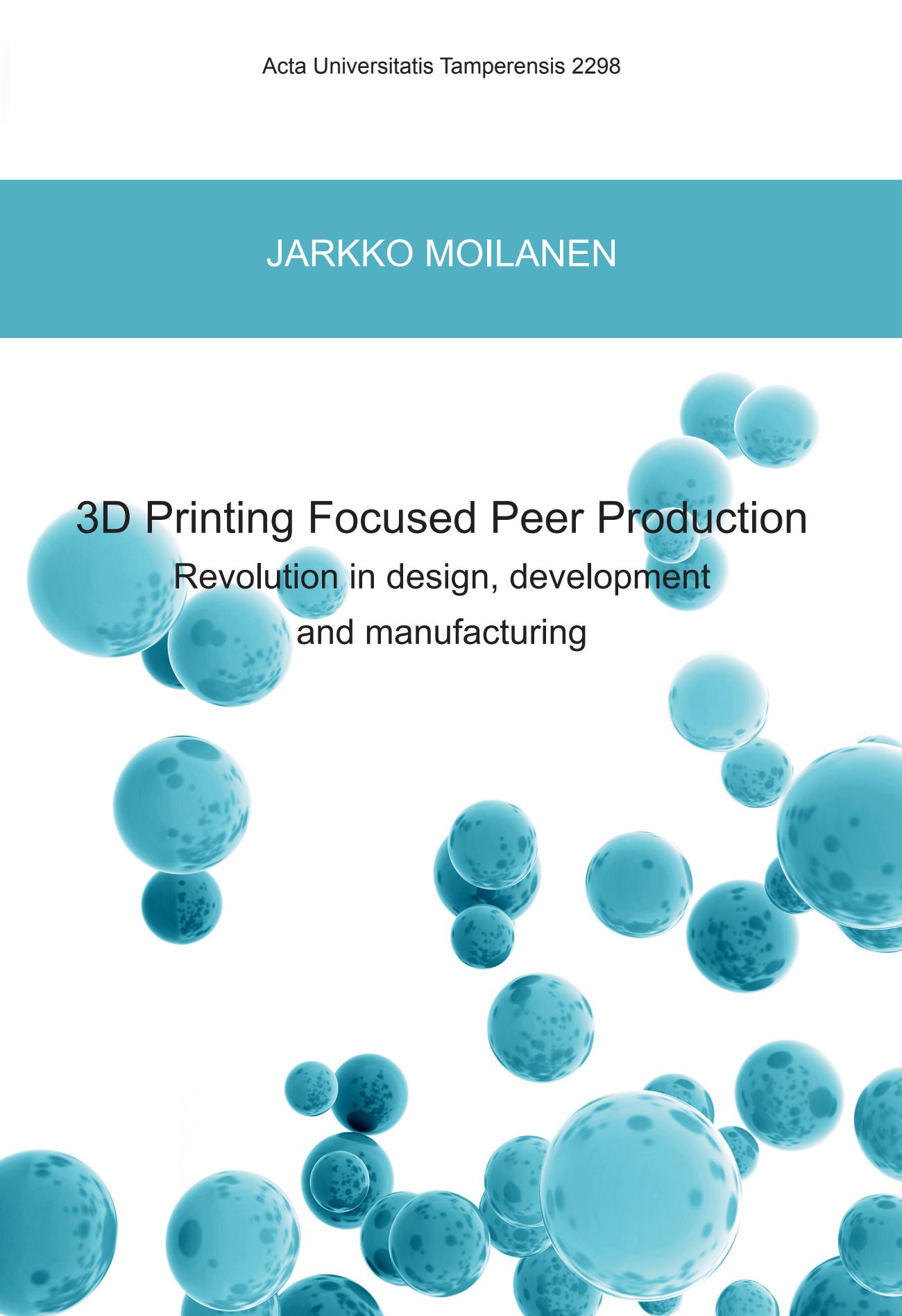


JARKKO MOILANEN



3D Printing Focused Peer Production

Revolution in design, development
and manufacturing



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ACADEMIC DISSERTATION

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the Faculty Council of the Faculty of Communication Sciences
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JARKKO MOILANEN

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1 Introduction

3D printing has been used in industry for decades ever since it was invented in the 1980's by Chuck Hull.[86] During its first decades it has mainly been a tool for prototyping new designs and manufacturing processes [12], but more recently the situation has changed. The technology has expanded to include also production. Nowadays 3D printing is utilized not only for producing functional spare parts for machines but also for humans as jaws, teeth, limbs, skull parts to name a few [16]. In addition to industry use for 3D printers, low-cost 3D printers have entered the playing field and changed the situation. Low-cost 3D printers, open source software and online design sharing platforms have enabled personalisation and local production of goods - 3D printing has entered the desktop[59]. The nature of the nascent ecosystem started to intrigue the author. It provided an interesting subject for research and comparison to other open approach driven ecosystems such as open source especially due to its physical aspects.

The pace of development is fast and the features that are expected in 3D printing include, for example, the ability to print electronic devices in one piece, wires and all[74]. 3D printing community (including both the professional community and the hobbyist community) is exploring the boundaries of this technology by applying it to food processing [46, 83], creating organs from scratch [55] and house production [24, 2] to name a few. This research was conducted when the nascent 3D printing economy was forming and in constant motion; evolving and seeking its initial boundaries. To be able to research such phenomena as they are happening are golden nuggets for researchers.

Until 2005, the tools and knowledge as well as the designs of 3D printing were kept inside companies, as closed-source proprietary assets. In 2005 Dr Adrian Bowyer initiated the development of an open source hardware 3D printer with the aim that it can mostly reproduce itself[34]. The printer was called RepRap - short for replicating rapid prototyper. The RepRap project released all of the designs it produced under the GNU General Public licence (GPL), allowing free use, distribution and modification. About a year later, in September 2006, a RepRap prototype was able to 3D print first part of itself [34]. That moment can be seen as a turning point in the history of 3D printing and the emerging ecosystem fueled by open design and open source.

After that moment, the legacy cathedral model where knowledge is in the hands of a few experts started to crumble and turn towards a bazaar model,

where knowledge and skills as well as results are shared among the members of the community (for the cathedral and bazaar metaphor, see [60]). All of this sounds quite familiar. The members of the new 3d printing communities are often referred to as makers and hackers. Hackers are the people who in the 1970's started building computers in garages and caused the birth of PC, personal computers. (see, e.g., [43]) Now the same kind of pioneers are causing what Jemery Rifkin [64] has labeled the third industrial revolution, where 3D printing is seen as fundamental part and enabler.

After 2011, 3D printing gained more publicity due to several articles in a variety of publications. In July 2013 Gartner located consumer 3d printing at the peak point of the hype cycle [36]. However, at this point the assembly and usage of low-cost printers required a significant amount of technical skills as well as an opportunity and the time to gain knowledge to operate it. Therefore it is not a surprise that initially the individuals who adopted this new technology were from the maker movement which had established hundreds of makerspaces and hackerspaces [5] around the globe. At the same time there was an increasing need for easy to use 3D printers among the population around the world.

This led to the development of a plethora of new 3D printers and software needed in the tool-chain. These new printers can be labeled as low-cost, because the manufacturing costs of the printers themselves were calculated in hundreds of euros, not in tens of thousands as was the case with legacy (industrial prototyping) 3D printing devices. Several companies were established with the business model of providing assembly kits for 3D printers. However, even with these low-cost 3D printers, the user was expected to put together sometimes hundreds of pieces of bolts and nuts and had to learn to use the needed software. The early user-assembled 3D printers were not suitable for the masses, the level of complexity and steps before first positive outcome was too long and hard. In other words, the learning curve was too steep. People wanted out of the box 3D printers, which can be taken into use just as easily as conventional printers.

One of the success stories in this wave of low-cost 3D printers was the MakerBot Replicator. It was one of the first out of the box ready low-cost 3D printers. A few years after RepRap initiated the development of low-cost 3D printers, Bre Pettis, Zach Smith and Adam Mayer established a company called MakerBot Industries to manufacture Replicator 3D printers for sale. According to Pettis, their motto was "[T]he big mission has always been to make 3-D printing accessible to everyone". Pettis is also one of the

founders of the Brooklyn-based hackerspace NYC Resistor where MakerBot has its roots. The MakerBot was built on a foundation of open hardware projects, such as RepRap and Arduino, as well as through using many open source software projects. It was seen as a successful example of the combination of open source hardware and business and it flourished. The business model benefited both the open source community and the company. The community gained traction and contributions from the company. At the same time community members poured knowledge and time to the product development. The model looked like a match made in heaven. However, quite suddenly in 2012 MakerBot closed the source of the Replicator which inevitably led to a conflict with the community. The conflict affected the company as well, and one of the founders left it due to this change in openness. Eventually MakerBot Industries was sold to Stratasys for \$403 million in 2013.

All along the way, the phenomenon and development of (low-cost, out-of-the-box) 3D printing raised some interesting questions. The development of low-cost 3D printers did not emerge from companies, but from the maker communities. What is the nature, the values and motivations of the communities from where for example the MakerBot emerged and what is their historical context? What kind of community is the 3D printing community and what are the motivations for participation? Much of the developments around low-cost 3D printers have been open design driven. That leads to the question: how does business thinking and profit-making fit into the picture? In the open source software community, licenses have been the tool for keeping development open. What are the licenses and practices used in the 3D printing community? These initial questions are discussed in more length later in the chapter on research questions, below.

This dissertation research was conducted as a set of empirical research cases with different focuses on the overarching theme of how commons based peer production organizes and operates in the internet. In other words, this research is descriptive in nature and analysis is mostly based on statistical methods while some in-depth interviews have been used too.

Academic research is always built on top of previous work. This dissertation is no exception. Several scholars have elaborated the contemporary P2P mode of production in some detail in earlier research [77, 61, 89]. That is also the reason not to focus on the historical aspect, but instead to concentrate on describing contemporary forms of peer production. Several other scholars such as Bauwens, Kostakis and Meretz [39, 13, 38, 48]

have identified and theorized the concept of peer production. While reading the articles of these scholars, the P2P focused journals and more, the author found some areas where research has been minimal or even missing. However, the articles collected here do not aim to fill in gaps in P2P theories. Instead, the focus is to provide more precise descriptive information about the chosen subjects based on empirical research.

Another key motivation to research peer production is personal interest in open source, maker and hacking culture, which are fundamental parts of peer production. The seemingly chaotic and obscure form of the 3D printing ecosystem needs to be described somehow. We need to conceptualize it to use it, understand it, learn from it and develop the model. This dissertation is one attempt to describe features of the nascent 3D printing focused peer production ecosystem. The concept of "ecosystem" is a description framework for collaborative peer production which relies of partially on open source tools and principles, uses open design in design processes, produces objects through 3d printing services and low-cost 3d printers which are often open source hardware driven.

2 Key concepts

2.1 Maker movement

The Maker Movement is where traditional artisan culture meets and mixes with the web generation. The Maker Movement is a global network of local communities of hobbyists, tinkerers, engineers, hackers, and artists who creatively design and build projects for both playful and useful ends. The maker movement has recently hit the eye of mainstream and businesses mostly due to Make magazine, MakerFairs, open source hardware and 3D printing.

This relatively new rising phenomenon can be seen as a significant change in and/or addition to the older hacking and hacker community. Recently, hackers have been forming new kind of communities, which are quite different compared to earlier hacker communities. The roots of the hacker movement can be followed back to 1950's.

Several hacker generations (see Figure 4) have been identified in previous research: 'True hackers' [43], Phone-phreakers [28, 80, 69, 75], hardware hackers [43], game hackers [23], Microserfs and Open Source [82, 40, 44, 61, 41, 71]. The author has suggested Peer Production generation as the label for the most recent hacker generation which is built on top of the values of the open source culture but focuses on open design and production of physical objects[50].

Different hacker communities use different names for their communities: hackerspace, fablab, makerspace, techshop, 100k garage. The variety of names for the new 'do-it-yourself' communities expresses the variety and diversity of the maker movement. The rise of the maker culture is closely associated with the rise of hackerspaces. Fablabs and hackerspaces/makerspaces are probably the most numerous communities. "Fablab" as a concept and term is defined and controlled by MIT, Massachusetts Institute of Technology. In contrast, hackerspaces are independent communities operating without restrictions from any organization.

Troxler [84] has adapted Gershenfeld's [25] term 'fabbing' to refer to "commons-based peer production of physical goods". He uses the term as an umbrella for all the forms of hacking communities listed above. The term 'fabbing' might be somewhat misleading since the word is derived from fab labs (short for fabrication laboratory or fabulous laboratory), which

are mostly the National Science Foundation (NSF) funded do-it-yourself communities. According to Troxler, hackerspaces are one form of 'fabbing'.

Troxler's view of 'fabbing' or 'do-it-yourself' culture is more or less focused on the physical production of goods, which neglects the community aspects. In contrast, hackerspaces typically emphasize the role of community, the role of members and independence from outside influences such as funding. Hackerspaces community has defined itself as:

Hackerspaces are community-operated physical places, where people share their interest in tinkering with technology, meet and work on their projects, and learn from each other. [5]

According to Chris Anderson [10], one of the icons among makers, the maker movement has three characteristics:

- People using digital desktop tools to create designs for new products and prototype them (“digital DIY”).
- A cultural norm to share those designs and collaborate with others in online communities.
- The use of common design file standards that allow anyone, if they desire, to send their designs to commercial manufacturing services to be produced in any number, just as easily as they can fabricate them on their desktop. This radically foreshortens the path from idea to entrepreneurship, just as the Web did in software, information, and content.

Later on in this thesis the term "maker movement" refers largely to all forms of hacker communities such as hackerspaces, makerspaces and fablabs.

2.2 Peer Production and Commons-based peer production

The terms “peer production” and “Commons-based peer production” are in the core of this research and thus discussed in details here. Scholars, not surprisingly, have different views about the meaning of the terms. As a rather new and intriguing term “peer production” raises interest and passions among scholars. It is common that polarization is lurking and some prefer to

stay in between when defining new terms. This applies to "peer production" as well.

Stefan Meretz's [48] has approached the realm of peer production from the pattern perspective. Meretz has been involved in the Oekenux network and has summarized the decade long discussion inside the network in ten "peer production patterns". From the patterns at least beyond scarcity, beyond commodity, beyond money fit into the picture of this thesis. Digital 3D models are by nature unlimited resource and are not exchanged as commodity. Instead digital models are often licensed under open licenses and thus freely modifiable. Therefore scarcity is created by social patterns and laws. Of course commons-based 3D printing contains contradictions and frictions with conventional economical models such as capitalism. The case of MakerBot Industries is one example of contradictions and therefore discussed in the thesis multiple occasions. Patterns of beyond classes, labor and exclusion are visible in hackerspaces since in those artificial bogus criteria such as gender, age or education are avoided. In addition hackers do what they like and with varying intensity they see purposeful.

Some scholars such as Rigi [66] consider peer production as replacement for capitalist system. According to these radicalists peer production and capitalism can not coexist in the long term. At the other end of the trajectory are radical left analysts and scholars such as Bauwens and Benkler who present theories in which the new social order or mode of production will coexist with the capitalist one. This, they argue, is mostly due to the reason that neither can exist or survive without the other. The result of the coexistence can be labeled "hybrid economy" and can be easily compared to the phenomenon of symbiosis in biology.

