form the UK, or Sonicangel form Belgium).
- E-commerce platforms, often combined with 3D printing hubs, enable sales for micro-producers (the US web side ETSY or the German DaWanda for instance).
- Makers, who have to be discussed more detailed now.

**Box 6: Fab labs and the 3D printing eco-system**

Source: Saublen 2014: 144

### 3.5. Consumer 3D printing – Makers

#### Makers –state of the art

'Maker' stands for individuals that make use of new technologies like 3D printing. The term 'Makers' refers to the individual actors who are grouped together in fab labs or hacker spaces. In other words the makers are the key actors of the so called open fabrication environment. The maker movement started in garages and workshops but soon formed communities on the Web.

'Maker' is the most quoted figure in the discussion about 3D printing. It has strong roots in the open source movement (Grassmuck 2010, Walter-Herrmann 2013). Anderson (2012: 33) works out three key assets of the new maker movement:

- people who design and prototype new products by digital desktop-means (digital do-it-yourself);
- a cultural norm committed to the idea that the design and prototypes are shared and further development within the community;
- the usage of common standards for blueprints that aims at closing or shortening the gap between maker and commercial service provider.

The maker movement in 3D printing has its origins at the Replicating Rapid Prototyper project at the University of Bath. The vision of the research team was to construct a 3D printer that would be able to produce its own parts. The project resulted in the launch of the first consumer 3D printers (RapMan, Makerbot, Ultimaker) in 2009 and 2010. At the same time first consumer-directed 3D printing platforms and services went online (Shapeways, Materialize, Ponoko).

Thingiverse - Digital Designs for Physical Objects<sup>18</sup> is a platform of hackers, designers, and makers committed to open source and was launched in 2008. It is dedicated to the sharing of user-created digital design files. Thingiverse is owned by Makerbot, one of the largest 3D printing companies. When Thingiverse altered its terms of use in 2012 it became focus of a controversy dispute about open source ('occupy thingiverse'). The conflict was between the interests of Makerbot to exclusively make more use of the ideas given by the platform on the one hand and makers strongly committed to the open source idea on the other hand (Moilanen et.al. 2013). This controversy shows that the maker community is much more differentiated as the myth of open source shows.

### **Maker and entrepreneurship – new business models**

Wolf/Troxler (2015): identified five business models from the open design community Thingiverse:

- Participation in online brokerage and sales platforms: participants use the platform to present themselves to potential clients and sell their products.
- Direct sale of objects via web shops: this business is centred on selling products. Web shops functions include show casting objects, ordering, payment and other fulfilment. The designs are worked out either by the web shop owners or by other designers.
- 3D printer retail: this model works like traditional retail business. The shops sell 3D printers mainly to 'hobbyists' and in most cases offer support and additional services.
- Customised prototyping for industry and private clients: the key activities are creating a 3D model (by drawing it on a computer or by scanning). Objects are prototypes, personal items, spare parts, or miniature statuettes often of the client. The customers range from industry to private clients.
- Research and education activities: the activities cover 3D printing courses, creating physical objects for educational purpose, or improving 3D technology.

Of course, these types are ideal types that work as hybrid in reality. The challenge is to combine individual business success and commitment to the community.

### **Maker and Prosumer: challenging big business?**

One of the most far reaching prognoses of the maker movement is Rifkin's claim that the "Prosumer"<sup>19</sup> is on the rise and will outdate capitalism step by step in the following coming decades. In short, he argues as follows (Rifkin 2014: 134ff):

- software is crucial, human work becomes marginal if not outdated;
- open source principle leads to a dynamic process and exponential growth;
- growth dynamics results in more sophisticated printer and falling prices;
- 3D printer improve themselves by printing their own up-dates;
- 3D printing is per se sustainable printing;
- 3D printer work decentralise, collaborative and lateral;

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<sup>18</sup> [www.thingiverse.com](http://www.thingiverse.com)

<sup>19</sup> Prosumer stands for the combination of producer and customer.

- in the end marginal costs tend to reduce to zero because renewable energy is supposed to become nearly free and transportation costs are reduced;
- potential lies in the attractiveness of 3D Printing and especially fab labs to make familiar young people with techniques.

This claim has a lot of social implications and assumptions that will be discussed in the last section. Nevertheless, it refers to further social implications and questions:

- 1) The prosumer in the understanding of Rifkin et.al. is the one who fits all or a all-rounder. What does it mean for traditional craftsmanship and division of labour basing on cooperating competences?
- 2) There is as certain division of labour inside the network, but who are the specialists. What is the business model for a community of volunteers and freelancers?
- 3) As Rifkin himself points out, the concept of privacy is under stress. This is not specific for 3D printing but for the open source movement in general.
- 4) What does it mean when everybody is a producer: decentralisation (Anderson 2012) or distribution (Zuboff 2010) of capitalism or the market driven colonisation of our everyday life (Boes et.al. 2015)?
- 5) What does it mean for innovation? When 3D printers have limited capacities in material and design, is there a trend to make innovation less sophisticated? Can it be seen as back to the core functional needs or is it a loss of functional quality?

As pointed out, authors like Rifkin (2014) and Anderson (2012) announce the revolution in manufacturing. Whereas Rifkin sees capitalism outdated by the rise of prosumers, Anderson anticipates the democratisation of capitalism. The activists seem to be more realistic than the prognoses. Josef Prusa (2013) answered when he was asked what's next: "Trying to predict what new stuff will be happening in 3D printing is impossible and I won't make fool of myself". And Gershenfelds (2012) reflects about a "curious sort of revolution, proclaimed more by its observers than its practitioners."

### 3.6. 3D printing in European projects

The EC considers Key Enabling Technologies (KET) to be a boosting factor of innovation. There are six KETs identified by the Commission: advanced materials, advanced manufacturing, nanotechnology, photonics, micro and nano electronics, and biotechnology. In addition the EU has identified 3D printing as one of the technologies that will drive forward the development of future products and services.

Projects related to additive manufacturing have been funded by the European Research Framework since the middle of the 1980s. The 7<sup>th</sup> Framework Programme (FP7) has funded over 60 research projects in 3D printing with EUR 160 million (EC 2014). Most of the projects are on technical aspects covering new materials, nano technology or new production technologies including projects on environmental aspects and standardisation aspects. Selected examples are:

- REPAIR - on the future repair and maintenance for the Aerospace industry by integrating direct digital manufacturing;
- MANSYS - about developing and demonstrating e-supply chain tools to enable the broad adaption of additive manufacturing;
- DINOVA - performing research on the future of digital production and mapped material innovation and application domains;

- NANOMASTER - on developing next-generation graphene-based thermoplastics for conventional and additive manufacturing;
- SASAM - a Support Action for Standardisation in Additive Manufacturing.

In June 2014 DG Research & innovation organised a conference where the projects were discussed and presented (EC 2014). The concluding round table session reflected the role of policy and innovation, the need of standardisation and of skills and training.

Under Horizon 2020, additive manufacturing falls under the Industrial Leadership pillar and is part of the track “Nanotechnologies, Advanced Materials, Biotechnology and Advanced Manufacturing and Processing”. One of the first projects is PHOCAM. This project focuses on two core techniques — 3D printing for high-performance ceramics and 3D printing with ultra-high resolution — and achieved remarkable results.