One of the long term P2P researchers and founder of the P2P Foundation, Michel Bauwens takes a position in the middle arguing that "peer production is both immanent, i.e. part and parcel of a new type of capitalism, and also transcendent: i.e. it has sufficient postcapitalist aspects that can strengthen autonomous production communities in building an alternative logic of life and production that may, under certain conditions, overtake the current system." [15]. Bauwens [15] prefers to define *peer production* by the following three interlocking characteristics:

- the 'open and free' availability of the raw material
- participatory 'processing' and

- commons-oriented output

Originally the term “Commons-based peer production” (CBPP) was coined by Harvard Law School professor Yochai Benkler to describe a type of socio-economic production in which the creative energy of large numbers of people is coordinated (usually with the aid of the Internet) into large, meaningful projects mostly without traditional hierarchical organization or centralised decision making[17]. In the book *The Wealth of Networks* Benkler describes in detail the idea and content of commons-based peer production. Benkler’s theory does not seem to describe an option in which commons-based peer production would replace or otherwise strongly alter the current social order. Rather, for him, CBPP seems to function as “an addition” built on top of or around the current capitalist logic.

Benkler makes a distinction between “commons-based peer production” and “peer production”. Bauwens defines ‘peer to peer’ as a relational dynamic that emerges through distributed networks. According to Benkler, Commons-based peer production is a socio-economic system of production that is emerging in the digitally networked environment, and is different from market-based and company-based production in that the resources used and the products produced are shared among the participants in the distributed network. A short definition of “commons-based peer production” according to Benkler is:

”The inputs and outputs of the process are shared, freely or conditionally, in an institutional form that leaves them equally available for all to use as they choose at their individual discretion.” [17]

A subset of commons-based production is the kinds of peer production in which participants are self-selected and decision-making is distributed. Implementations of peer production are for example Youtube and Facebook. Well-known examples of commons-based peer production communities are Wikipedia, OpenStreetMap and RepRap 3D printer.

In this thesis, we will use Bauwens’ definition of the term “peer production” and “commons-based peer production” is understood in the sense of Benkler’s definition.

When the concepts of peer production and commons-based peer production are applied to 3D printing, we move from the world of knowledge

and executable software, to the world of design-for-making. Concrete examples of this are Arduino and Raspberry Pi. One of the latest additions to the list of commons-based peer production communities is the RepRap [8] community and projects related to it. RepRap was one of the the first low-cost 3D printers, and the community has had a vital role in igniting the open-source 3D printer revolution around 2007. It is also an example of commons-based peer production extending to the physical world out of the purely digital realm in which for example PirateBay resides. RepRap contains both of the worlds; it utilizes the digital world in the form of enabling co-operation and sharing while aiming at enabling a network of distributed production of replicable 3D printers as tools for manufacturing.

2.3 Open Design and Open Source Hardware

A popularized definition of Open Design could be something like: development of physical products, machines and systems through the use of publicly shared design information. Historically, Open Design has been influenced by the Open Source movement and its principles. Open Source as a practice has found its shapes earlier but can, conceptually, be seen as a case of Open Design. Likewise, Open Source Hardware (OSHW) which will be discussed later, can be categorized as a sub-set of Open Design.

Ronen Kadushin, a famous industrial designer coined the term “Open Design” in his Master’s thesis 2004. Later the term was formalized in the “Open Design Manifesto” in 2010 [35]. According to the Open Design manifesto, as defined by Kadushin, the method relies on two preconditions:

“An Open Design is CAD information published online under a Creative Commons license to be downloaded, produced, copied and modified. An Open Design product is produced directly from file by CNC machines and without special tooling.” [35]

Massimo Menichinelli has coined the term “Open P2P Design” to emphasize the role of social interaction in design processes [47]. According to Menichinelli, Open P2P Design is a proposal for a co-design methodology. The core difference from common Open Design is that in Open P2P design collaboration does not develop just by sharing open licensed documents. Instead, a successful open design project requires the existence of a community which collaborates. Menichinelli’s analysis is useful not just in

the case of open design, but also for co-design in multiple fronts such as creating businesses based on communities, and developing and managing participatory public services.

The Open Source Hardware Association (OSHW) [7], formed in 2012, is an association focused on open source hardware. The community is active and has developed an open hardware project template which is a proposal for how to present project contents. The template describes and defines the structure of project documentation. The association has also published a definition for open-source hardware, released on February 10th, 2011:

”Open Source Hardware (OSHW) is a term for tangible artifacts — machines, devices, or other physical things — whose design has been released to the public in such a way that anyone can make, modify, distribute, and use those things.” [7]

The OSHW 1.0 definition has been endorsed rather widely including endorsements by significant industry stakeholders such as MakerBot Industries, Bug Labs, Scratch & MIT, SUSE Linux, Creative Commons, Arduino, Adafruit Industries, MIT Media Lab and Sparkfun Electronics.

Boundaries and freedoms for utilizing open design results are often defined by licenses. Licenses are key elements in enabling sharing and distributed co-creation as well as co-production as defined by Bauwens and Benkler.

2.4 Open Licenses and Terms of Use

Since commons-based projects exist under open licenses, I will discuss licensing only in the contexts of open licenses. Discussion of proprietary licensing is excluded from this thesis. In the 3D printing context, licensing is applied at least in two ways. First of all, operating a 3D printer requires software. Some of the widely used applications are licensed under open source licenses. Open source licenses allow end users, developers and commercial companies to review and modify the source code, the blueprint or the design for their own purposes whatever those might be. Secondly, licensing is applied to the digital design files of 3D printers and artifacts manufactured with 3D printers. Consequently, licensing affects not only open design 3D printer developers and manufacturers, but also the end users.

Designs are often shared in a digital format across the community by utilizing purpose-built online sharing platforms such as Thingiverse.com and

Ponoko.com. The platforms are often maintained by businesses. Some designs are uploaded to the Github platform which is widely used by the open source software community. PirateBay also has category for 3D printing designs, but that has never been adopted widely as platform by the 3D printing community. The process of sharing is simple and normally contains the following steps: designers 1) upload the digital design files to platform, 2) add some instructions for makers, 3) add tags and category to enable discovery and 4) attach a license to the designs. Some of the platforms are more than repositories for open design files and extend the services for example by offering paid 3D printing services and version control.

Across industries, it is common practice that before an end user is allowed to upload any content to a platform, they have to accept Terms of Use, which are not open for discussions. The user must accept the Terms of Use before operating the service. From the end users point of view, the Terms of Use can be seen as a primary license. Secondary licenses (discussed below) define the freedoms and limitations for the user uploaded content which is shared horizontally with other users.

Due to the fact that open source software has been developed since the 90's, a plethora of open source licenses exists. The 3D printing community has adopted the usage of common open source licenses. Most widely applied open source licenses are Open Source Initiative (OSI) approved licenses such as Apache, BSD, MIT and Mozilla licenses.

The most widely applied open license for digital 3D design files is a Creative Commons license (CC) [53]. Creative Commons is set of licenses which enable the free distribution of an otherwise copyrighted work. The popularity of Creative Commons can partly be explained by the ease of use which is embodied in the facilitated selection of an appropriate license. The selection is easy to do and understand since the system has a user-friendly layer on top of legal documents. The Creative Commons community has created a simple website (and translations of it) which guides the user in license selection.

In practice, platform owners such as MakerBot Industries have given Thingiverse.com repository (a free to use collection of design files) users a list of licenses to apply to each of the digital designs uploaded to the service. If license information is not attached to the digital design, others can not freely utilize the creation. Depending on the license freedoms might be restricted to reuse while some licenses allow modification. Licenses guarantee freedom to utilize digital designs in 3D printing. Open licenses enable end users and

designers to reproduce the artifact with help of 3D printers which can be personal or shared with the local community (single 3d printer or cluster). In addition digital 3D models can be reproduced via 3D printing services, which normally utilize 3D printer farms or clusters - hundreds or even thousands of devices.

2.5 3D printing

3D printing was invented in 1983 by Chuck Hull [86] who is the co-founder, executive vice president and chief technology officer of 3D Systems, which is currently one key player in the 3D Printing ecosystem. Hull is also the inventor of the solid imaging process known as stereolithography, which was patented in 1984, and of the 3D printing file format .stl, still widely in use.

3D printing is a popularized term which normally refers to additive manufacturing (AM). AM refers to the process of joining materials to produce artifacts from digital 3D model data. The process is based on adding layer upon layer, as opposed to subtractive manufacturing methodologies. This seemingly small distinction of adding rather than subtracting means everything: for example, the amount of waste is nearly zero. Another advantage of AM is the ability to construct complex structures and geometries that could not be manufactured otherwise. In addition AM offers a possibility to create functional parts without additional assembly.

3D printing has been utilized by the industry for decades already. According to Wohlers 2009 report 16% of AM process use was for direct part production, 21% for functional models, and 23% for tooling and metal casting patterns. [91] The AM industry is growing rapidly. Its value surpassed \$5 billion in 2015 and is expected to balloon to more than \$26 billion by 2021. [92]

The term rapid prototyping (RP) is commonly connected to additive manufacturing and refers to a group of techniques used to rapidly create a system or part representation utilizing three-dimensional computer aided design (CAD) data before putting it to production.

The rise of low-cost 3D printers started the new wave of 3D printing around 2006 when RepRap emerged. This phenomenon is the core focus of the thesis: the aim of the thesis is to add our knowledge and understanding of the open design driven low-cost 3D printing happening in and through P2P networks.

3 Research questions, methods and data

3.1 Research strategy

The research was exploratory in nature. Consequently, there was no predefined system for data collection or methodology, and no established scholarly community. Instead openness in research was selected as strategy. The author chose to cooperate with other researchers interested in the same subjects and topics. The initial problem was how to find others and gain their attention and co-operation. Moreover, the research has been conducted while working on other areas. Thus, methods to find other scholars via other routes than doctoral schools had to be built.

The cooperation network with other scholars was created with the help of a website, Statistical Studies of Peer Production ¹, which was established by the author in 2011. Using a well-known host, the Peer to Peer Foundation initiated by Michel Bauwens, helped the author's entry to network of scholars interested about same topics. Initially the website was drafted as minimum viable product on the author's own servers. After meeting Bauwens in Tampere and short discussions about the research, the website was rebuilt on the P2P foundation servers by the author. Thus, a virtual home for the research was founded and established.

Surveys and statistical methods were utilized widely in order to gain an overview of a given phenomenon at hand. Plans and initial results for surveys as well as other data were published on the <http://surveys.peerproduction.net> website, which resulted in contacts and discussions with other scholars. These contacts, in turn, led to cooperation in the form of further research and co-authoring articles. The web-driven research network building was supplemented with attending academic conferences where research results were discussed.

One part of the strategy was crafting an overview of the problem field and discussing it with the academic community. The first discussion took place at the Aalto University organized CO-CREATE conference in 2013. The article included in the conference proceedings contains an illustration (Figure 1) describing the layers of Commons Design Economy. One of the rare attempts to describe open design as a whole, is Michel Avital's (2011) description of four interdependent conceptual layers: object layer, process

¹<http://surveys.peerproduction.net>

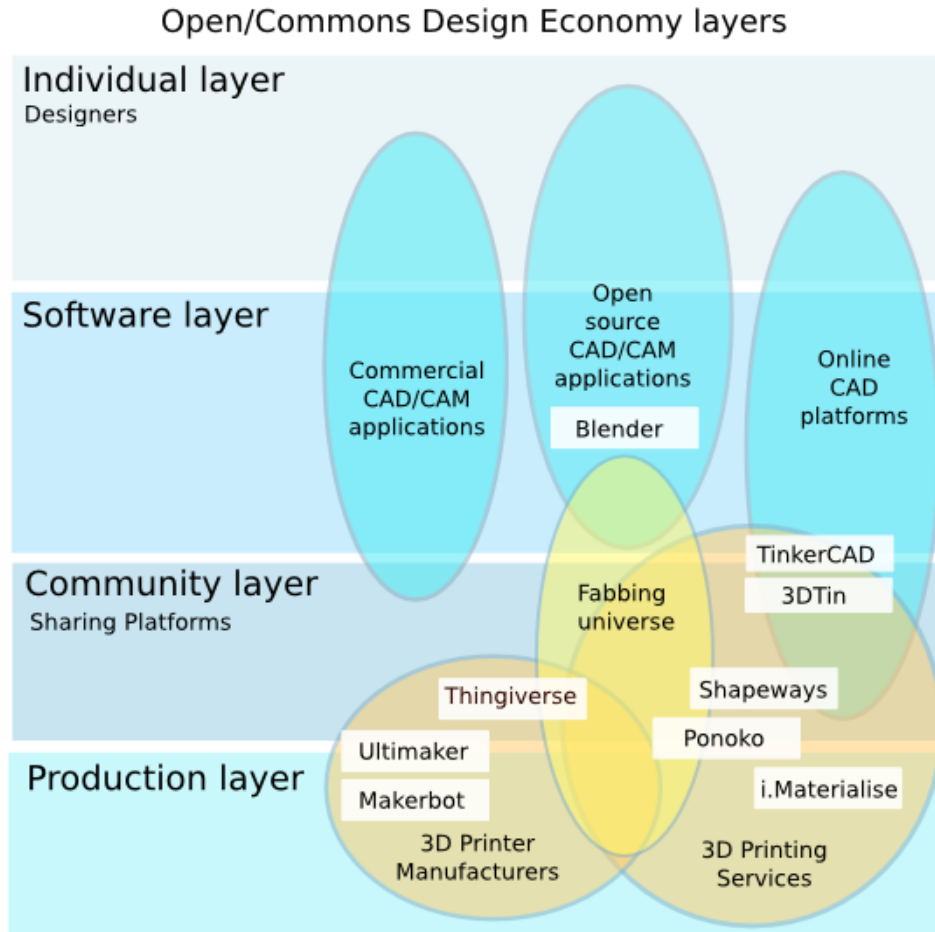


Figure 1: Open/Commons Design Economy Layers [52]

layer, practice layer and infrastructure layer. The intention was not to provide a rival theory, but to complement Avital's work and to construct a more detailed model of emerging from 'Commons Design Economy' with a similar layer approach.

The illustration enabled more thorough discussions and discovery of weaknesses in the approach and initial model. The discussions led to research on Thingiverse licenses and eventually to a peer-reviewed article.

The author is also a co-founder of the hackerspace in Tampere, Finland.

The hackerspace - Tampere Hacklab - was established already 2009, well before the start of this dissertation research. At that time the author was writing a Master's Thesis about hackers called "Realms of Cyberwarriors - Definitions and Applications". A local hackerspace was a method to gain access to the somewhat closed hacker circles in Chaos Computer Club. During summer 2011 the author 'resigned' from active duties in the hackerspace board, which was more or less a rubberstamp for the desires of the community. The experience of living with the community offered insights that researchers are seldom able to gain. After summer 2011, the author's role was more passive observation and taking random notes about the activity and values that were discussed a lot in the community during the first years. At the time of writing this thesis, the Tampere Hacklab community has around 250 members.

In sum, instead of advancing with a fixed set of tools, the methodology and approach were solved case by case for each phase in the research. Each phase produced a peer reviewed article.

Research phases

The research had four phases outlined in figure 2. In the first phase, the focus was on hacker and maker communities. It must be noted that getting familiar with the maker movement began already 2009 by participating in establishing one of the first hackerspaces in Tampere, Finland. The aim was to discover the nature of maker movement by identifying features of the community and the values as well as motivation to participate in it. Prolonged participatory observation was supplemented with two annual surveys.

During 2011-2013, the focus was transferred to low-cost 3D printing community which was visible in the maker movement already in the phase one. During this phase values and practices of the 3D printing community were explored with surveys. The research phase was prolonged because at this point author was CTO in a startup - Want3D - crafting solutions for distributed 3D printing. This position offered a front seat to the practical aspects of low-cost 3d printing since the company utilized only early stage Ultimaker 3D printers.

In the third phase, the focus was on practices of sharing the open designs with others. The aim of this phase was to discover licensing practices in the 3D printing related design communities. Open design is a fundamental part of the development of low-cost 3D printers. Thus, in the last phase the

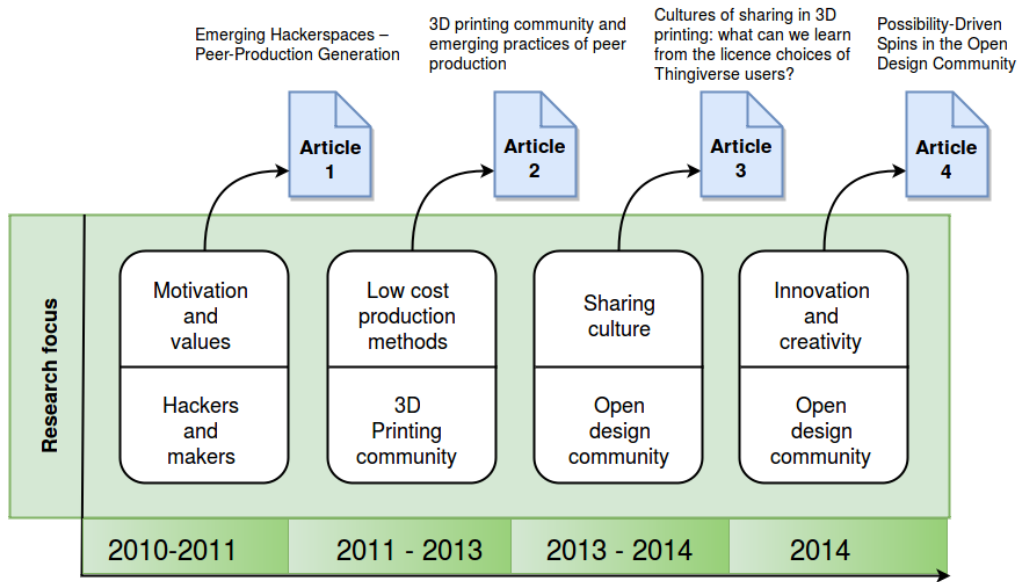


Figure 2: Research focus in timeline. Each blue spin-off paper is an article discussed in the thesis.

focus was turned towards the open design community and their processes and values. The aim was to construct a general model for open design process with semi-structured interviews among designers in the open design community.

3.2 Research questions

The research of this dissertation thesis is two-folded. The first focus was on the peer production community and the somewhat overlapping 3d printing community. The second focus was on open design practices and sharing of open design driven 3D printing design files. The first part of the research (articles 1 and 2) answers to the questions Q1 & Q2. The latter part of the research (articles 3 and 4) focusing on open design process and sharing answers to the questions Q3 & Q4. In addition some broader scale questions were explored as well (questions Q5 & Q6).

Table 1: Research questions

Q1 - article 1	What kind of hackers/people participate in hackerspaces, what is the motivation to participate and what do people do in hackerspaces? Additionally, what is the bigger context of hackerspaces?
Q2 - article 2	What are emerging patterns of 3D printing participation and some of the major bottlenecks in terms of creating a commons?
Q3 - article 3	How users of the leading online 3D printing design repository Thingiverse.com manage their intellectual property, and in doing so exchange information?
Q4 - article 4	What are the main characteristics and novel methods of operation within the open design community?
Q5	What is the structure and status of the low-cost 3D printing and open design driven ecosystem? In addition, what is the role of hackerspaces in the innovation processes?
Q6	What is the nature of the bigger socio-economic change the peer production movement is a part of?

3.3 Delimitations

One of the obvious and fruitful research areas in the 3D printing economy is existing and emerging business models. Even though this subject is touched upon in the following, in the end a more detailed discussion is out the scope of this dissertation. The author is not an expert on the subject and it would have broadened the scope of the thesis beyond the resources available.

Another excluded topic for in-depth research and analysis is 3D printing service usage among the open design driven 3D printing community. The subject is intriguing, but due to the nascent nature of the ecosystem, the 3D printing services were at the time of the research just emerging. The amount of available services and usage of the services in open design driven community was low. Thus research on 3D printing services would have not been fruitful. The situation has changed and now the subject might be relevant for further research.

Research related to the usage of commercial legacy 3D printers used by industry were excluded because the research focus was on forms of open design and the low-cost 3D printing driven ecosystem.

3.4 Data collection

Data for the purposes of the research was collected with online surveys, interviews and through software that was written specifically for the purpose.

3.4.1 Observing Peer Production movement

Observing the local Tampere hackerspace community for a prolonged period (two years) and participation in hackerspace events organised by various hackerspaces in Finland was a method to gain access to the Peer Production movement, gain knowledge about the rhetorics used, and learn about the applied values and practices. As such, observation was not a data collection method, but more like a pathway to the subject and the community it related to. The observed local community acquired in 2010 low-cost 3D printers, and later a CNC mill, laser cutter and plasma cutter tools to manufacture open 3D designs. Members gave tutoring lessons to each other in 3D design as well using the tools. By following the activity of members, the author was able to understand the tool chain and skills needed to use 3D design files for manufacturing with low-cost 3D printers as well as with other production methods.

3.4.2 General notes about the surveys among peer production movement and 3D printing community [articles 1 & 2]

The below description concerns surveys related to articles created in research phases one and two. Annual surveys were conducted among the members of peer production communities (hackerspaces and makerspaces) during 2010-2011. Another annual survey was conducted among 3D printing community members 2012-2013. The first pilot survey was created with Google forms, but participants of the survey as well as global hackerspace community members on the IRC channel #hackerspaces advised the author to select a less debatable tool for conducting further surveys. Some of the comments referred to Big Brother accusations towards Google. After this experience, the following surveys were done by using for purpose-built survey engine under surveys.peerproduction.net. The survey engine was based on the open source LimeSurvey software and was one of the platforms suggested by the members of the community. Any additional comments for used survey platform stopped and community seemed to accept it. Getting the survey tools aligned with the values of the community was vital for the survey, since

without it some of the members would not have participated in the surveys. Data collected was exported to CSV files and uploaded to Github for others to use.

3.5 Methods of analysis

The questions in the surveys contained multiple-choice questions and Likert-scale questions. The replies were recorded in a database, from which the replies could be presented in numerical and various chart forms. The surveys among peer-production and 3D printing communities contained hundreds of responses (peer-production surveys: 451 participants, 3D printing surveys 358 participant). The results were presented in selected charts, and relationships between responses were illustrated by cross-tabulation between variables.

Data exploration was applied to discover license practices among the open design community. From the data, selected charts were constructed and used in analysis. As noted above, the interviews were continued until saturation. For analysis, the answers were thematically grouped.

3.5.1 Cultures of sharing in 3D printing [article 3]

In the case of this study, the author created bespoke software for the automated collection of metadata from the digital 3D model repository Thingiverse.com. The purpose of the application was to collect needed meta information about each accessible digital 3D design. The technique used was screen scraping since the available API in the Thingiverse.com platform was seen too complex for the purposes and the learning curve was too steep. For each object the following data was collected: database identifier, author handle, secondary license choice, creation date, how many times the Thing had been commented on, how many times object has been remixed, how many times it had been viewed, any tags the creator had attached to it. The data was collected between 16. and 18. August 2013, and contained metadata about 117,450 Things — both public and private — dating from January 2009 to August 2013. The data represents a snapshot of the repository metadata. The data was stored in relational database locally. After data collection, an additional application layer was created to construct selected charts from the data by utilizing existing open source D3.js library.

3.5.2 Design Revolution in 3D Printing Processes [article 4]

In this detailed case study both quantitative and qualitative methods were used to gather and analyze the data. A global online survey was conducted on the 3D printing community in May 2012 under the auspices of the Peer to Peer Foundation (as discussed above). The survey created a baseline to characterize the active members of 3D printing open community. Quantitative data to describe the amount of uploads done within 3D printing community was also collected (discussed below). A pilot email survey was done to verify the relevance of the questions related to the design processes, ways of working and the roles of 3D printing community members. Although the pilot survey was semi-structured, the feedback indicated that the community members did not understand the questions or the aim of the survey. As a result of the pilot, the format of the email survey was changed; the open community members were asked to draw their design process. The final survey was sent to people whose email addresses were gathered from the web page of an open design contest.

Interviews with designers were continued until saturation point was found, i.e. the same topics and concepts started to reappear. Six interviews with semi-structured questions were conducted among open design community members. Some of the interviewees provided sketches about their design process while others answered only briefly to the stated questions. Two interviews were conducted via Skype chat, one as Skype call, and the other were email interviews.

3.6 Reliability and validity of the study

As mentioned earlier, the author was a co-founder and a member of one local hackerspace in Tampere while conducting this research. At the same time, the research included surveys and analyses targeted to hackerspaces and makerspaces.

The research contained both use of quantitative and qualitative methods. Statistical methods were used for establishing validity and reliability of research findings. In qualitative parts design and incorporation of methodological strategies were used to ensure the ‘trustworthiness’ of the findings. Firstly, in order to minimize biased results and injection of personal opinions, the surveys and analysis of the responses were always paired with work with another scholar. Secondly, thorough clarity in terms

used in the processes during data analysis and subsequent interpretations were applied. Comparison to similarities and differences with close-by communities such as open source movement was used to ensure that different perspectives are represented. Regarding the articles 1 & 2 participants of the surveys were invited to view and comment on the research findings and themes by publishing preliminary results in the research homepage <http://surveys.peerproduction.net>.

Interviews audio data was recorded (skype sessions) which allowed for repeated revisiting of the data to check emerging themes and discussions about the emerging themes with academic colleagues. The results were given to respondents to view and comment before publishing as article (4).

4 Summary of findings

4.1 Peer Production movement (article 1)

”Hackerspaces are community-operated physical places, where people share their interest in tinkering with technology, meet and work on their projects, and learn from each other.”
[hackerspaces.org]

The emergence of hackerspaces, fablabs and makerspaces has changed and is continually changing how hacker communities and other like-minded communities function. The sheer amount of peer production communities (currently around 1400) whether they call themselves hackerspaces, makerspaces, fablabs or something else, makes their role significant in open innovation and product development (see figure 3). Thus, an understanding of the nature of hackerspaces helps in detailing the features of contemporary peer-production.

Some of the fundamental parts of 3D printing device development (such as RepRap, Ultimaker and MakerBot Replicator) have started from peer-production communities. The MakerBot Replicator, mentioned in chapter 1, was innovated in the facilities of NYC Resistor hackerspace by one of the founders of it. Hackerspaces have had significant role in the development of low-cost 3D printing. Hackerspaces are petri dishes for new innovations which are created in diverse groups of people and which are built on top of freedom from external influences. However, valuing freedom over resources and restraining external (often business related) influences, does not exclude creating new business.

This research phase started with living with one of the local hackerspaces (Tampere Hacklab, Finland) for several months, empirically observing the community, their habits, learning the rhetorics and getting familiar with the subculture of makers. The position of an observer for a prolonged period of time offered insight into the community which would have otherwise been impossible. The second phase of the research were annual surveys in 2010 and 2011. The gained insight via observation helped in crafting survey questions and in understanding the phenomenon more thoroughly.

The author’s share in article 1 was to construct survey questions, managing the survey process, analyzing the survey data and constructing selected charts. The article was co-written with Tere Vadén.

Building on previous work on 'fabbing' (Troxler 2010), two different sets of results were presented: (1) empirical observations from a longitudinal study of hackerspace participants ; and (2) a theoretical description of hacker generations as a larger context in which peer-production can be located. Based on the surveys and prolonged observation some features can be identified regarding hackerspaces and members of them.

Dominantly male altruistic communities

A typical hackerspace member is a 27- 31 (35%) years old male (90%) with college level or higher education and committed to one hackerspace.

Altruism, community commitment, meeting each other and and having fun seem to be most important motivational factors to participate in a local hackerspace. Members are willing to help each other in projects, use time to build and maintain a shared physical space and participate in costs by paying monthly fees. In return, members get a 'club' in which they have a role, they can meet like-minded people and get an opportunity to influence in the management as well as decision making. In addition, members get a space to store projects, and the facilities normally have a variety of tools, machines, 3D printers, plasma cutters, CNC mills, components and materials for everyone to use.

Heterogeneous and open

Hackerspaces do not have bogus criteria for members. Anyone with any background, education, gender or age can become a member. The situation is different compared to for example university driven tech clubs, where members have to be students in the university. Hackerspaces act as a ground for the kinds of apprentice-master relationships that we have seen in the past. Skills and knowledge are gained by doing under the guidance of the more experienced.

The hackerspace population is heterogeneous although members usually have high interest in technology. Due to the open membership model, members of hackerspaces vary from youngsters to retired persons. One benefit of the diversity is that different skills, ideas, viewpoints and experiences mix and function as a fertile ground for new ideas and solutions which are normally explored via experimentation. Even though the community is more heterogeneous than a typical open source community

[26] , the characteristic core group can be identified as above.

Shared living room or hive

Hackerspace communities have strong social motivation factors compared to other motivation models in other open source communities [40]. In other words, members have high interest to meet each other in real life instead of just using digital environments to cooperate. Average amount of time used in hackerspace is about 10 hours per week during which members tinker with software and hardware.

Hackerspaces can be seen as external spaces between home and work, an extra living room where like-minded people gather together to have fun, take a beer, build in a relaxed environment. Hackerspaces can be seen as hacker versions of ‘third places’ defined by Oldenburg [56]. These ‘third places’ facilitate and foster broader, more creative interaction. Since the average member is male, hackerspaces can also be seen as man caves even though discrimination based on criteria such as gender is not allowed.

Freedom from external influences

Hackerspace members have a high desire for freedom and thus any influence from external organisations is avoided as much as possible. Fear of someone pulling the strings and by so doing limiting freedoms of members or the local community is avoided. Taking monetary donations from companies is not a preferred approach to manage costs. Instead, hackerspace members often pay monthly fees and if needed make personal donations to the hackerspace.