Whereas technical aspects of additive manufacturing are top on the agenda of European research and innovation politics consumer 3D printing or fab labs stay outside the Framework Programme as well as further European programmes. The potential for activities and funding is given in cohesion policies and in Interreg activities. For instance:

- fab labs could play a role in regional smart specialisation strategies;
- the role of Fab Labs in urban renewing and creative industries comes on the agenda;
- projects focusing on urban renewing are of interest;
- cooperation between industrial users and fab labs has to be strengthened;
- the use of the potential for technical learning and education based on 3D printing is outstanding.

### **3.7. 3D printing and additive manufacturing – trends, options and implications**

3D printing is on its peak of development as far as emerging technologies are concerned. Brody/Pureswaran (2013: 5) sees four reasons that hasten the ongoing growth in innovation and application:

- rapid reduction in cost
- increase in accuracy
- increase in the variety of supporting material, and
- expiration of critical patents

As far as serious market studies are available they underline ongoing expectations.

The global market for systems, service and materials for AM currently totals EUR 1.7 billion (2012) and is expected to quadruple over the next ten years (Berger 2013: 5). The prognoses are not clear but the expectations are high.

McKinsey Global Institute (2013): 105ff estimates that 3D printing could generate economic impact of \$230 to \$350 billion a year by 2025. In detail they foresee:

- Consumer use of 3D printing is expected to count for a global economic impact between \$100 and \$300 billion in 2025; this is based on the assumption that 5% to 10% of relevant products like toys could be 3D printable by the consumer.
- Direct product manufacturing is expected to replace 30% to 50% of products in relevant categories with 3D printing; cost savings by complex low volume items like implants and tools and by complex low-volume parts sum up to an economic impact of \$100 to \$200 billion.
- Tool and mould manufacturing by 3D printing results in production cost reduction that count for an economic impact of \$30 to \$50 billion.

Further potential applications are expected but not sizable, so far. The total estimated economic impact is a compromise between the large spread of the estimation and reflect ongoing uncertainty about the speed and scope of diffusion of 3D printing. Further on, additive manufacturing and 3D printing work in different contexts and depend on the strategies of the actors and the regulative frame. Therefore a view on bottlenecks and challenges is helpful to work out a broad line of further development.

### **Challenges and bottlenecks**

The key challenges shaping the future are different depending on the starting point. From the point of view of additive manufacturing, the most important success factors for increasing market penetration for additive manufacturing are: (DMRC 2011: 44)

- design rules
- surface quality
- process reliability and part reproducibility
- new materials quality assurance systems
- layer thickness
- process costs multi-material processing
- certifications

Recent research does not cover all of these challenges. Top research topics (Gausemeier 2012, slide 30) of the leading institutes are focusing on technical aspects:

- mechanical properties (PBF-plastic & metal)
- new Materials
- material Quality
- microstructure Manipulation
- material/Powder Generation

Low research intensity is going on with challenges like

- supply chain optimization
- machine costs
- process automation
- material costs/recycling costs

Recently, personal fabrication simple objects are still dominating and a lot of waste is produced in this experimental phase (crabjects = crappy objects or physical spam): “As they exist today, most 3D printing technologies might more readily be classified as sophisticated sculpting techniques than as mature manufacturing technologies.” (Townsend et.al. 2011: 4)

The same authors see three factors that limit the potential growth of open fabrication (31)

- design tools remain too specialised
- intellectual property frameworks favour big players
- a Gordian knot limits the applicability of personal 3D printing (multi-material processing is outstanding).

**Open questions in this respect are:**

Topic	Open question/Challenge
Technical aspects like material costs especially for fine particulates or limited software	Can be expected to be less important because it goes hand-in-hand with further diffusion and implementation of additive manufacturing or 3D printing.
Standardisation	Several international institutes are dealing with regulation and there is a need to coordinate the different activities. Also the industrial base in European countries is very heterogeneous and different national standards have to be avoided. Otherwise the danger is a fragmented European innovation eco-system.
Intellectual property rights	Open source versus protection of intellectual rights. Whereas the open community accuses that the given IP rights law protects big business, the companies often discuss private 3D printing under the aspect of product piracy
Liability law and practices	Who is in charge in the case of misuse or accidents? Did the printing process follow the regular and certificated way? Liability issues concern the machine, the data and the used material. Who is the producer? What is the case when products are adapted or changed?
Mode and location of printing	What will be the division of labour between large scale production companies, shared local production facilities, and private makers. In this context a further question is what the point is when a 3D printer becomes a production machine and has to respect industry, distribution and commerce regulation. What for instance is going along with fine particulates in the printing process?



Topic	Open question/Challenge
Infrastructure management	What about taxation and cross-border duty when the objects are not moving but the data do?
Urban planning rules	In Germany for instance local planning makes it difficult to install production facilities in quarters dedicated to housing.
Implementation of new business models	This is important for consumer 3D printing and for additive manufacturing. So far, this field of emergent technology is on its way from experimentation to professionalization. Business models are crucial to overcome the experimentation phase and new companies can work as facilitator in reframing value chains. So far, new business models prefer to work on an intermediate level or nearer to the customer (print on demand, education, and retail) and link up in the open source community. New business models initiated by established industrial companies (new ways of distribution and retail, mass customisation) are vague, so far.
Future of innovation	First links between open source innovation and additive manufacturing are given. For instance in 2013 General Electric (GE) announced a pair of global “additive manufacturing quests” with focus on complexity and precision challenging innovators and entrepreneurs to design a light-weight bracket and hangers for a jet engine, and to produce complex parts for healthcare. In the long run the key question is how the integration of the customer and/or crowd based communities influence innovation.

### Paths in 3D printing and additive manufacturing

Table 6 summarises the state of the art and the disruptive potential in the field of 3D printing and additive manufacturing. It starts with the state of the art, includes the most advanced practice and takes a look at the expected disruptive potential.

**Table 6: Summarising paths in 3D printing and additive manufacturing**

	STATE OF THE ART	MOST ADVANCED PRACTICE	DISRUPTIVE POTENTIAL
Additive Manufacturing	Replacing functions like tooling and welding, and small complex production lines, stock reduction (Aircraft, automotive, Electronics)	Reframing basic modes of innovation and production (Health, Dental)	Transforming the value chain: economies of scale, on demand manufacturing, customisation, local elasticity
Fab labs	Fab labs as place of experimentation and technical learning, Fab labs as nod of shared design and prototyping in creative industries	Fab labs as focus for renewing industry and a new urban economy	Fab labs as locations of shared production challenging given modes of industrial production
Personal	Mono materials and	New consumer driven	Could be interpreted

	STATE OF THE ART	MOST ADVANCED PRACTICE	DISRUPTIVE POTENTIAL
3D Printing	simple objects	business models (print on demand, franchising models, reframing retail)	as a 'democratisation of capitalism, undermining capitalism'

In any case the implementation of additive manufacturing will change the given production lines. In health and dental care the dynamic is highest and bio-material based printing is a priority field for innovation. The impression is that electronics is on the way to move in this field of most advanced practice by printing high complex electronic circuits. The tap of the potential is open and depends on the context of implementation the one hand and the way consumer driven 3D printing establishes on the other.