Peer Production in the continuum of hacker generations

The results support previous research on commons-based peer production [18, 21], where transparency, volunteerism, self-selection, self-direction and the freedom to act in accordance with self-articulated goals and principles have been found to be essential features. Hackerspaces as instances of peer production have a clear identity and constitute a large, growing and global movement. Yet previous literature has not provided the historical context for them. The hacker generations preceding the phenomenon of hackerspaces have been acknowledged by some scholars (see for example [75, 80]), but peer-production has been ‘hanging in the air’. Hackerspaces and previous hacker generations share some values such as altruism and belief in a hacker

ethic. What differentiates hackerspace members from the previous hacker generations is obsessive focus on making and on physical aspects of tinkering. In addition, a strong social factor which is built around a physical shared space is not visible in previous generations. Therefore, peer production can be seen as distinctive generation in the continuum of hacker generations (see figure 4)

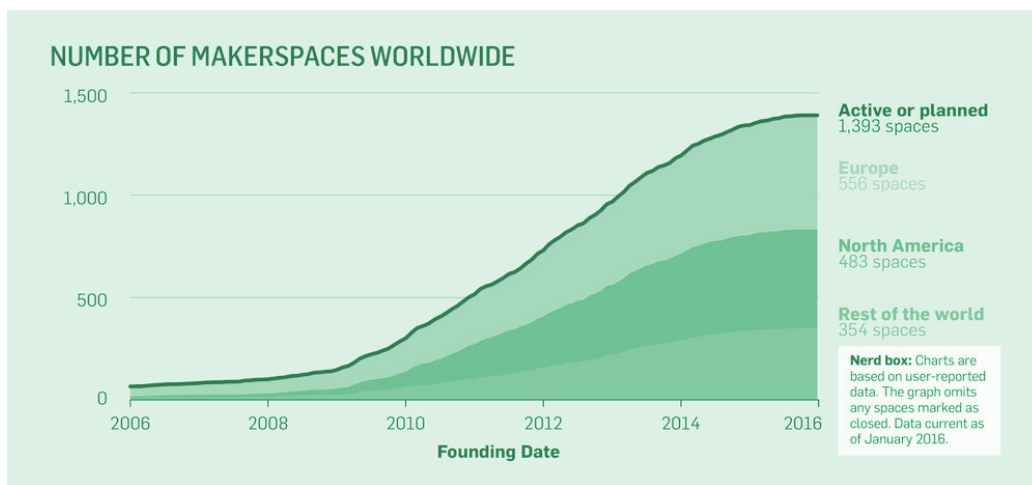


Figure 3: Number Of Makerspaces Worldwide.
<http://www.popsci.com/rise-makerspace-by-numbers>

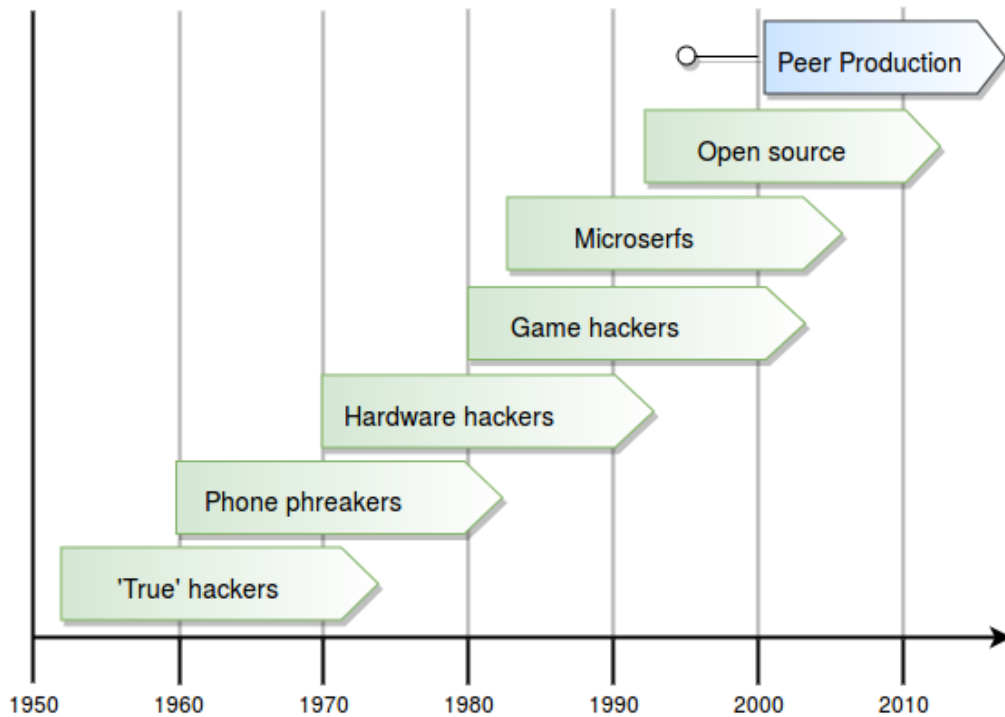


Figure 4: Hacker generations timeline. Reproduced and modified from Moilanen (2012) for the sake of readability

4.2 3D printing community and emerging practices of peer production (article 2)

In the first phase of the research discussed above, a general overview of the Peer Production community was outlined. It became obvious that the 3D printing community resides at least partially in peer production communities such as hackerspaces and makerspaces. In this research phase focus was tightened to the 3D printing community to gain more insight of the community.

The 3D Printing community with strong open source component is a vital component in low-cost 3D printing development. Most notably, the low-cost 3D printer RepRap relies on open source and open design driven development in 3d printing community. Understanding the status and maturity of the community helps us to estimate the future development of the community by comparing the results to close-by communities such as open source software

movement and the more general peer production discussed in the previous phase. Knowledge on the nature of the underlying community enables us to understand more thoroughly the development of open design driven low-cost 3D printers.

The aim of this research phase was to discover the demographics and self-identification of the community, as well as to describe participants' printing activity based on the results of a 2012 survey on people doing 3D printing. Combining results from the survey with insights from research literature, we analysed emerging patterns and practices of 3D printing as a subdivision of a more general trend of physical peer production.

The author's share in article was to construct initial survey questions in English, to oversee survey translation to selected languages (French and Spanish) with help of the research community, to manage survey process, to pre-process gathered data, to analyze the survey data and construct selected charts. The article in which the results were outlined was written together with Tere Vadén.

Part of Maker Movement

3D printing community is male-dominated, which is not a surprise for a technology-oriented community. The average age is 35 years, and 56 percent have at least a bachelor level degree. 50 percent of the respondents lived in Europe. When the results are compared to results found from open source communities, 3D printer community members are slightly older and the relatively high amount of university degrees is lower than in some of the largest open source communities. Clearly the studied 3D printing community overlaps with the Peer Production community. Over half (55%) of the respondents participate in one or more open source projects. The percentage is even higher (nearly 75%) when the person is also member of local maker movement community. In addition, nearly half are not members of maker movement communities such as a hackerspace or a makerspace. The respondents clearly identify more with the maker movement than with peer production. One of the reasons for this might indicate an aversion to the "ideological" nature of the term or the phenomenon of Peer Production. As a whole, the community has a strong open source component.

Five most common applications for 3D printed items are: 1) functional models, 2) artistic items, 3) spare parts to devices, 4) for research/educational purposes and 5) direct part production. High amount of artistic items might

indicate significant role of maker culture and exemplifies the heterogeneous nature of 3d printing focused peer production.

Maturing technology and community

The results exemplify both physical friction of technological attributes (including factors like task granularity and modularity, software requirements, versioning system and bug tracking) and community aspects (including factors like participant involvement, leadership, social capital, financing, marketing, group homogeneity) in Schweik's tri-partite division of variables influencing a developer's commitment to a project [72]. The five most common bottlenecks in the community were all technical in nature. The third group in Schweik's model is institutional (operational, collective choice and constitutional level rules), which did not appear in the results.

The absence of a commons for the physical end products is the factor most clearly separating 3D printing from the models of commons-based peer production in terms of software.

Unlike in open source software, copies of the physical 3D printings are not perfect. Tacit knowledge is required to get best possible results in printing. Thus printing quality was one of the bottlenecks identified by the community. Achieved low quality with local 3D printer has pushed some users towards printing services when high quality print is a necessity. Sketching and drafting can be managed with local printer, but whenever something has to be shown to customer or investor, eyes (and money) turns to 3D printing services. In a way this resembles the situation in paper printing, where top quality brochures are still printed in commercial print shops.

3D printing should be seen as a process, not as a tool. It involves design and process management. A 3D printer is one part of the process and it has to be bundled with different kind of software. A process requires a tool chain. From the end user's point of view a lot has to happen before the design is sent to the printer. This was also visible in the results, as one responded puts it: "That is too many pieces of software and the workflow going from computer model to physical print is very convoluted, involving lots of different pieces of software."

Even if the tools are available and the user has aptitude to learn use of them, the software needed to design objects were seen difficult to use. The same applies to 3D printer management software. Open source software was more often associated with a steep learning curve than commercial software.

This clearly indicates the immature nature of low-cost and open design driven ecosystem; therefore we used the term pre-ecosystem. When compared to open source software community, the status of 3D printing community is easier to understand. It has taken a few decades for the OS software community to find shared values, practices, rules, boundaries and tool chains. The 3D printing community is still mostly battling with technical issues. A community is more than tools and technology as we have seen with the hackerspaces and as one of the respondents put it: "lack of organization, lack of quality control and lack of test plans." A community is about people, shared values and practices. The nascent 3D printing community still probably needs to touch the remaining aspects of Schweik's model to become a mature community – and that probably takes years.

4.3 Cultures of sharing in 3D printing (article 3)

"We're hoping that together we can create a community of people who create and share designs freely, so that all can benefit from them" MakerBot Industries

The quote above refers to commons, which, in brief, include cultural and natural resources which are held in common, not owned privately. Open designs can be included in 3D printing related commons by distributing the designs in a digital format on the internet. The preference for a commons in open design is manifested by attaching open licenses such as Creative Commons, BSD, Apache or MIT licenses to digital designs. To understand how open design community manages intellectual property with licensing, we need to know what licenses are preferred. How to study open design community licensing practices? In this study the focus was on the leading sharing platform Thingiverse and the licensing practices of it's users.

As discussed above, MakerBot Industries was the pioneer in consumer low-cost 3D printers production and sales. They had a problem of not knowing what people do with the 3D printers. To gain that knowledge – which they wanted to use in 3D printer development – they created in November 2008 an online service called Thingiverse.com, where anyone can upload their digital 3D Models for others to use and modify. Digital models started to pour in with increasing speed. Thingiverse became the repository for 3D printing community. After five years the amount of digital 3D models was around 117 000. Since sharing platforms have already become hubs for

open designs, it is important to understand the limitations and practices of these platforms.

In the study, licensing was approached from two angles: vertical and horizontal. Vertical sharing and licensing relates to the relationship between the community and MakerBot industries. That relationship is controlled by the Terms of Use of the Thingiverse platform. The agreement changed 2012 and the changes affected the relationship between the company and the community. At the same time MakerBot changed its licensing policy with the Replicator from open to closed. Furthermore, in mid-2014 MakerBot began to patent parts of the 3D printer which was originally based on open design RepRap. These three issues were analysed in the study. The second approach, horizontal, was about licensing practices between the users of Thingiverse platform. This secondary license is most often one of the open licenses. The research used metadata including license information from more than 68,000 Thingiverse design files collected from the site.

The author's share in the article was to develop the for-purpose-built application which collected metadata about Thingiverse.com uploaded 3D designs (Things), pre-process collected data and develop additional application layer on top of data which constructed the selected charts. In addition, the author participated in analysing the results. The article in which results were outlined was co-authored with Angela Daly (Swinburne University of Technology/European University Institute), Ramon Lobato (Swinburne University of Technology) & Darcy Allen (RMIT University).

Clashing messages and interests

The commons-oriented quote in the beginning was used in marketing the Thingiverse service and used in promoting the sales of MakerBot printers. This flagship of low-cost 3D printing sits in the middle of conflicting practices with the community. The message given to the public is about open sharing, but for example Thingiverse Terms of Use was changed 2012 so that it gave MakerBot Industries more freedoms to freely utilize user uploaded content (often under open licenses) in MakerBot 3D printer development which was closed by design and software 2013. It is good to remember, that the Terms of Use are non-negotiable; the user must accept them as-is in order to utilize the platform. Initial MakerBot design was based on open design driven effort of the community. Yet according to Bre Pettis complete openness and sharing of design did not seem a viable option for the company:

”For the Replicator 2, we will not share the way the physical machine is designed or our GUI because we don’t think carbon-copy cloning is acceptable and carbon-copy clones undermine our ability to pay people to do development.” Bre Pettis [58]

Looking from the perspective of the open design community, closing the design casts shadows on top of MakerBot and the message of open sharing it promotes. The changes in openness resulted in disputes inside the company with the consequence that one of the founders left the company. In addition, one of the most influential ’makers’ in open design 3D printing community, Josef Prusa, ignited Occupy Thingiverse movement, which encouraged community members to pull away their designs from Thingiverse. The case clearly indicates the difficulties of combining closed source driven company interests with the interests of open design driven community. What probably irritated the community even more was the sudden change towards closed source.

Quasi open community

Thingiverse is advertised as an open design hive and the repository for open design community. Analysis of the Things in Thingiverse tells another story. Analysis revealed that nearly 42 percent of the Things in Thingiverse were private and not accessible by anyone else but the creator and MakerBot industries. Reasons for keeping a ”Thing” private were not found, even though some of the owners were contacted. For the remaining public 58 percent Things we had metadata including license choice. Most commonly used licenses were different versions of Creative Commons (90%):

Table 2: Most commonly used licenses

Attribution (CC BY)	36%
Attribution- ShareAlike (CC BY-SA)	36%
Attribution-NonCommercial (CC BY-NC)	10%
Attribution-NonCommercial-ShareAlike (CC BY-NC-SA)	8%

The popularity of the licenses follows the order in which they are offered in Thingiverse user interface in a dropdown menu. The selection method of license might have an effect on license choice for some users. Non-sticky licence (CC BY) seems to be preferred by Thingiverse platform users when it comes to remixing (combining components) 3D printing designs. Sticky licenses (such as CC BY-SA) are used more often when the design is more finished production-wise. CC BY-SA licensed Things are also more often reprinted by other users than any other Things with different license. This might indicate that sticky licenses are attached to more mature and high quality designs. If the huge amount of private Things (42%) is put aside, the results support Thingiverse’s nature as platform of derivative works and collaborative projects among it’s users.

4.4 Design Revolution in 3D Printing Processes (article 4)

As discussed in the previous chapter, sharing of open design principles driven 3D designs is common in the 3D printing community. Sharing of open designs is channeled via platforms such as Thingiverse.com, Ponoko.com, i.Materialise.com, Shapeways.com and Cubehero.com and in some rare cases via Github, where users upload 3D design files and attach often Creative Commons license. The next questions to seek answers to are related to the process how these openly and freely distributed 3D designs are crafted in the open design community. During the previous research phase, the phenomenon of open design raised up multiple times. It was constantly visible in every aspect of the community. If design is open, what does it really mean? What is the process? How are the designs shared for others to build upon? Such questions became irritating and required research.

The design processes widely used in industry have been explored thoroughly [29, 20], but open design community processes have remained untouched mostly due to the nascent nature of the open 3D printing sharing economy. What makes 3D printing popular in open design community is largely related with the magic and freedom of creation, not the speed of production which characterizes most recent industry level 3D printing.

The purpose of this case study was to shed light on the main characteristics and novel methods of operation within the open design community. The results contain a potential direction for the future

development and production of artifacts and diverse functionalities that support the new and self-sufficient methods of operation.

This inductive case study was a description of the 3D printing community as a part of the open design community. The study identified main characteristics and ways of working that frame and drive activities in the open design community. Mainly qualitative research methods were used to gather and analyze the data. Work in the open design community is collaborative; it is a symbiosis of interests between profit making companies and volunteer members of the community resulting in win-win situations. Research methods contained semi-structured interviews of open design community members. Interviews were continued with the designers until saturation was reached after eight interviews. Previous results from surveys among 3D printing communities (article 2) were used as supportive resources.

The author's share in the article was to design the survey and analyse the results. Interview questions were created co-operatively, and the analysis was co-operative, as well. Author's knowledge and experience of the open design community practices was crucial to the research. The author was responsible for crafting the introduced possibility-spin model. The article in which results were outlined was co-authored with Pia Tamminen.

From consumer to prosumer

In peer production, traditional roles of consumer, producer, designer are mixing together. Examples of this phenomenon are communities in which hackers build and develop 3D printers, share the knowledge via internet to everyone online. Consumer 3D printing has reached the peak moment of hype around summer 2014. Ordinary people are now able to utilize 3D printing at home and at local communities and it is relatively easy. Tools to create or modify needed digital 3D models are easy to access and in some cases even browser based which enables time and location agnostic 3D model production. Modeling an artifact is no longer a privilege of highly educated 'priests' in monasteries commonly known as offices. The above describes in common language what open design in practice is. Open design resembles participatory design (see for example [62, 63, 37, 70]) with the difference that users design and produce the objects.

According to the results, design and design process are far from just finding solution to the end users needs known as problem-driven approach [68]. Instead the opposing approach defined by Desmet and Pohlmeier [22]

stress that people want to design future technologies because the activity generates happiness, well-being and direct improvement to people's lives. Design for pleasure, design for personal significance and design for virtue in Desmet and Pohlmeier's model are the foundation of possibility-driven design. Well-being is divided into two categories in the current research: hedonic and eudemonic. Hedonic approach focuses on happiness built by avoiding pain and preference of pleasure. Eudemonic stresses meaningful activities and self-realization. When the design process in open design driven 3D printing community is analyzed through these two filters, we can see similarities. According to previous research five most common applications for 3D printed items are: 1) functional models, 2) artistic items, 3) spare parts to devices, 4) for research/educational purposes and 5) direct part production which is well in line with the eudemonic approach [54]. The high amount of artistic items can also be seen as implementation of a hedonic approach.