Fab labs meanwhile are places of learning and a global eco-system is on the way to become established. In certain fields of creative industries the (shared) use of professional fab labs became routine. Most ambitious activities aim at renewing urban industry but it is too early to estimate the potential. If professional fab labs become widely available and well performing they form a serious competition to traditional industrial value chains.

Personal 3D printing by individual actors is limited so far. Even if a personal 3D printer becomes cheaper their private use will remain limited due to their complexity. Some business models aim at offering printing on demand and will grow by franchising but again the range of products is limited. Nevertheless, when we see printing in the context of open source based shared economy and see it in a line with new business model in printing, in music, or in transportation (UBER) far reaching impacts on production and work can be expected.

### **The human factor: Impact on qualification and work flow**

The discussion of the human factor in 3D printing often claims that nothing but software development is left for human work to contribute (cf. Rifkin 2014: 134). Others claim that it is very simple to handle a 3D printer and no specific qualification is needed: "Such production machines are able to print, cut or mill objects from data files without any human intervention" (Herrman/Büching 2013: 10.)

Ratto/Ree (2012: 16f) criticise that this assumption of workless production because it only refers to "effort exerted by the maker exclusively at that particular place and time". It is seen that a 3D printer "is the manifestation of knowledge, skills and labor involved in its design, manufacture and maintenance."<sup>20</sup>

<sup>20</sup> <http://www.businessnewsdaily.com/5125-3d-printing-jobs.html>

A first impression about the complex process produces a list of professions that are searched by 3D printing companies and applicants:

- 3D design
- 3D computer-aided design (CAD) modelling
- Research & Development
- Biological and scientific development
- Architecture/construction modelling
- Education
- Lawyers and legal professionals
- Business opportunities
- 3D-Printing-as-a-Service franchises
- Operations and administrative positions

The concrete implications on work flow and qualification depend on the context. Additive manufacturing without any doubt is on the way to change work in a fundamental way. With focus on the German Industry 4.0 activities, Buhr (2015) highlights four general trends:

- the workflow will become more flexible in time and space
- the workflow become more digitalised and de-centralised and less hierarchical
- the workflow becomes more transparent
- more and more routinised functions become digitalised and automated

What this means in detail depends on the way human work and machinery is combined. When automation dominates systems and guides human work and the work flow, human work becomes supplementary and the required qualifications are limited. When a hybrid approach dominates technologies, machinery and human work become interactive and cooperative and high qualified work and flexible work is needed. When the focus is on specialisation machinery like 3D printer works as a tool that needs handling by skilled work (Buhr 2015: 15).

A related controversy in personal 3D printing is about the future of craftsmanship. (Ratto/Ree 2012: 16f). As shown above professional 3D printing is much more than programming and printing. Machines have to be prepared, materials to be selected, post-processing activities and finishing is needed. All these activities need competencies in handling machinery and material as well as cooperation between the different disciplines involved.

The shortcoming in the discussion on the future of personal 3D printing is that the awareness of the difference between materialisation and information is lacking (Ratto/Ree 2012). Townsend et. al. (2011:5) make the point when they claim: "But atoms are different from bits, and open fabrication can't be expected to play out like open-source software, for a couple of reasons."

## **The regional dimension**

The rise of 3D printing and additive manufacturing has far reaching consequences on the spatial distribution of industrial production. Again the future is open but several – in certain terms contradictory – trends are discussed.

The location of core production remains an open issue. The state of the art in implementing industrial additive manufacturing has few spatial consequences so far. The situation becomes different when additive manufacturing replaces the given way of mass production. In this case reshoring of productive industries from low developed and emerging countries to leading industrial countries becomes possible. This potential relies on two arguments. On the one hand it is said that reshoring comes on the agenda because labour costs in the production tend to be marginal. On the other hand it is assumed that the matching of human work and machinery needs skilled workers that are not available outside the industrial core countries.

More far reaching in the spatial discussion is the assumption that the shift from mass consumption to mass customisation will be realised. Again there are several options: From the 3D printing point of view the creation of local fab labs or 3D printing shops will spread. A further option is that the industry develops new business concepts and shifts production to local or regional contractors. But in contrast it could be also possible that a customer orders their product and this is printed in 3D fabrics for instance in China and then shipped to the customer.

With reference to the fab lab community the potential for a renaissance of urban industries is of interest. Fab labs work as places for learning and experimenting with new technologies. Fab labs in small creative industries and the ambitious Fab City project in Barcelona give a first impression on the potentials. Cooperative fab labs established by regional or local craftsmanship companies are discussed but not realised so far. The cooperation between industrial production and innovation and fab labs is a missing link.

So far, the open source committed community and established industrial companies seem to follow conflicting approaches. They meet on separate conferences and events and the basic conflict is on intellectual property rights. Whereas patenting, intellectual property right, trademarks or confidential agreements are key assets of industrial innovation strategies, the unlimited flow and use of knowledge is the best seedbed where personal 3D printing and fab labs can flourish.

Nevertheless, there is some cooperation between established companies as the example of the Vigyan Ashram Fab Lab (Box 4) shows. Some fab labs are located in technology parks (for instance the Brainport Fab Lab in Eindhoven) but beyond technical learning the links between industrial additive manufacturing and fab labs are outstanding.

## 4. CONCLUSIONS AND RECOMMENDATIONS

### 4.1. 3D Printing and Open Innovation – Co-drivers of a new industrial revolution?

How do open innovation and 3D printing impact the current and future structure of our industry and of our economy and society at large? Open innovation defined as “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively” has opened up a variety of different pathways for innovation. New open innovation-based networks and innovation communities have emerged, together with open innovation intermediaries and platforms. This also holds for related notions such as *user innovation* and *open source*. Together they have inspired new creative ways of idea generation and collaboration, such as ideation and design contests, technology scouting, and crowd sourcing tournaments (‘broadcast search’). Combined with recent other new tools such social media analysis, big data and data analytics they drastically change the innovation landscape. This holds especially for firms, notably large multinational corporations who have embraced the open innovation concept already, but increasingly also for SMEs enterprises. Yet open innovation, user innovation and open source also provide new opportunities for citizens and end users, by enabling them to co-create and directly contribute to innovations, but also by providing new impetus for grass-root innovation movements and new alternative ways of organising production and consumption. The ‘prosumer’ - first coined by futurologist Alvin Toffler who already in 1980 predicted that the difference between producers and consumers would blur and merge - is becoming a reality. With the surge of open source, 3D printing, and with the (communications) Internet converging with the Internet of Things (IoT) and a renewable energy internet, we are entering an era in which prosumers produce what they consume and share what they have on a Collaborative Commons (Rifkin, 2014).