Possibility-driven spin model

Low-cost 3D printing and open design [87] both represent disrupting forces and together construct a doubly disrupting force towards both design and production of artifacts. The disruptive potential is visible in the possibility-driven spin model [79]. Detailed description of the design process is discussed below. The process of innovating new artifacts in open design resembles a spring. The process normally begins with one designer who starts to design a new artifact for his/her own purposes or for a client. Even in the latter case, the designer often needs personal interest towards the result and design. In other words, designers can be picky. The spring has several possible outcomes from the further phases. The first outcome type is design for personal use and it is not shared with the community. The reasons for keeping a design only for personal use vary, but most common reasons are: small added-value for the community, the object is novelty or incomplete for others to utilize. The second outcome type is a contribution to the 3D printing commons which is licensed often under Creative Commons license. The third identified outcome type is commercial artifact which can be closed or open design. The amount or type of outcomes from a project is arbitrary and unpredictable.

The possibility-driven spin (see figure 5) model describes the possible outcomes from a design project. The process for design was also explored in the research and an initial model with four steps was identified.

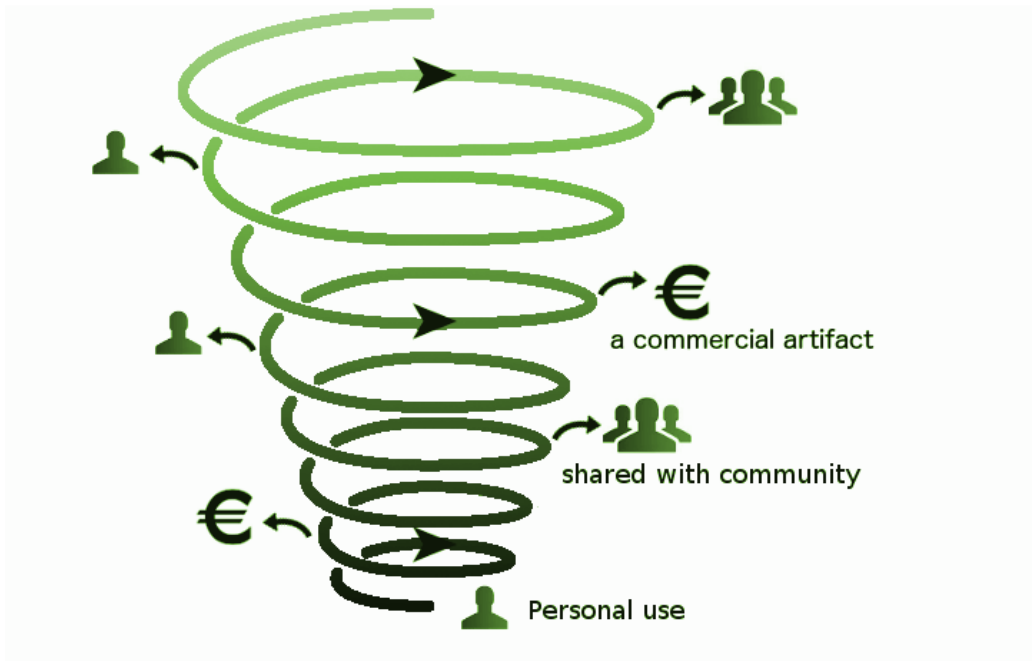


Figure 5: Spin model of the method of operation in the open design community [79]. Drawing modified by fixing spelling error 'articact' to 'artifact'.

Four step design process

The open design process labeled by the authors as possibility-driven design is characterized by unpredictability, the process is unending, open-minded thinking leading to disruptive solutions, driven by intrinsic motivation and self-selection. In addition there can be constant changes in, for example, methods of operation, roles taken by the community members, employed tools and platforms, and even targets of the development projects.

Even though open design is nascent in nature, some forms and processes can be found. Based on the interviews conducted among the community members, a four phase design process was identified:

1. ideation phase
2. opportunity seeking
3. sketching and sharing of working designs
4. prototyping

In the first phase, the sources for ideas can be grouped into three: 'scratch an itch', 'think outside the box' and 'derived work'. Scratch an itch is one of the identified motivation factors in open source software development, simply meaning designing something to fulfill an immediate personal need. Thinking outside the box refers to seeing and seeking new applications for a given object in ways that it was never meant to be used. This kind of thinking resembles the findings from hacker culture [42]. Derived work refers to the basic notion of utilising existing innovations. Design rarely begins from scratch. The second phase contains opening the ideas for the community to discuss or, as one of the interviewees put it, "filling the tank". Third phase results in digital designs which are shared with others via digital sharing platforms. The final fourth phase is about manufacturing the digital design. In here, the designer has at least three options: 1) use own low-cost 3D printer, 2) utilize the community offered 3D printer by a local hackerspace or 3) use 3D printing services.

Open design community is an intriguing nascent community which partially relies on hackerspaces and makerspaces, and utilizes the new opportunities of low-cost 3d printing. Open design projects are dynamic, never-ending processes and there are many ongoing parallel projects in different phases at the same time. Compared to open source software development, similarities and approaches are very much alike.

5 Conclusions and Discussion

Based on the research described in the thesis we can outline the situation of low-cost 3D printing focused peer production and describe the overall phases in the development regarding devices, tool-chain and sharing of open design artifacts.

Currently, everyone can become a designer and manage the production of artifacts. This means a revolution in production. Local production with the help of 3D printing is entering mainstream. The combination of availability of open designs shared in open access platforms, low-cost 3D printers (out of the box ready), and free open source design tools have initiated a road towards local production and reproduction of simple artifacts. Currently available low-cost printers enable 'good enough' quality in 3D printing. At the same time, the rise of 3D printing services has enabled distributed production of high quality artifacts. These new production modes have challenged legacy mass production of goods.

Free design tools are becoming easy to use and encouraging people to modify and personalize artifacts. Design tools have entered the browser age. Previously the open design community in the form of enthusiasts was dependent on closed source applications to produce open design 3D printable designs. The community has used also open source design applications (Blender), but the learning curve for those has been (and still is) rather steep for layman use. Recently browser based easy to use design tools such as TinkerCad, 3Dtin, 3dslash and Shapsmith with limited but sufficient features for layman usage have entered the markets thus lowering the barrier for everyone to become designers.

After RepRap opened the Pandora's box in 2006, low-cost 3D printers have emerged in the markets – Ultimaker, MakerBot Replicator, Printbot, Solidoodle, FlashForce to name a few. At the same time the amount of openly shared hackable digital 3D design files has been growing[54]. The repositories such as Thingiverse and Ponoko have provided easily accessible global channel for distributing digital 3D designs. Thingiverse.com alone has over 1 million openly shared 3d designs [4]. This phenomenon is an example of the on-going digitalization in modern societies, in general, and of building the 3D printing commons discussed in details, below.

The change in 3D printer development is towards openness even though some glitches exists. Open design driven solutions have taken solid foothold in the markets but not at the front-line. Open source hardware 3D printers

are favored by members of maker movement. Makers tolerate the sometimes steep learning curve and are ready to spend time on learning how the device is assembled, how it functions and also to learn the necessary tools to operate it. Development of low-cost 3D printers follows the path of Open source software. After open source software entered the markets a few decades ago, the proprietary application providers feared that they might become obsolete. This never happened, but instead a hybrid market emerged. Open and closed source coexist. It seems that this is the case with 3D printing as well, even though relationship might be problematic once in a while.

The layman segment requires out of the box solutions, e.g., just unbox the device, plug it in and start using. Consumers do not want to assemble devices. They do not assemble conventional paper printers, refrigerators or mobile phones. This is where companies step in and commoditise the solutions, make them easy to use, which enables rapid success in the hands of common people. Nowadays 3D printers for everyone to use are sold in online stores (such as Amazon) and also in conventional stores.

This rather complex and nascent 3d printing ecosystem (see figure 6) which builds on top of peer production includes markets for 3D printer devices and software, sharing of designs via sharing platforms, design tools, 3d printing services and open design driven community.

The nascent 3d printing ecosystem outlined in figure 6 is built on top of often (but not always) commons-based peer production. The definition of the latest hacker generation - peer production - is a result of this dissertation research and discussed in the following chapter in comparison with the preceding generations discovered in previous research.

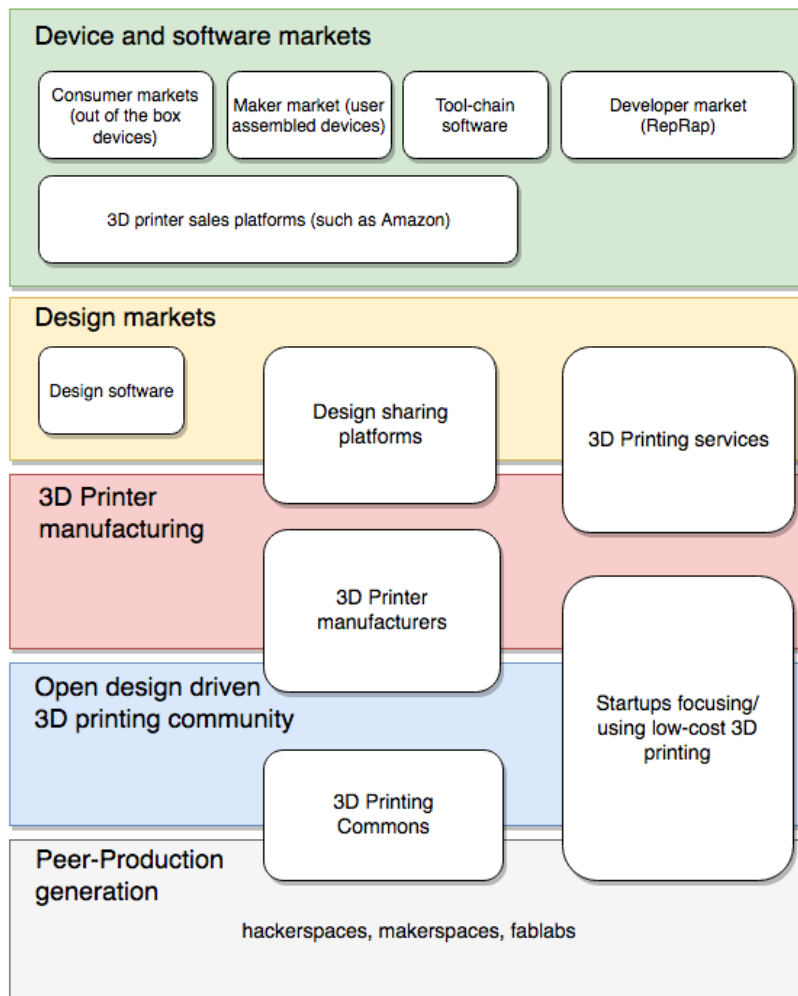


Figure 6: Simplified overview of nascent 3D printing ecosystem

5.1 New hacker generation - Peer Production

The peer production generation often popularized with the term Maker movement consisting of members of different flavors of makerspaces and hackerspaces quickly adopted the new low-cost 3D printer technology because the development of low-cost 3D printers took partially place in these community maintained spaces. Thus it is important to understand what characterizes the underlying innovation layer behind low-cost 3D printing.

According to the research [50] the early adopters in open access hackerspaces and makerspaces where anyone with any background, education, gender or age can become a member are typically 27- 31 (35%) years old males (90%) with college or higher level education and are committed to one hackerspace.

Most common motivational factors to participate in local maker community activities are altruism, community commitment, meeting each other and and having fun. Compared to open source software movement, maker communities have strong social motivation factors, e.g., meet each other in physical world instead of relying only on virtual co-operation for example on IRC channels, discussion forums and code repositories.

The current Peer Production generation which might be popularized as 'Maker generation' is distinct from previous hacker generations and thus can be added to the context and historical timeline of hacker generations (Figure 4). Hackerspaces' history predates maker movement which was described first time in Cory Doctorow's novel 'Makers' 2009 although Make Magazine was established already 2005. The beginning of hackerspaces can be traced all the way back to 1995 in Berlin when the world's first hackerspace known as C-Base was established. The breakthrough of hackerspaces began in the early days of this millennium when the amount of hackerspaces began to rise. Another name for hackerspace is makerspace, which is sometimes preferred due to the negative stigma attached to the word hacker. In addition makerspaces focus more on making and sometimes have a more educational aspect.

Unlike the open source software focused hacker generation, the peer production generation has a strong social factor which is visible in hundreds of hackerspaces around the globe. The requirement for physical space and meeting each other physically are unique for this generation. Average amount of time used in hackerspace is about 10 hours per week during which members tinker with software and hardware.[50] Focus on doing and tinkering with physical objects and technologies such as 3D printing also differentiates peer production from 'fiddling with computers and software' which is the fundamental element and focus of open source software generation. Nevertheless, open source software is part of the peer production since software is needed often as well. The peer production generation is characterized by transparency, volunteerism, self-selection, self-direction and freedom to act with self-articulated goals which is inline with the previous commons-based peer production research [18, 21]. A short definition of the

peer production generation can be formulated as

diverse community of hackers and makers built on top of the values of the open source culture with focus on open design, tinkering and production of physical objects, designs of which are shared publicly under open licenses.

Hackerspaces can be seen as external spaces between home and work, an extra technology-focused living room where like-minded people gather together to have fun, take a beer, hack with software and hardware, build and innovate in a relaxed environment. Thus hackerspaces and makerspaces can be seen as hacker versions of ‘third places’ defined by Oldenburg [56]. These physical ‘third places’ facilitate and foster broader, more creative interaction among technology and hacker ethic prone members of societies. Learning by doing is part of the culture and contains elements of apprenticeship - master relationships between community members.

According to the research discussed in this thesis we have a new generation of hackers in the timeline (see Figure 4). Based on this addition to the research tradition about hackers we can discuss what is the significant change that has occurred. One of the biggest changes in the rise of hackerspaces and maker movement, in general, is the change in publicity and the public image of hackers and hacking.

Discussion

Hacking has become socially acceptable

”Hackers believe that essential lessons can be learned about the systems – about the world – from taking things apart, seeing how they work, and using this knowledge to create new and even more interesting things.” Levy [42]

The peer production generation of hackers has changed the public opinion of how the subculture of hackers is interpreted. Previously in the media the words ”hacker” and ”hacking” have been loaded with negative connotations and figures of speech. Then came the Maker Movement, Make magazine, startups, tinkering and hackerspaces. Suddenly hacking is socially acceptable. Hacking is becoming mainstream.

Hacking in the form of an ability to understand and write applications is part of national curriculum in K12 education in various countries such as Singapore, Malaysia, England, Denmark, Estonia, Greece, Ireland, Italy, Lithuania, Poland, Portugal and Finland (mandatory, cross curricular theme starting from first grade) to name a few. In other words, hacking has become part of formal education.

Part of the hacker culture is to organize events to meet each other. One form of such events are hackathons. Originally hackathons were events in which programmers met to do collaborative computer programming[19]. Over the recent years hackathons have entered mainstream [27] and are now organized also by businesses and public sector organisations. One example from Finland is IndustryHack, a series of hackathons hosted by various industrial companies such as Kone, KoneCranes, Ponsse, RollsRoyce to name a few. Also governments have adopted hackathons to some extent. The format of hackathons has also broadened from programming to include topics such as art, design and games. At the same time, the participant profile has changed to include others than just hackers. Hackathons were adopted also by startups, which use the events to innovate quickly new ideas, build mockups and prototypes for new services and products.[19] In other words, hackathons which were an event type for hackers, have become mainstream.