A parallel development is the emergence of a manufacturing industry that is markedly different from the one we know. Whatever it is labelled – Industry 4.0, smart industry - the way manufacturing production is steered and organised is strongly changing, driven by the emergence of the Internet of Things, digitisation and automation. Whereas in the 1990s and 2000s we have been witnessing a strong surge in outsourcing and off shoring made possible by reconfiguring - slicing up - the value chain, the 2010s may be the start of a third industrial revolution, enabled by a fast spreading use of sensors and actuators, almost omnipresent cheap computing power and the convergence of the communications internet with the Internet of Things. The impact of this revolution does not only challenge the production process itself, but also the modes of innovation, configuration of (global) value chains, the dividing lines between production and consumption, and last but not least the future role of the production factor labour in our economy.

The challenges and potentials of digitisation have already been long recognised as a key aspect in European policy, both in Europe’s Lisbon Agenda (2000-2010) and in the current Europe 2020 strategy, as a flagship initiative (2010-2020). The role and importance of manufacturing industry for the European economy has been the subject of renewed attention and recent reconsideration, motivated by the 2008 economic and financial crisis, but also as a reaction to the dominant off shoring trend of the 1990s and 2000s, of relocating European industry to elsewhere, notably East-Asia. One of the effects of this re-evaluation was the Europe 2020 flagship for a renewed industrial policy.

## 4.2. Open innovation and 3D printing from a policy perspective

Both open innovation and additive manufacturing are key elements in the new European strategy towards industrial renewal and digitalisation. Open innovation and additive manufacturing also stand for a broader ongoing development, in which services, mass customisation and customer involvement are becoming more important, and in which industry but also services make use of big data, become open towards 'external' ideas and collaboration, and become more flexible. Whereas open innovation and additive manufacturing refer to new directions and avenues for the established industry, open source innovation and 3D printing are often seen as an alternative different path towards industrial renewal, challenging not only the way of production but also the current dominant mode of market exchange.

But rather than opposites and mutually exclusive, both developments should be viewed as parallel and even reinforcing developments. The challenge for European politics is to support the renewal of European industry and at the same time not to miss the potential resulting from the bottom-up approach that is, among others, associated with open source innovation and 3D printing. Most important is that both additive manufacturing and open innovation, and open source innovation and 3D printing are not stand-alone technologies or innovation strategies, but embedded in a broader context of change.

### Open innovation and 3D printing in current EU policy

In its 2010 Communication on "An Integrated Industrial Policy for the Globalisation Era", the Commission underlines that it will continue to apply a targeted approach to all sectors and that it will *"promote industrial research, development and innovation on advanced manufacturing technologies, building on the 'Factories for the Future' initiative, in order to facilitate the modernisation of the EU industrial base and providing a response to societal challenges like energy efficiency, climate change and resource scarcity"*; ... *"promote new business concepts and related manufacturing technologies focused on the development of sustainable, user-driven design-based products"*, and *"launch an initiative to promote the wide and timely deployment, take-up and commercialisation of competitive Key Enabling Technologies"*. Although additive manufacturing is not one of these six KETs (i.e. industrial biotechnology, nanotechnology, advanced materials, photonics, micro- and nano-electronics, and advanced manufacturing systems), it is an important aspect of industrial renewal. It already started funding research in 3D printing during its first research funding round, the 1<sup>st</sup> Framework Programme (FP1) which ran from 1984 to 1987. In FP7, which ran from 2007 to 2013, it spent over EUR 160 million on over 60 research projects in 3D printing. Under Horizon 2020, the current funding round that runs from 2014 to 2020, it continues funding 3D printing projects.<sup>21</sup>

### A need for rethinking innovation strategies

Innovation strategies have been dominated by the concept of *triple helix* to which open innovation is strongly linked. Nevertheless, the idea of open innovation also incorporates the potential to overcome the dominant technology push focus in innovation strategies. Innovation strategies (and politics) need a *stronger demand-driven approach* by co-involving customers as well as public interest stakeholders in the innovation process.

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<sup>21</sup> E.g., [http://horizon-magazine.eu/content/3d-printing-eu\\_en.html-0](http://horizon-magazine.eu/content/3d-printing-eu_en.html-0)

Start-up companies are often pragmatic in making use of new tools: some of them use open crowd source tools or services, others follow blogs of customers (for instance, blogs of patients in health affairs) and again other companies use the new media to intensify interaction with customers.

There is a need to better and more firmly incorporate social and societal aspects in the innovation process; innovation alone is not sufficient to cope with the key societal challenges in a successful way (Baroso 2009). So far, *social innovation* and *technological innovation* have not been linked in a promising way. Open innovation and open source innovation have the potential to close this gap, especially when it succeeds in bringing customers, engineers and others together in a problem-solving discourse. Additive manufacturing can only be successful when work place innovation finds a solution to organise the human-machine interaction in a fruitful way. 3D printing, especially in the context of fab labs, gives a unique opportunity to make young people more interested in and aware of the potential of technologies and to overcome the expected scarcity in qualified workforce.

Open source innovation and 3D printing offer ample opportunities for renewing the regional base, by creating new potential links between local activities and global production networks. They provide not only the chance of starting new business activities, but they also give new inspiration for reshaping regional innovation strategies. Combined with the concept of smart specialisation and its underlying concept of entrepreneurial discovery, this provides a strong new impetus to regional strategy renewal. Regions should be open to follow different pathways. Open innovation strategies provide tools to bring together large companies, small and medium companies, public authorities and customers to work out smart specialization strategies. Fab labs have the potential to combine open innovation strategies and locally committed cooperation between makers, craftsmanship, or cultural industries.

#### **4.3. Challenges and open questions**

"Prediction is very difficult, especially about the future."<sup>22</sup> What is clear is that the current pace of technological development and innovation, combined with the opening up of the innovation process itself, provides powerful opportunities for economic and societal change. How radical these changes in practice will be is difficult to predict. The sheer embeddedness of additive manufacturing and open innovation strategies makes it impossible to isolate the impact of these factors and to make any serious prognosis about their possible impact on the labour market or specific industrial sectors. The challenge, however, is to frame these developments in such a way that the potential of social and technological innovation can materialise in the most fruitful and beneficial way and thus positively contribute to societal welfare in the medium and longer term.

#### **The legislative and regulatory framework**

An important element in the incorporation and integration of these new developments is our legislative and regulatory framework, both at European and national level. What should be prevented is that current rules and regulations work as a barrier to change. But we should also avoid to drastically and overnight adapt our legislative and regulatory framework and embrace new technologies and openness as much as we can.

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<sup>22</sup> Quote by Danish physicist Niels Bohr.



Europe needs to stay aware of its industrial strength and its unique institutional framework, but at the same time open up sufficiently to include and embrace the new digital economy potential.

The following key legislative and regulatory challenges can be identified:

**Standardisation.** Additive manufacturing and open innovation, but also 3D printing and open source innovation integrate the overall value chain, and link the local with the global level of production activities. In order to reach the full potential of these developments, they should be based on shared and firm standards. Standardisation can take place as a result of self-organisation by industrial actors, or, alternatively by and within open source and crowd communities. Governments can also take initiative to harmonise and standardise. Standards, however, are always and necessarily the result of a bargaining process. However, different actors might prefer different strategies of standardisation. Important is the level at which standards are set. The challenge is to set standards that stay open for the potential of all actors that are involved in the process of renewing and reshaping industry. It is hence important to involve small and medium companies in the standard setting process. One particular aspect that should be emphasised in this context is internet safety and security – or even Internet of Things security – which is crucial not only to companies but also to customers and citizens at large.

**Intellectual property (IP).** Intellectual property rights are the most controversial issue in the discussion about additive manufacturing. Whereas the 3D printing community sees given intellectual property rights as a form of regulation that favours the large companies, companies see 3D printing as a potential tool for product piracy. “The biggest issue for the AM industry is the generation of mistrust because of non-controlled environment at the consumer goods level” (European Commission 2014: 37). But there are other basic questions to be clarified: 3D printing is based on computer programming but these programmes are not protectable by patenting. And if the object is concerned the copyright rules do not fit. The intellectual property question does not involve 3D printing for personal use but it becomes an important issue when machines are shared in fab labs for instance.

Intellectual property is an important topic for open innovation and the current European IP system needs serious reconsideration. An active IP portfolio is part and parcel of the open innovation approach. However, the costs of patenting in Europe are still much higher than elsewhere in the world and also the time to grant a patent is longer than elsewhere. Fragmentation and high costs function as a barrier to innovation, and are especially a burden for start-ups and small companies.

**Liability regulation and taxation.** So far liability regulation is based on the assumption that the one who produces a product is responsible and liable. But this being the case, it is still an open question who is liable where 3D printing is concerned: the one who did the software programming, the printer, the printing company or the distributor? The same open question also relates to taxation: should the tax be on the programme, the printed product or at the location of printing? Similar questions relate to products from open source and user innovation origin. Still other questions concern also the industry code (German: Gewerbeordnung). This is especially true for 3D printing within fab labs. The key question here is: when does printing end and production begin? Despite of formal definitions, key questions have still to be clarified, relating to fire protection, machine security, electrical isolation, and health issues, in particular health issues related to fine dust, when pulverised or granulated material is processed.

### **The potential for start-ups and fast growing companies**

Additive manufacturing and open innovation provide potential for start-ups in very different fields. On the one hand we can observe the producers of 3D printers and 3D components themselves which are often new founded companies. So far the value chain is still rather fragmented. Start-ups in this phase of development are the most important way of innovative competition.

Software development is a bottleneck in 3D printing and additive manufacturing because of high complexity, requiring highly specialised competences that can be delivered by newly founded companies.

There are also different new functions to be found at the intersection between the digital world and the real world. The organisation and activation of peer groups as well as anonymous groups in the cloud can provide new business models that are needed both in 3D printing and in open source innovation.

As long as we accept that it is not possible or effective that private makers have the facilities to print complex objects, intermediate actors are needed

Fab labs are the most promising way to link industrial and consumer 3D printing. They are based on different business models and resources: on contract printing, on education services, on sponsoring or on public funding. Funding instruments should take account of the specific functions and culture of fab labs.

And last but not least, retail business is under pressure. 3D printing and specific ways of additive manufacturing are more and more committed to consumer-specific production, with the creation of new 3D printing hubs and intermediaries.

As regards open innovation, one of the more remarkable developments of the last decade is the rise of innovation intermediaries, companies and platforms that actively support companies and others who want to engage in open innovation. Open innovation and the process of opening up and being more prone to innovation in itself brings huge potential of both business creation (start-ups) and the speeding up of the growth and maturation of existing companies.

### **Education and qualification**

In additive manufacturing in 3D printing it is obvious that mechanics, electronics and informatics become linked. Informatics becomes crucial but engineering, designing and construction remain crucial. The future of industrial production is interdisciplinary. One important question concerns hybrid qualification. Universities start to launch hybrid interdisciplinary or cross-technology courses in additive manufacturing or in other industrial fields like e-mobility. But it is an open question whether hybrid education and vocational training is the best solution. Especially the speed of technological change and cross-technology development is an argument that the ability to cooperate between different professions will be crucial. In this case education needs more integration of issues like project management, communication, or work organisation than in a more hybrid approach.

A further aspect related to additive manufacturing concerns skilled work and craftsmanship. Even in additive manufacturing functions like preparing the machine (or the printer), handling the material, quality testing, or post-processing stay important. Maybe these functions become more important because quality control is different in single object production than in serial production.

The same is true for craftsmanship. Some writers about 3D printing suggest that everybody will be able to become a craftsman by using 3D printer. But craftsmanship needs much more than printing: in general in fab labs or other types of local printers the functions are the same like the functions needed in additive manufacturing. And not at least we have to ask whether in which way creativity changes. The key question is in which way experimenting and testing with real material can be replaced by digital experimentation.

Not at least, the potential of fab labs for learning seems unexplored, so far. The challenge is not only to vary the objects that are printed but to combine learning, material processing or engineering with 3D printing.

Whereas open innovation can relate to many different sectors and businesses, team work and networking skills along with other soft skills are in high demand. This also relates to the emergence of innovation intermediaries ('innomediaries').

### Environmental aspects

There is widespread consensus that 3D printing can save materials by reducing waste and that it has the potential to reduce distribution and related traffic. Nevertheless, waste streams resulting from support structures and post-production still remain. Because of the specifics of the printing process the question of recyclability is not really discussed. "The idea that the technology is fully green and clean particular in manufacturing stage is not right in all cases" (European Commission 2014: 17).

Petschow et al. (2014: 26ff) summarise the expected positive and negative impacts on issues of sustainability (Table 5). The positive aspects are the reduction of waste in the production process, avoidance of dangerous materials like cutting fluid, more use of light materials that reduce energy, efficient production of rare components, and reduced needs in transportation. In contrast, negative aspects could be the waste caused by post-processing, energy needs by printing single units tends to be higher than by given standardised processes, insecurity about recycling, the danger that simplifying of production results in overproduction, the danger of defect components because non-professionals have not the needed competencies.

**Table 7: Advantages and disadvantages of 3D-printing compared**

Supposed advantages of 3D-Printing vs. established subtractive technologies	Supposed disadvantages of 3D-Printing vs. established subtractive technologies
Reduced waste by the production process, potential for zero-waste production	Post-processing work could generate waste
Use of cutting fluids that threaten health can be avoided	Energy use per unit tends to be higher than in given production processes
Use of the potentials of light weight construction reduces energy consumption in the use-phase of components	Recyclability of material is unclear and not studied so far
Rare or sold-out replacement equipment can be produced efficiently	The simple mode of production runs danger to result in additional production
Reduction of transportation by shorting global production chains	Non-professional experimentation in 3D-printing rise risk of deficient components and "crapjects" (crappy objects)