The word "hacker" also became part of the startup culture in marketing, where the phrase "growth hacker" was coined by Sean Ellis in 2010. [30] Growth hacking is about measured innovative marketing with scarce resources to find out about market/product fit. [31] A growth hacker is lean startup marketer.

The peer production generation often popularized as Maker movement with hundreds of makerspaces and hackerspace acts as a petri dish for early stage inventions. The development is based on open source and open design. This is the pioneer area and consists of thousands if not tens of thousands of people exploring the boundaries of technology while having fun. On top of the peer production movement is the startup layer, which sometimes spins from the peer production base, as exemplified by MakerBot Industries. This pre-commercial layer is needed in order to make the solutions – which are normally more or less hacks (working prototypes) developed by the community - into marketable products. Problems arise with different interests as was proven in the MakerBot Replicator 2 case.

It seems that the word "maker" is more acceptable than "hacker" even though the people designated by the two words are the same. One reason for

this development might be the success of the open source software movement, which preceded the maker movement. Open source is a fundamental part of societies and more and more (still mostly) an invisible part of every day life of common people. One example of the widespread nature of open source is the Android operating system, which relies on open source development and community.

To sum up, hackers 'disguised' as makers created a network of hundreds of spaces around the globe. They changed the common view about hacking from criminal activity to the belief that hacking can be a virtue. More thorough research on the role of hackerspaces as pre-incubators for startups and new innovative products is needed to understand better the dynamics of the innovation engine residing in hackerspaces.

5.2 3D printing community

In the above chapter, the new generation of hackers - the peer production generation - was defined and discussed as an addition to the previous research in commons-based peer production. Now we can turn the focus to the 3D printing community which resides at least partially in the peer production generation. Based on the research of this thesis, first, we provide a short outline of the low-cost 3D printing device development and, second, we will discuss what characterizes the low-cost 3D printing community.

3D printing industry has been dominated by two giants, Stratasys and 3D Systems, from the 1980's. Their focus has been in serving industry by offering tools for rapid prototyping and lately also for production of 3D printed parts. The rise of low-cost printers around 2010 changed the situation. The emergence of low-cost 3D printers was initiated by RepRep in 2006 and soon after that a plethora of 3D printers emerged – Ultimaker, MakerBot Replicator, da Vinci MiniMaker, Printrobot, Solidoodle, FlashForce to name a few. Now 3D printers are sold online, assembled or in parts, and some via major platforms such as Amazon. A simple search November 2016 in Amazon alone produced 1525 hits for 3D printers.

3D printing is following the development of open source software. Open source hardware 3d printers and open source software are expanding their user base outside early adopters and enthusiasts. 3D printing has entered the desktop with the influence of readily available end-user targeted low-cost 3d printers and easy to use design software which are partially web browser driven.

One question that arises is who are the people who develop and use low-cost 3D printers and what is their background? The 3D printing community can be divided to the following three segments which were also used in the survey: developers, early adopters and end users. According to the survey, an average 3D printing community member is a 35 years old male who has a university degree and lives in Europe or US.

It is intriguing to know what low-cost 3D printers are used for. The question of what do people do with 3D printers was one of the topics explored in 3D printing survey conducted 2012 and 2013 [54]. The most common applications of low-cost 3D printers are: 1) Functional models 2) Artistic items 3) Spare parts to devices 4) For research/educational purposes and 5) Direct part production. 3D printing is used second most for artistic ends, which might indicate an attitude of 'making' instead of 'fiddling with software and computers' which is more the territory of open source software community.

Commercial 3D printing services are used mostly by non-developers and most common reasons are: 1) professional quality 3D prints, 2) to make money by selling models, 3) to test how 3D printing services work. The answers reveal that 3d printing service providers have enabled business models in which the designer can benefit too. The result also indicates immature nature or at least low familiarity of 3D printing services.

The members of 3D printing community identify themselves more with the maker movement than with peer production. One reason to avoid association with peer production might be explained by the possible ideological stigma attached to the term. Fifty–five percent of the participants were involved in at least one open source project, which indicates considerable overlap with the open source movement. Experienced 3D printers are more often members of some local hackerspace. This indicates overlap between the 3D printing community and the previously discussed hackerspaces. In other words, 3D printing community resides in between the fully digital open source community and the physical space focused hackerspace communities, absorbing and utilizing practices from both.

As it was discussed earlier, hackerspaces are 'third spaces' originally defined by Oldenburg [56] residing in between home and office. The 3D printing community is another form of 'third space', often physically in hackerspaces but with one foot also on fully digital open source software.

Discussion

Deriving from the results of this dissertation thesis, we can identify some market segments in the nascent 3D printing economy with regard to 3D printers and emerging 3D printing commons. However, more research on these topics is needed to gain better understanding of the structures of 3D printing economy.

3D printer markets

Based on the research we can see at least 3 market segments around 3D printers described in figure 7. Firstly, the initial market of makers, who are ready to accept a steep learning curve and ready to do little fixes in hardware design and software. An example of products in these markets is the RepRap. Secondly, at the other end is consumer markets, where users expect to have an out of the box ready product, a plug-it-in device which is easy to use and reliable. Products are often closed both in terms of design and software. The MakerBot Replicator 2 is an example product in this market. In between is the third market, in which users are ready to assemble 3D printers from factory manufactured parts and use open source driven software. The assembly instructions and documentation might be community driven. The Ultimaker is one of the products which exemplify these markets. High quality 3d printing services only rarely take advantage of low-cost 3D printers, mostly due to reliability issues and needs of automation in 3D printing, which can be offered by more traditional legacy 3D printers. Another reason why 3D printing services stick with traditional 3D printers is the need for multimaterial printing, including different metals. The situation might be changing in the future when features of low-cost 3D printers include reliability, end-to-end automation of printing process and reliable multimaterial printing.

3D printing Commons

Based on the results it seems that one of the fundamental concepts of 3D printing as peer production which requires more research is 3D printing commons; what it contains, the nature of it and what are the rules for building and maintaining it.

The open source movement has built commons in software by publishing code in open repositories (such as Github) with open licenses, by creating

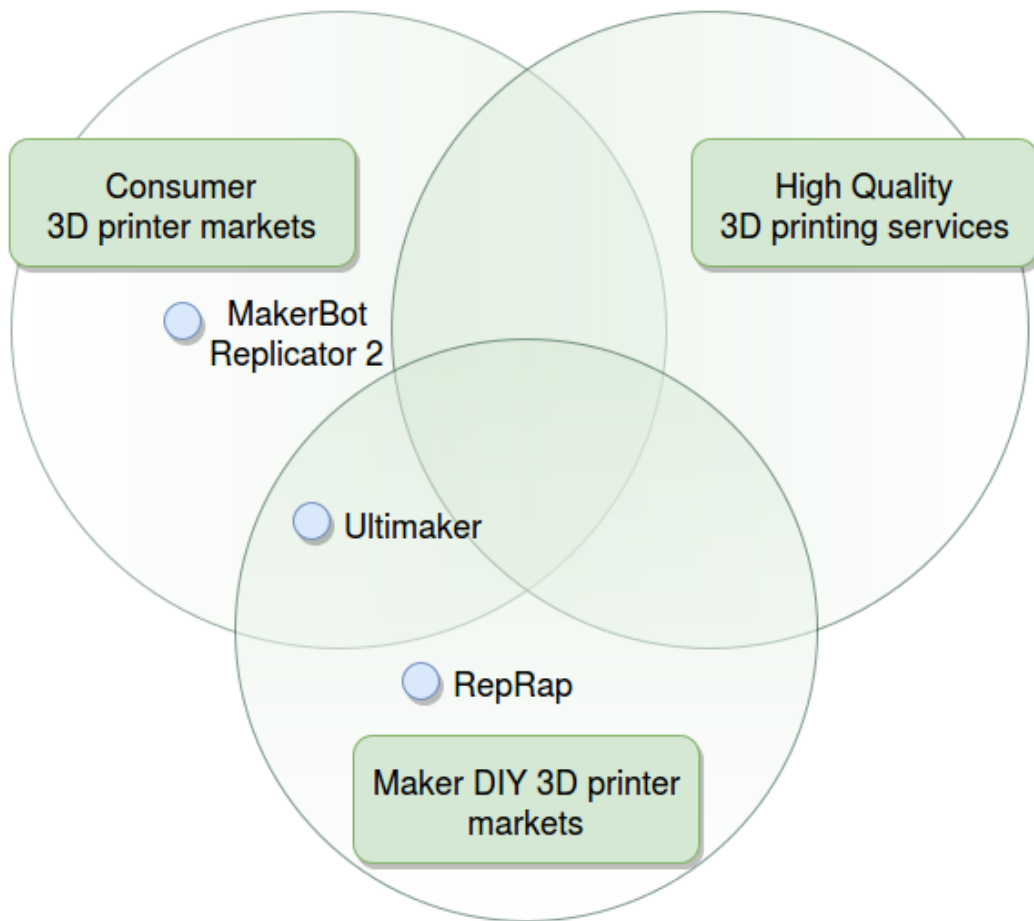


Figure 7: 3D printer markets

documentation for the software, by providing feedback such as bug reports and by making freely available digital end-products such as software. The 3D printing community is also building a commons, but it has some differences. The development of 3D designs contains friction caused by the need to build physical objects which can not be shared. Instead, what is shared are digital design files, manufacturing instructions, open source design tools and production tool-chain knowledge. Regarding the software needed in 3D printing, there is overlap between the communities. Another difference between open source communities and 3D printing communities (often residing in hackerspaces) is the desire and need for physical space, which in some cases provide 3D printers and other tools for manufacturing the

digital designs.

Based on the results from articles discussed earlier, we can draft an initial model for the 3D printing commons outlined in figure 8.

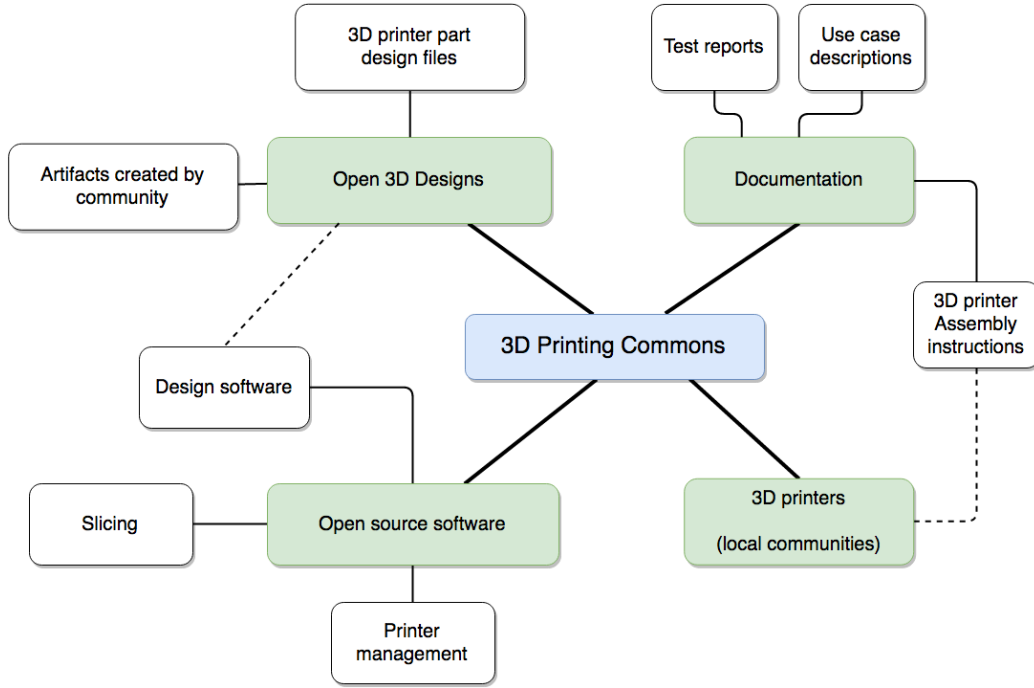


Figure 8: Initial model for 3D printing commons.

3D printing commons includes 4 major components: 1) open 3d designs, 2) documentation, 3) open source software and 4) low-cost 3d printers. Open 3d designs contain designs for 3d printers and other artifacts created by the community. The designs are shared in dedicated platforms and thus become a part of the 3D printing commons. Privately held 3d designs are not part of the 3D printing commons. Shared designs must be licensed under open licenses to provide open access for others to utilize in other projects. The designs are created with 3D design software, which can be standalone or browser based. Standalone software should be open source and/or free. Documentation refers to reports, assembly instructions for 3D printers, tool-chain information, end-user documentation and best practices. Documentation is co-authored in wikis and other platforms such as youtube. The last part, 3D printers, reside in the local hackerspaces, schools and libraries. Some of them might be low-cost open design driven 3D printers.

Funding for the 3D printers is from public sector or local community members.

A shared understanding of what constitutes the 3D printing related commons can help businesses operating in low-cost 3D printing and open design driven communities to find working business models which benefit both businesses and communities and creates win-win situation for all. Examples of working business models exist, for example, between 3D printing services and designers, where designers can use printing service platforms as markets for designs. A shared understanding of 3D printing commons might reduce the friction and disputes witnessed in the MakerBot Replicator 2 case. Thus it is important to explore and research the 3D printing commons in the future. One interesting path for future research on the 3D printing commons would be to apply the Common Pool Resource rules defined by Ostrom [57] in 3D printing.

5.3 Nascent open design driven sharing economy

Based on the research results, the open design community can be described a nascent ecosystem which has the following characteristics.

The open design community creates 3D designs for different purposes, whose number is all the time expanding: spare parts, art, parts of 3D printers, functional models and educational purposes [54]. The designs are not part of the 3D printing commons discussed above or part of Commons-based peer production if the designs are not shared. Businesses around low-cost 3D printing have established sharing platforms such as Thingiverse.com and Ponoko.com for sharing user uploaded designs in public. The purpose of the sharing platforms varies, but for example Thingiverse gave MakerBot Industries a possibility to see for what tasks 3d printers are used. Another purpose is to create a vibrant community around the technology and by doing so expedite product sales.

The above mentioned sharing platforms are open design world versions of open source world code repositories such as Github. The amount of designs in sharing platforms, for example, in Thingiverse has been enormous. The platform was established 2011 and by the end of 2013 the amount of uploaded designs was around 117 000 [54]. In October 2015 the uploaded Thing count exceeded one million [4].

When the license choices of users of leading sharing platform Thingiverse.com were analyzed 2014 [53], it was discovered that 90 percent of the publicly available designs (58%) were licensed under Creative Commons (see table 3).

Attribution (CC BY)	36%
Attribution- ShareAlike (CC BY-SA)	36%
Attribution-NonCommercial (CC BY-NC)	10%
Attribution-NonCommercial-ShareAlike (CC BY-NC-SA)	8%

Table 3: Most commonly used licenses in Thingiverse.com

In open source according to BlackDuck [33] most common licenses (2016) used are 1) MIT license (29%), 2) GPL v2 (19%), 3) Apache License 2.0 (15%) and GPL v3 (8%). MIT and Apache licenses are permissive and leave more freedoms for other users with the code than strong or weak copyleft

licenses such as the GPL. When open license choices of Thingiverse.com users are compared to license choices in open source software communities we can see similar pattern. In both cases most common license is so called permissive and second most common is "sticky" copyleft license.

When the usage of open licenses in Thingiverse.com was taken under in-depth analysis, three phenomena were discovered. Firstly, sticky licenses such as CC BY-SA are used more often with finalized designs and CC BY-SA licensed Things are reprinted more often than Things licensed otherwise. This might indicate that sticky licenses are attached to more mature and high quality designs. Secondly, the popularity of licenses followed the occurrence of licenses in Thingiverse.com user interface. Some of the users might not give thorough thought on licensing but select one from the top instead. Thirdly, 42% of the Things in thingiverse.com were private and thus not accessible by anyone else but the original designer and MakerBot Industries. This finding diminishes the advertised nature of Thingiverse as an open design hive which was often portrayed in public by MakerBot Industries.