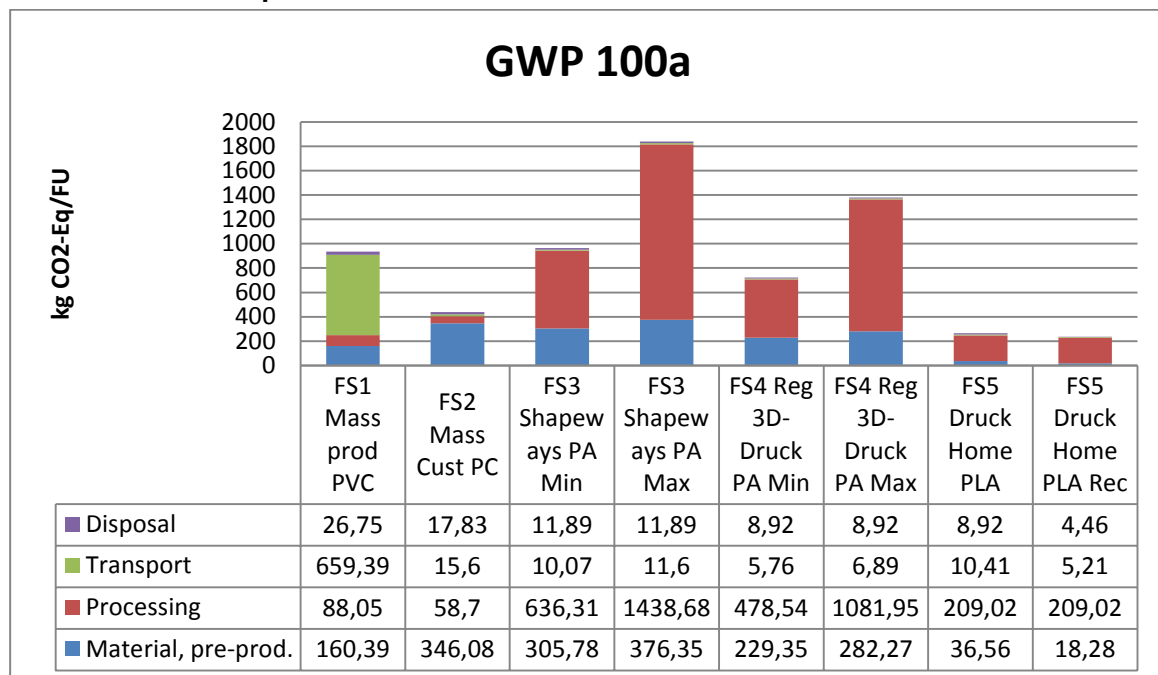
**Source:** Petschow et.al. 2014: 27

The above mentioned study (Petschow et. al. (2014: 42)) presents a case study covering greenhouse gas emission of cell phones. the case study compares five scenarios:

- State-of-the-art mass production
- Mass customization production
- Production by a 3D-print center (factory shop)
- Production by a decentralized 3D-print center
- Production by a home 3D printer

According to the case study in all five scenarios the impact of disposal is marginal compared to the overall impact of the cell phone life cycle. The highest impact comparing the whole life cycle comes with transportation. Mass production on the other side has comparably little impact when produced by 3D-printing. However actual percentages of environmental impact are difficult to obtain and not documented so far (Figure 10).

**Figure 10: Greenhouse emission potential by different modes of production compared**



**Source:** Petschow et.al. 2014: 42.

These are first impressions and much more detailed and comprehensive research is needed. Further on, the authors highlight that the ecological impact depends not only on the specific technology but on social factors like professionalization or modes of usage.

According to Petschow et.al. (2014) making better use of the ecological potential in 3D-printing faces three key challenges: 1) making more use of overall resource efficiencies potential; 2) strengthening energy efficiency; and 3) improvement of re-using and recycling practices.

#### **4.4. Policy recommendations**

##### **A. What can be done at EU level?**

###### **Rules and regulations**

- Re-examine and where necessary rethink the legislative and regulatory business framework with specific attention for new technologies and developments: open innovation, open source, user innovation, 3D printing, and new technologies at large (including, but going beyond, the six Key Enabling Technologies).
- Avoid regulation that hinders new business activities.
- Reconsider Intellectual Property legislation, and try to lower IP costs and patent grant times, especially for start-ups and small companies.
- Encourage the coordination between the different actors that are involved in regulation.

###### **Horizon 2020**

- Launch projects that focus on so far neglected aspects: business models, linking social and technological aspects of innovation, environmental issues, workplace innovation and qualification; open innovation in services; open innovation and SMEs.
- Encourage start-up and SME participation by lowering the administrative burden and the lead time of granting proposals (requested by the EP 2003, see also Think Small First: A Small Business Act for Europe (COM(2008) 394).

###### **Cohesion policy**

- Encourage the involvement of fab labs and related facilities in regional innovation policies.
- Promote the use of open innovation tools in regional strategy development (smart specialization strategies).
- Collect, communicate and disseminate good/best practice examples.
- Check funding rules that fit with the idea of crowd-based activities.

###### **Interreg (European Territorial Cooperation)**

- Encourage European cooperation projects between fab labs and between fab labs and industrial 3D printing.

###### **Specific actions EU policy-wide**

- Launch projects on those issues which have been neglected so far (for instance global comparative studies, work place innovation).
- Organise a dialogue between the different actor groups in the field of additive manufacturing and open innovation.
- Take care that social and technical aspects of innovation work together in European projects in an integrative way.

- Public support should be subject to clear and firm rules, with target companies being independent, not subsidiaries of larger companies, be spending 15-20% of their overall budgets on R&D and not older than 10 years<sup>23</sup>.

## **B. What can be done at Member State level?**

### **Rules and regulations:**

- Rethink the national legislative and regulatory framework and avoid regulations that hinder new business activities.
- Do not try to stop or slow down new developments including technological change. Provide room for regulatory experiments. Avoid one-size-fits-all approaches.

### **Innovation policy:**

- Innovation policy is mostly a national policy and the use of additive manufacturing and open innovation largely depends on the state of development of industry and leading sectors in the Member State. Keep an open eye for different developments. Avoid concentrating on one way of supporting 3D printing.

### **Education and training policy:**

- Re-examine and rethink existing approaches to education and training in view of digital economy and societal needs.
- Work out rules for new modes of labour related to the digital economy.

## **C. What can be done at the level of the Regions?**

- Rethink regional innovation strategies by making room for and incentivising open innovation approaches.
- Take an integral all-embracing approach to regional innovation, preferably based on the *smart specialisation* concept.
- Be aware of open source and user innovation communities and their importance to innovation processes.
- Launch local nodes where actors from traditional industry and actors from digital economy (fab labs) can meet and 'be matched' in mutual learning.

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<sup>23</sup> Recently, Chesbrough and Vanhaverbeke (2011) have advocated the use of new public policy incentives in Europe for investment in rapidly growing and innovative companies, and in particular R&D-based ventures.

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## ANNEX 1: GLOSSARY

This annex provides an overview of concepts used in close connection to the concept of open innovation.

**Absorptive capacity** is the ability of a firm to recognise the value of new, external information, assimilate it, and apply it to commercial ends, being critical to its innovative capabilities (e.g. Cohen and Levinthal, 1990).

**Co-creation** refers to the joint creation of value by the company and the customer (Prahalad and Ramaswamy 2000; 2003; 2004). Co-creation not only describes a trend of jointly creating products, but is also about customers who go beyond buying products and services as transactions, but as part of an experience. From a societal view, the focus of co-creation is not only in solving existing challenges but in creation of new futures, *with* society. Co-creation is usually characterized by a profound interaction between actors over a longer period of time.

**Co-creation mechanisms** refer to the joint development of knowledge through relationships with specific partners. Examples of relationships are consortia of competitors, suppliers and customers, joint ventures and alliances, as well as with universities and research institutes. Organizations can for example integrate external ideas from customers or users, can co-create their platforms based on those ideas with a university or another company, and distribute certain tasks of value creation to other individuals or groups. Tools used for co-creation can be traditional, such as workshops, meetings and projects, or online tools, such as platforms, social networks, virtual working spaces or chat rooms. (European Commission, 2014).

**Hackathon** typically refers to a 1 or 2-day event where computer programmers and developers collaborate to develop a new software based on a pre-specified challenge posed by sponsors. Also known as hackday, hackfest.

**Innovation eco-system.** Inspired by and analogue to biological eco-system, an innovation eco-system is a complex set of relationships among the actors or entities whose functional goal is to enable technology development and innovation. The elements of the ecosystem including higher education institutions, public research organisations, firms, finance sector, public funding agencies, policy-makers and citizens (Debackere et al., 2014).

**Living Labs** can be defined as user-centred, open innovation ecosystems based on a systematic user co-creation approach that integrates research and innovation processes in real life communities and settings (e.g. S3 Platform).<sup>24</sup>

**Open innovation** refers to “the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.” [This paradigm] assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology.” (Chesbrough et al, 2006)

**Open innovation 2.0 (OI2)** relates to open innovation to the notion of a networked innovation ecosystem with open innovation not being an isolated activity but part of a co-creation process which has an impact on entire economy and society. Co-creation takes place in different places of the ecosystem and requests knowledge exchange and absorptive capacities of all the actors (Debackere et al., 2014). Open Innovation 2.0 is presented as a

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<sup>24</sup> <http://s3platform.jrc.ec.europa.eu/living-labs>

new paradigm based on a *Quadruple Helix Model* where “government, industry, academia and civil participants work together to co-create the future and drive structural changes far beyond the scope of what any one organization or person could do alone. This model encompasses also user-oriented innovation models to take full advantage of ideas’ cross-fertilisation leading to experimentation and prototyping in real world setting. OI2 builds on principles of integrated collaboration, co-created shared value, cultivated innovation ecosystems, unleashed exponential technologies, and extraordinarily rapid adoption.”<sup>25</sup> There are five key elements in the new Open Innovation process:

- networking;
- collaboration: involving partners, competitors, universities, and users;
- corporate Entrepreneurship: enhancing corporate venturing, start-ups and spin-offs;
- proactive Intellectual Property Management: creating new markets for technology;
- research and Development (R&D): achieving competitive advantages in the market.

**Open innovation mechanisms** refer to the directionality of open innovation, in three main types (Enkel et al, 2009): 1) outside-in; 2) inside-out; and 3) coupled processes. The outside-in process refers to enriching the company’s own knowledge base through the integration of suppliers, customers, and external knowledge sourcing. The inside-out process refers to earning profits by bringing ideas to market, selling IP, and multiplying technology by transferring ideas to the outside environment. Companies that establish the coupled process combine the outside-in process (to gain external knowledge) with the inside-out process (to bring ideas to market) and, in doing so, jointly develop and commercialise innovation.

**The Quadruple Helix** innovation model embeds the Triple Helix by adding as a fourth helix focusing on ‘civil society’ and the ‘media-based and culture-based public’. The Quadruple Helix focuses more than the Triple Helix on the perspective of the knowledge society and of knowledge democracy (Carayannis and Campbell, 2009). The Quadruple Helix represents the transition towards systemic, open and user-centric innovation and to different forms and levels of co-creation/production with consumers, customers and citizens.<sup>26</sup>

The **Quintuple Helix** innovation model includes both the Triple and the Quadruple Helix but adds the helix of the ‘natural environments of society and the economy’, stressing the necessary socioecological transition of society and economy in the twenty-first century. See e.g. Carayannis et al. (2012).

**The Triple Helix** innovation model focuses on university-industry-government relations (Etzkowitz, 1993; Etzkowitz and Leydesdorff, 1995) and their interaction as that source of innovation and economic development in the Knowledge Economy/Society. The Triple Helix signifies the shift from a dominating industry-government double helix in the Industrial Society to a more prominent role for the university, in what is termed the “*hybridisation* of elements from university, industry and government to generate new institutional and social formats for the production, transfer and application of knowledge.”<sup>27</sup>

<sup>25</sup> <http://ec.europa.eu/digital-agenda/en/open-innovation-20>

<sup>26</sup> E.g. [http://www.cligproject.eu/en/activities/research/quadruple\\_helix\\_research/?id=127](http://www.cligproject.eu/en/activities/research/quadruple_helix_research/?id=127)

<sup>27</sup> [http://triplehelix.stanford.edu/3helix\\_concept](http://triplehelix.stanford.edu/3helix_concept)

## ANNEX 2: EURIS - OPEN INNOVATION GOOD PRACTICES

Source: <http://www.euris-programme.eu/en/documents>

Creative Conversion Factory - Eindhoven - The Netherlands  
 Bioenergy for the Region Cluster - Lodz - Poland  
 MEUPOLE Method - Navarra - Spain  
 PROTOTEC - WestTransdanubia - Hungary  
 Competence Centres - Stuttgart - Germany  
 CEMITEC - Navarra - Spain  
 Innovative Technology Firms (EIBT) Network - Navarra - Spain  
 RETECNA (Navarra Network of RTOs) - Navarra - Spain  
 High Tech Automotive Campus Helmond - Eindhoven - The Netherlands  
 Flanders Institute of Biotechnology - Flanders - Belgium  
 Mobile Heights Business Center - Oresund - Sweden/Denmark  
 Innovation Design Entrepreneurship Science - North West - UK  
 Birmingham Science Park Aston - West Midlands - UK  
 Regional S&T Talent demand study - Navarra - Spain  
 Holst Center - Eindhoven - The Netherlands  
 High Tech Campus Eindhoven - Eindhoven - The Netherlands  
 Program for the analysis of RTDI Collaborative projects - Navarra - Spain  
 Waterloo University - Ontario - Canada  
 BioForum - Lodz - Poland  
 Aalto Desig Factory - Otaniemi - Finland  
 Knowledge Management Center - West Transdanubia - Hungary  
 Medical Implant Lab - Lodz - Poland  
 Technology Transfer Center Technical University of Lodz - Lodz - Poland  
 MiPlaza - Eindhoven - The Netherlands  
 Business Incubation - Eindhoven - The Netherlands  
 Encouraging Open Innovation - West Transdanubia - Hungary  
 Living Labs on V4 region - Hungary - Slovakia - Poland  
 Business Angels - Stuttgart - Germany  
 PUSH! - Stuttgart - Germany  
 Partnership AUDI Motors - University - West Transdanubia - Hungary  
 Art Inkubator - Lodz - Poland  
 Kitchen Budapest - Hungary  
 Regional R&D institutions potential analysis - Lodz - Poland  
 Innovation Manager - Lodz - Poland  
 Stuttgart Region Automotive Cluster Initiative - Stuttgart - Germany  
 United Brains - Eindhoven - The Netherlands  
 Innovation Lab - Eindhoven - The Netherlands  
 Technology Transfer Initiative - Stuttgart - Germany  
 Technology License Bureau - Stuttgart - Germany  
 Demola - Tampere - Finland  
 MINC Incubator - Skåne - Sweden  
 Media Evolution - Skåne - Sweden