Discussion

Given the situation described above, the 3D printing community and the businesses operating nearby are challenged with the following situations. Thingiverse and its competitors are platforms as they offer a mix of functions including design supply, hosting, customization, co-creation and crowd-sourcing, as well as offering print-on-demand and other bespoke manufacturing services. Major sharing platforms are controlled by businesses both in open source software development (for example, Github) and in open design economy (for example, Thingiverse and Ponoko).

A platform is a service, which at the same time controls the foundations and systems for community, but also provides platform users new opportunities to create and grow new business. Thingiverse is in the nexus for sharing digital 3D design files in the community despite the IP related disputes which were caused by changes in Thingiverse Terms of Use, closing the source of a popular 3D printer and patenting new innovations where community activity was also present. The changes regarding openness in the field where open culture prospers cause disputes and are likely to turn innovative people away from the service in question. In the Thingiverse case, the backfire manifested as the Occupy Thingiverse movement, where members of the community were inspired to withdraw their design files from

Thingiverse.com. The effects of Occupy Thingiverse movement is not known and requires more research. Perhaps bigger effect of the Occupy Thingiverse movement was that it raised a lot of public discussion about the MakerBot's change in openness.

At large, such changes if done by 'market leaders' affect the whole community by creating mistrust in ecosystem. It is also likely that issues encountered by, for example, Youtube are bound to pop up in 3D printing ecosystem as well. For software industry it has taken years to find a kind of symbiotic relationship where both for-profit businesses and freedom-embracing communities can prosper. Yet, after a few decades of coexistence, even in software business there are disputes and legal issues when combining open and closed source development results.

Unchallenged nascent 3D Printing platform economy rising

Über and AirBnB have stirred up existing markets in their business areas by creating platforms which operate with different rules compared to traditional models. In 3D printing we are also witnessing formation of platforms and polarisation. Existing long term 3D printing giants such as Stratasys and 3D Systems are making purchases and hoarding new market entries. Purchase of MakerBot Industries by Stratasys was one of the signs of this polarisation which is visible also in other sectors such as social media.

3D printing might be going towards the business models of Über and AirBnB, which are examples of a new economy. The difference is that Über was a new business which challenged the existing markets and business models. In 3D printing we are witnessing the power of giant corporations, which have not been challenged. At first sight the MakerBot Industries case could be seen as überization of 3D printing. The fact that MakerBot did not enter and challenge existing markets, but went to the untouched area of consumers indicates a more traditional gold digging phenomenon. The consumer market was not included in the business strategy of the giants, instead their focus was in the industry sector. MakerBot could have been the game changer, but evidently a new business model where sharing economy could prosper was not found as Bre Pettis says: "People believe in sharing and in a world without money — and that worked for us in the beginning." [90] Instead of challenging the status quo, MakerBot owners decided to do a merger. Existing patents in 3D printing could be claimed to hinder challenging the existing situation due to possible law suits.

However, for example, Über did not seem to care much about legal issues or fear law suits, instead they challenged national laws around the globe. In addition, unlike Über and the like, MakerBot Industries did not create or apply disrupting business models but preferred to stick with the old models.

Commons enabling disruption

The disruption triangle (figure 9) is a combination of open design driven community and sharing culture, startup culture with agile and lean methods and low-cost 3d printing. It offers a promising foothold for disruption in the development of physical artifacts and markets.

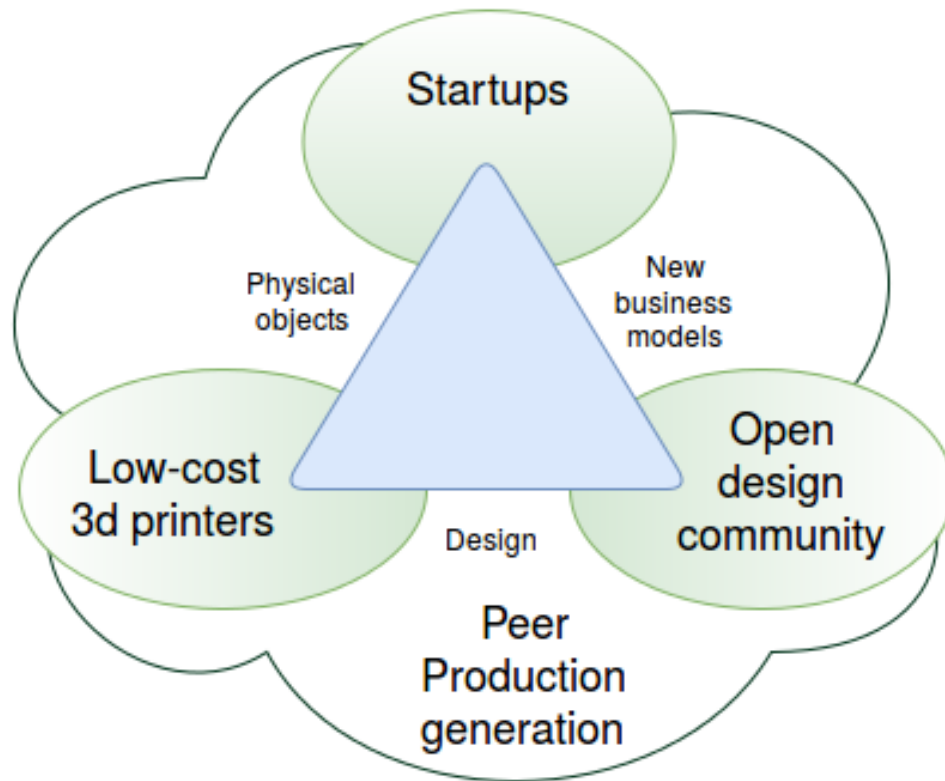


Figure 9: Disrupting triage: startups, low-cost 3d printer technology and open design community

For startups, open design driven low-cost 3D printers utilizing ecosystem offers new tools to enter the physical world. So far, startups have been focused on disrupting digital services. Readily available 3D printing services and printers have been rather expensive and few in numbers. Now startups, like other users, have a plethora of low-cost 3D printers to choose from, millions of 3D designs in repositories and an open design aligned community to co-operate with in creating new innovations for end-users in various sectors. The question remains: what kind of process is used in design? It is to this question we turn in the following chapter.

5.4 Intrigued by the freedom of creation

The results on sharing and licensing practices in the open design community were discussed above. One fundamental part of understanding the practices of the open design community is to know how design projects are constructed, what are the phases and outcomes of the construction process.

To some extent, consumers are intrigued by individualism. With 3D printing every item can be individual. 3D printing and publicly shared open licensed hackable designs enable personalization created by services [1] or with open source 3D design tools and mass customization [85] of goods such as jewelry [9]. The 3D printing community is a melting pot, which brings together designers and engineers. The most fruitful ground for this kind of activity seems to be openly managed and community maintained hackerspaces and makerspaces. 3D printing fascinates the users by freedom of creation rather than speed of production. The design tools - both standalone open source software and browser based - and low-cost 3D printers along with a plethora of openly shared hackable 3D designs have entered the desktop providing everyone a chance to become designers. The knowledge needed to utilize 3D printing and design tools have busted out of the cathedrals (offices) and entered the bazaars which can be labeled as 3D printing commons.

The nascent open design community uses a possibility-driven spin model in projects. The process is evolutionary, unpredictable and has multiple outcomes in terms of the designs: personal use, shared with community (contribution to 3D printing commons) and commercial (see figure 5)

At the same time the 3D printing community is sharing designs under open licenses. According to research on user license choices in one platform (Thingiverse), Creative Commons licences are used in 90% of cases. The results indicate that outcomes from possibility-driven spin model applied by

the open design community are mostly community oriented and commercial outcomes are in minority. The use of open licenses indicates a desire to share creations openly for others to build on top of. Use of open licenses enables designers to apply derived work process to own design, to remix designs together and create personalized designs which can be manufactured with 3D printers or via 3D printing services.

The design process in open design resembles commonly used design processes, but has a few differences. The open design process contains four stages which can happen in parallel: 1) ideation phase, 2) opportunity seeking, 3) sketching and sharing of working designs and, 4) prototyping. In the last phase, the digital 3D design is transformed into a physical object by utilizing 3d printers which can be personal, shared 3D printers in a local hackerspace, or owned by a 3D printing service. One form of prototyping used in open design communities which is not commonly used in traditional design processes is peer-prototyping. In peer-prototyping, other members of the (global) community manufacture the design locally and give feedback to the designer. This distributed peer-prototyping enables agile and broad testing of given designs also manufacturing-wise.

Discussion

Unlike the open source software community, the open design community does not have low-cost tools to track commercial use of openly licensed designs. Design can be reverse engineered but with costly efforts[88, 45]. The open source software community can use freely available reverse engineering tools to some extent to discover and show usage of open source licensed components in closed source applications. For the open design community, the ability to track usage of open design components stops when digital becomes physical, e.g., when the part has been manufactured. The lack of transparency in commercial processes casts a shadow of doubt on top the products and companies in those cases where co-operation exists between commons driven community and company. This was visible in intellectual property related discussions around MakerBot Replicator.

MakerBot Replicator version 2 was one example of problematic combination of open and closed development. It was based on the open design work by the community. MakerBot Industries developed some new features on top of the open design and decided to close the result. The example shows that the ecosystem is not mature yet and it is likely that

finding a status quo like in software business, will still take more time. At the same time, some fundamental patents expired in 2013 [32]. This probably increased the interest to enter the 3D printer market since fear of legal action became less obvious.

The maker community has risen in barricades against closed source approach. "If you cannot open it you do not own it" is a popular slogan in maker movement. The slogan contains notion of getting familiar with the inner life of machines and products.

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6 Included articles

Following pages contain reproduced articles, which have been published in various peer reviewed journals. Reproduction is just for the sake of readability and to gain unified style. Detailed information about original publication is added before each article.

The articles are the following:

(6.1) MOILANEN, Jarkko. Emerging hackerspaces–peer-production generation. In: IFIP International Conference on Open Source Systems. Springer Berlin Heidelberg, 2012. p. 94-111.

(6.2) MOILANEN, Jarkko; VADÉN, Tere. 3D printing community and emerging practices of peer production. *First Monday*, 2013, 18.8.

(6.3) MOILANEN, Jarkko, et al. Cultures of sharing in 3D printing: What can we learn from the licence choices of Thingiverse users? *Journal of Peer Production Issue #6 Disruption and the law*, 2014

(6.4) TAMMINEN, Pia; MOILANEN, Jarkko. Possibility-Driven Spins in the Open Design Community. *The Design Journal*, 2016, 19.1: 47-67.

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6.1 Emerging Hackerspaces – Peer-Production Generation

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Abstract. *This paper describes a peer-production movement, the hackerspace movement, its members and values. The emergence of hackerspaces, fablabs and makerspaces is changing how hacker communities and other like-minded communities function. Thus, an understanding of the nature of hackerspaces helps in detailing the features of contemporary peer-production. Building on previous work on 'fabbing', two different sets of results are presented: (1) empirical observations from a longitudinal study of hackerspace participants; and (2) a theoretical description of hacker generations as a larger context in which peer-production can be located. With regard to (1), research data has been collected through prolonged observation of hackerspace communities and two surveys.*

Introduction and motivation

Hackers form a global community, which consists of multiple micro-communities [2]. The autonomous micro-communities are constantly on

the move; evolving, mixing, forking, hibernating and dying. The hacker community exists both in the real and the virtual worlds, although the latter is often emphasized. The diversity and autonomy of hacker communities can be described through the different type of activities that hackers participate in. For example some hackers are more prone to do network related hacking while others might be more interested in social hacking. In the broadest sense hackers see the society as a system which can be hacked. Not all hackers are interested in the same set of technologies or programming languages. Some might be more interested in phones, hardware, games or biohacking.

Over the past years hackers around the world, mostly in Europe and North America, have begun to move hacker networks and communities out of the virtual into the real world. They have begun to form hackerspaces, hacker communities which have both virtual and real world bodies. The history of hackerspaces begins already in the 1990's. Farr (2009) has defined three development waves in hackerspace history. During the early 1990's "[t]he First Wave showed us that hackers could build spaces" (Farr 2009). Examples of hackerspaces of the 90's are L0pht, New Hack City (Boston and San Francisco), the Walnut Factory and the Hasty Pastry. The second wave occurred during the late 1990's and European hackers (especially in Germany and Austria) began building spaces. The second wave also initiated early theoretical discussions about the development of hackerspaces. The second wave was about "proving Hackers could be perfectly open about their work, organize officially, gain recognition from the government and respect from the public by living and applying the Hacker ethic in their efforts" (Farr 2009). The third wave started after the turn of millennium. The amount of active hackerspaces in 2010 was 254 (Moilanen 2010) and currently there are over 500 active hackerspaces around the world¹ and a few hundred under construction.

This proliferation of hackerspaces can be seen as a significant change in hacking and the formation of hacker communities. Hackers are setting up new kind of communities, with features unknown in earlier hacker communities. Since the hackerspace movement is relatively new, a simple and compact definition of "hackerspace" is still missing even among the persons who are involved in the movement. Different hacker communities use different names: fablab, techshop, 100k garage, sharing platform, open source hardware and so on. The variety of names for the new 'do-it-yourself' communities expresses the variety and diversity of the movement, which might be best described as a "digital revolution in fabrication [... which] will allow perfect macroscopic

objects to be made out of imperfect microscopic components” (Gershenfeld 2007, p. 10). Scientific attempts to clarify the differences of various ‘do-it-yourself’ hacking communities are still rare. A shared understanding of how to use the different descriptions and names of the movement is still missing, but some attempts toward a consensus exist.

Methodology and research questions

The hackerspace community has gone through several discussions about what a hackerspace is. Consensus has not been reached, but the discussions have brought up some criteria for what being a hackerspace means. Firstly, a hackerspace is owned and run by its members in a spirit of equality. Secondly, it is not for profit and open to the outside world on a (semi)regular basis. Thirdly, people there share tools, equipment and ideas without discrimination. Fourthly, it has a strong emphasis on technology and invention. Fifthly, it has a shared space (or is in the process of acquiring a space) as a center of the community. Finally, it has a strong spirit of invention and science, based on trial, error, and freely sharing information.

The five criteria have been tested by conducting a yearly survey of hackerspace communities. So far, the survey has been conducted twice, in July 2010 and June 2011. In addition to questions on the criteria, the survey contains questions which aim to provide more information about the values, interests and motivations of members of different hackerspaces around the world. The overall research setting contains elements of social anthropology and ethnographic methods such as observation. The author has been an active member of the hackerspace community both locally and internationally since 2009. The information gathered by living and working as a part the community is used in directing and conducting the research.

The research was inspired by discussions that have been going on through the hackerspaces mailing list (<http://hackerspaces.org/wiki/Communication>) for ages. The discussions have included several questions such as “What is a hackerspace? How can it be defined? Should some of the spaces listed in hackerspaces.org be removed or not? If so, based on what criteria?” The result has been almost always the same. Hackerspaces can and should not be defined rigidly, because that would create artificial boundaries and that is not a part of hacker culture or values. Discussions have involved business aspects, too. Some hackerspaces are more oriented toward business than oth-

ers. It has been debated whether so called commercial hackerspaces should be seen as hackerspaces or not. Consequently, an interesting research question is the attitude towards donations (money, devices, equipment) coming from companies. Does the desire to be independent rule company donations out? What about governmental support? Is that more acceptable? Thus, questions on funding were added to the initial set of questions, that can be grouped under four headings: 1) What kind of hackers/people participate in hackerspaces? 2) What is the motivation to participate and 3) what do people do in hackerspaces? Additionally, 4) What is the bigger context of hackerspaces?