## ANNEX 3: OPEN INNOVATION SUCCESS CASES\*

OI case	Organisation(s)	Focus	Location
<i>Aalto Entrepreneurship Society</i>	Helsinki University of Technology / Helsinki School of Economics / University of Art and Design Helsinki	Business accelerator/ entrepreneurship/ networking/ coaching	<b>Finland</b>
<i>DEMOLA Network</i>	Hermia Group / Visoriai Information  Technology Park / Latvian IT Cluster / Infobalt / Budapest University of Technology and Economics / Business Kitchen / Mobile Heights / Norrköping Science Park / RAZ:UM	Bridging/ entrepreneurship/ ideas and product development	<b>Finland / Lithuania / Latvia / Hungary / Sweden / Slovenia</b>
<i>High Tech Campus Eindhoven</i>	More than 125 companies (originator: Philips)	Patenting/ networking/ ideas and product development	<b>The Netherlands</b>
<i>Innovation Design Entrepreneurship and Science (IDEAS)</i>	Lancaster University Management School / University of Liverpool Management School / Manchester Business School	Entrepreneurship/new model	<b>UK</b>
<i>Innovation Mill</i>	Spinverse	Business accelerator/ entrepreneurship/ networking	<b>Finland</b>
<i>Catapult Programme</i>	The Technology Strategy Board	Product and service development/ capabilities and equipment access/ commercialisation	<b>UK</b>
<i>France Brevets</i>	Government / Caisse des Dépôts	Patent exploitation and promotion	<b>France</b>
<i>BAE Systems Investment in Innovation</i>	BAE Systems	Idea and product development/business model development/ facilities sharing/ IP, processes and project management advisory	<b>UK</b>
<i>Knowledge Transfer</i>	University of	Idea and product development/ access to	<b>UK</b>



<b>OI case</b>	<b>Organisation(s)</b>	<b>Focus</b>	<b>Location</b>
<i>Partnerships</i>	Wolverhampton	funds and expertise	
<i>Team Academy</i>	University of Applied Sciences	Entrepreneurship	<b>Finland</b>
<i>Innovation Alliances</i>	Federal Government	Facilitate long-term cooperation/ create positive spill over for the territory	<b>Germany</b>
<i>MIT Technology Licensing Office, MIT's Office of Corporate Relations, MIT Industrial Liaison Program</i>	Massachusetts Institute of Technology	Licensing/ networking/ product and service creation	<b>USA</b>
<i>Knowledge Transfer Programme</i>	Kementerian Pendidikan Malaysia	Training/networking/ sharing of physical facilities/ IP, expertise, learning and skills exchange	<b>Malaysia</b>
<i>Technology Transfer Initiative (TTI GmbH)</i>	University of Stuttgart	Support new ideas, product and services/ networking/ access to capital advisory	<b>Germany</b>
<i>The Oxford-Man Institute of Quantitative Finance</i>	MAN Group / Oxford University	Expertise creation	<b>UK</b>
<i>TU Berlin entrepreneurship</i>	Technische Universität Berlin	Entrepreneurship/ technological and administrative assistance/ start-ups creation	<b>Germany</b>
<i>University of Central Florida Incubation Program (UCFIP)</i>	University of Central Florida	Business incubator and accelerator/ stimulate territorial development/ entrepreneurship/ business ideas/ patenting	<b>USA</b>
<i>Fraunhofer Society</i>		Contract research/ out-licensing/ spin-offs	<b>Germany</b>

\* **Source:** JIIP (2014) Compendium of short case studies of new types of OI and Knowledge transfer (KT) practices identified from Europe or elsewhere. Part of ongoing EC project "Study on Knowledge Transfer and Open Innovation". DG RTD/ Joint Institute for Innovation Policy (JIIP), Brussels

## ANNEX 4: EURIS – OPEN INNOVATION BUSINESS MODELS

Case (industry)	Characterisation of the business initiative (business model renewal or enhancement)	Type of open innovation
Bosch (Engineering and electronics)	Keeping existing products up to date and so keeping up value creation for existing customers and value capturing potential for Bosch. (business model enhancement)	Inbound: collaboration with research partners to access a variety of new technologies.
MechaniCo (Engineering and electronics) <sup>6</sup>	Keeping existing products up to date and so keeping up value creation for existing customer and value capturing potential for MechaniCo. (business model enhancement)	Inbound: collaboration with research partners to access a variety of new technologies.
Bodegas Ochoa (Food)	Adding an additional product to its portfolio of gastronomic products (i.e. olive oil) and so creating value for existing distributors and end-consumers and additional value capturing potential for Bodegas Ochoa. (business model enhancement)	Inbound: collaboration with research partner to access knowledge and competences with regard to agricultural growing techniques.
Bruns (Exhibition engineering)	Offering standardised exhibits, as well as custom made exhibits, as a new value proposition for new customers (i.e. smaller museums, shopping centres, and amusement parks). (business model renewal)	Inbound: collaboration with customers of the original business model and a design agency for re-design and promotion
Ingeteam Energy (Power plants-equipment design and development)	Offering standardised components as a new value proposition for new customers (i.e. new entrants to the wind power industry from other geographical areas). (business model renewal)	Inbound: collaboration with universities, technical centres, and prescription engineers to access a variety of technologies and market knowledge.
FEI (Electron microscopes)	Offering a low cost electron microscope as a new value proposition for new customers (i.e. smaller companies and research institutes, and less research intensive educational institutions). (business model renewal)	Inbound: collaboration with mechatronics firm and software firm for several value chain activities.
Kugler-Womako (Printing and paper processing)	Offering a wire mesh machine as a new value proposition for new customers (i.e. tier 1 automotive suppliers). (business model renewal)	Inbound: collaboration with potential customer to access industry knowledge.
Frenos Iruña (Brake systems design and manufacture)	Offering brake systems for wind turbines as a new value proposition for new customers (i.e. wind turbine manufacturers). (business model renewal)	Inbound: collaboration with universities and technical centres for research, new customers for co-creating, and a firm for manufacturing competences.
Philips (Electronics)	Offering research support services as a new value proposition for new customers (i.e. research institutes and technology intensive start-ups). (business model renewal)	Outbound: opening up research support services to other organisations
Van Gansewinkel (Waste management)	Offering technical knowledge with regard to materials and recycling as a new value proposition for new customers (i.e. product developers and designers). (business model renewal)	Outbound: Offering technical knowledge with regard to 'design for recycling' as a consultancy service to other organisations

**Source:** Smits, A. et al. (2012). Note: MechaniCo is a pseudonym.



## DIRECTORATE-GENERAL FOR INTERNAL POLICIES

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