The latest survey was launched on June 16th, 2011 and was closed on June 30th, giving two weeks time to participate. A message about the research and a link to the online survey was posted to hackerspace discussion list ², the diybio list³ and some other minor hacker oriented lists. The survey was not advertised in social media in order to avoid biased participants. If twitter or other social media would have been used in launching the survey, some non-hackers would have most likely taken the part. A reminder was posted a few days before closing.

The longitudinal survey discussed in this paper continues 2012 as P2P Foundation project, which can be found from <http://surveys.peerproduction.net>. All information collected with surveys will be anonymized and open sourced under Commons license.

Results

The survey in 2011 seems to confirm most of the results found in 2010. No dramatic changes were found. (A comparison of the basic numbers from both surveys is presented in table 1.) Two hundred and fifty (250) participants (25 females, 223 males, 2 ‘no answer’; mean age = 31 years, range: 13-62 years) from 87 hacker communities in 19 countries took part in the study; in 2010 there number of participants was 201. The majority of the respondents were from active hackerspaces (90,4%). Similarly, the most of the respondents were members in only one hackerspace (90,8%). About 48% of the participants lived in Northern America, 39% in Europe, over 9% in Australia and 3,6% in Southern America. One participant was from Asia (China). None of the

²<http://lists.hackerspaces.org/mailman/listinfo/discuss>

³<http://groups.google.com/group/diybio/topics>

participants were from Africa. Compared to the stats of the survey in 2010, the percentage of European respondents dropped by nearly 9%, and hackers from Australia found the survey this year (8,7% up). The low amount of Asian respondents might be partly explained by limitations in access to web content (for example in China).

Basic statistics	2010	2011	Change
Participants	201	250	49
Men	185	223	38
Women	12	25	13
Mean age	30	31	1
Age range	15-53	13-62	-
Amount of different communities	72	87	15
Geographical distribution	2010	2011	Change
From Northern America	48,0%	48,0%	0,0%
From Southern America	0,0%	3,6%	3,6%
From Europe	47,5%	38,6%	-8,7%
From Asia	4,0%	0,4%	-3,6%
From Asia	4,0%	0,4%	-3,6%
From Australia	0,5%	9,2%	8,7%
Amount of different countries	20	19	-1

Table 4: General view of 2010 and 2011 survey statistics.

Members – age, gender and education

The gender and age distributions of hackerspace community members follow the results found in FLOSS related surveys (Aalbers 2004, Mikkonen et al. 2007). In 2010, the typical member was a 26-29 years old male (94%) with college level or higher education. In 2011, the typical member is a 27-31

(35%) years old male (90%) with college level or higher education (64%). It must be noted that even though 90% of respondents were male, this does not necessarily imply that the same applies to hackerspaces in general.

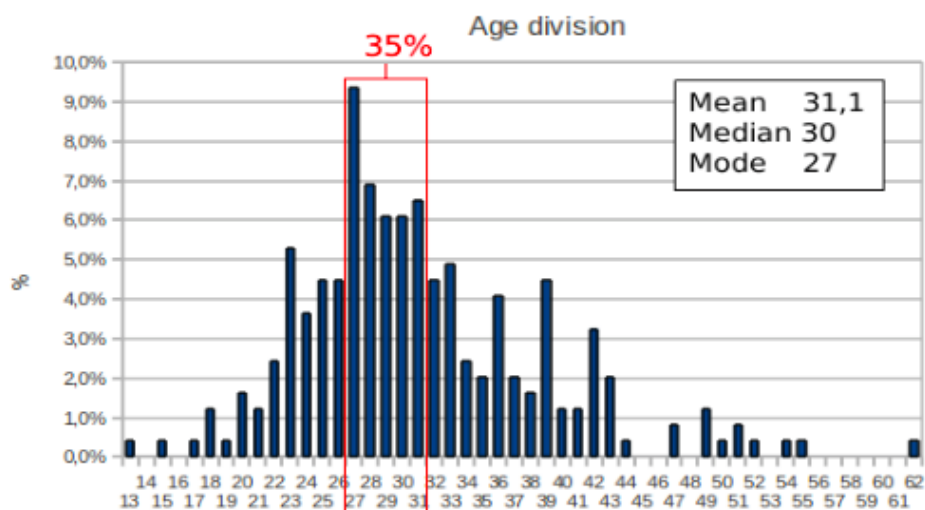


Figure 1: Age division 2011.

When respondents are grouped by age, gender does not vary much (see graph 2). In both genders, 26 – 35 year old members are the majority (women 58%, men 52%). The minors (under 18 years old) are rare and only men.

With regard to education, the only significant change between 2010 and 2011 is the increase in the amount of hackers with a Master’s Degree. In 2010 it was 14% and this year it was over 20%. (Detailed comparison in table 5)

Members – membership

Based on the survey results, most hackers are members of just one community (nearly 91%). Compared to the results in 2010, memberships in two communities has dropped by nearly 7%. The trend seems to be that respondents are members in fewer hackerspace communities. This can be seen when comparing multi-community membership counts in 2010 and 2011 (see Graph 4).

This might suggest that hackers have found their ‘home’ and are more engaged and committed to one local hacker community. This could be partly

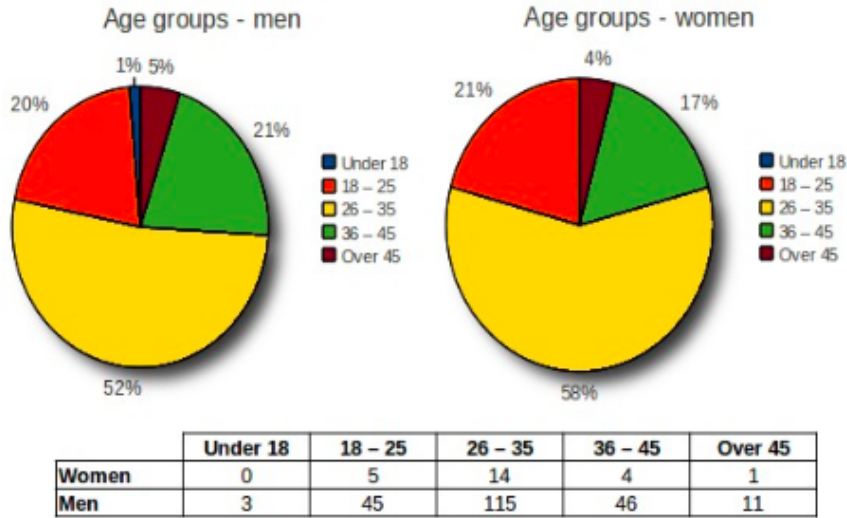


Figure 2: Age groups by gender 2011.

Education level	Percentage 2011	Percentage 2010
Less than high school	3%	3%
High school / GED	8%	6%
Some college	22%	27%
2-Year college degree (associates)	10%	9%
4-Year college degree (BA,BS)	32%	32%
Masters degree	21%	14%
Doctoral degree	3%	5%
Other	1%	5%

Table 5: Respondents' education 2011 and 2010.

explained with the disappearance of some hackerspaces, causing membership concentration to strong and active hackerspaces. However, at this point this

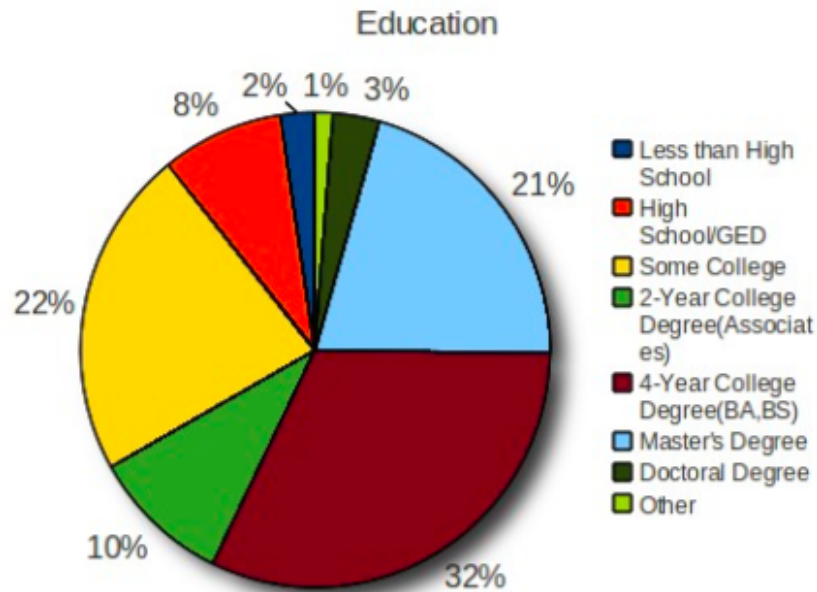


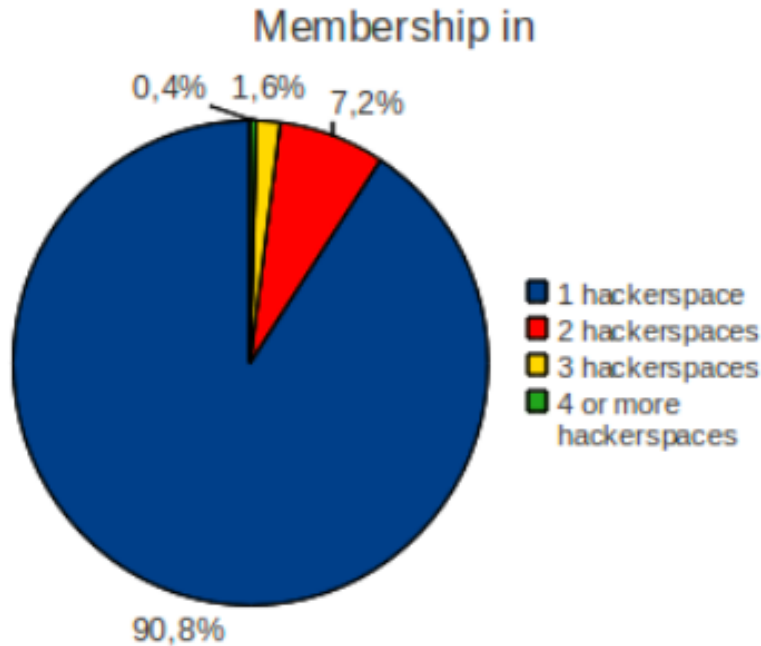
Figure 3: Respondents' education in 2011.

is just speculation and can't be confirmed from the data. Another possibility is that simply the raised participant count in 2011 has caused the change.

Members – interests

Members interests were inquired about in one question: "In general my interest with the hackerspace is MOSTLY about ...". Respondents were given list of predefined groups of interest areas such as software hacking, networks and building objects. Respondents were informed to choose max. 3 options, but some selected all.

In the 2011 survey one new option was added: in 2010 the social aspects of hacking communities were not present on the list. Since then the need for that option has become clear. The term 'social aspects' refers to events and meeting people – the term was clarified to respondents in parenthesis. Respondents were also given an opportunity to choose 'Other' and give some sort of clarification. Graph 5 present a comparison chart.



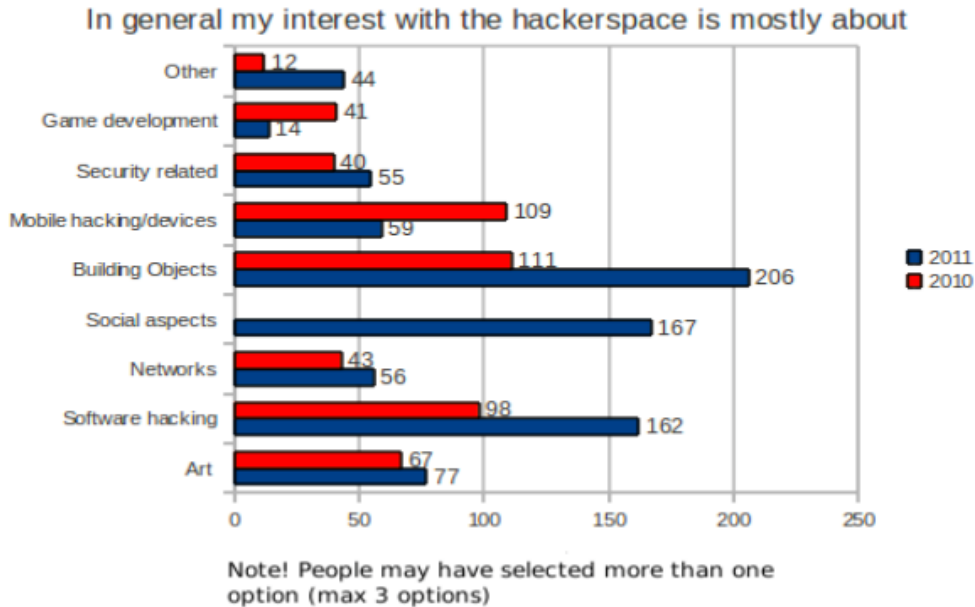
	2011	2010	Change
1 hackerspace	90,8%	84,7%	6,10%
2 hackerspaces	7,2%	13,9%	-6,70%
3 hackerspaces	1,6%	1,0%	0,60%
4 or more hackerspaces	0,4%	0,5%	-0,10%

Figure 4: Hackerspace membership 2010 and 2011.

In the 2011 survey, the top three interests are building objects (82%), social aspects (67%) and software hacking (65%). Compared to 2010, both mobile hacking and game development dropped. Of course, adding the new option 'social aspects' might have partly caused the change.

Nevertheless, it seems to be clear that hacker communities are about building things. Option 'other' included several topics and areas as identified by the respondents. To mention just a few: learning, biohacking, biology,

Figure 5: Interests in 2010 and 2011 in comparison.



biotech, energy, diybio, robotics, 3D printing, chemistry, science & math, foundry work, fabrication techniques not available at home, podcasting, fibre-crafts and chemistry & physics. Among the above topics, the term ‘Learning’ appeared several times, which suggests that learning in general is important for participants. Also robotics and biology related hacking were mentioned several times. This suggests that hackers are getting more and more active in DIYbio (referring to communities focusing on biology), a fact that has also caught the attention of the press (see for example Mackey 2010, Mosher 2010, Bloom 2009).

Members – Motivation

The participants were asked to tell how significant different reasons for contributing in hackerspaces are. The question included eight claims and options were presented using a five-point Likert scale (see graph 6).

Altruism, community commitment, meeting other hackers in real world

	Strongly agree	Agree	Do not know/does not matter	Disagree	Strongly disagree
participate for the fun	69%	29%	2%	0%	0%
want to help people, without getting something in return	34%	46%	16%	3%	1%
participate because you re committed to the community	34%	41%	21%	4%	1%
want to help people and expect to get something in return	5%	24%	44%	20%	7%
participate to build up a reputation	10%	44%	26%	15%	5%
participate because need software/hardware improvements	12%	36%	30%	16%	6%
participate to earn money with it	1%	7%	27%	26%	39%
to meet (in real world) other hackers/hacker-minded people	70%	25%	3%	2%	0%

Figure 6: Motivation for taking part in hackerspaces - 2011.

and having fun seem to be the most important factors of motivation. About 80% (last year 77%) of the participants seem to be contributing to community without expecting something in return. About 75% feel that commitment to community is one of the most important sources of motivation. For nearly all (95%) meeting other hackers and hacker-minded people and having fun (98%) are the most important reasons to participate in hackerspace activity. In other words, the social factor of peer production communities seems to be the key element.

When compared to results in 2010, no major changes can be found (see Graph 7). Attitude towards earning money and reputation building have become slightly less negative.

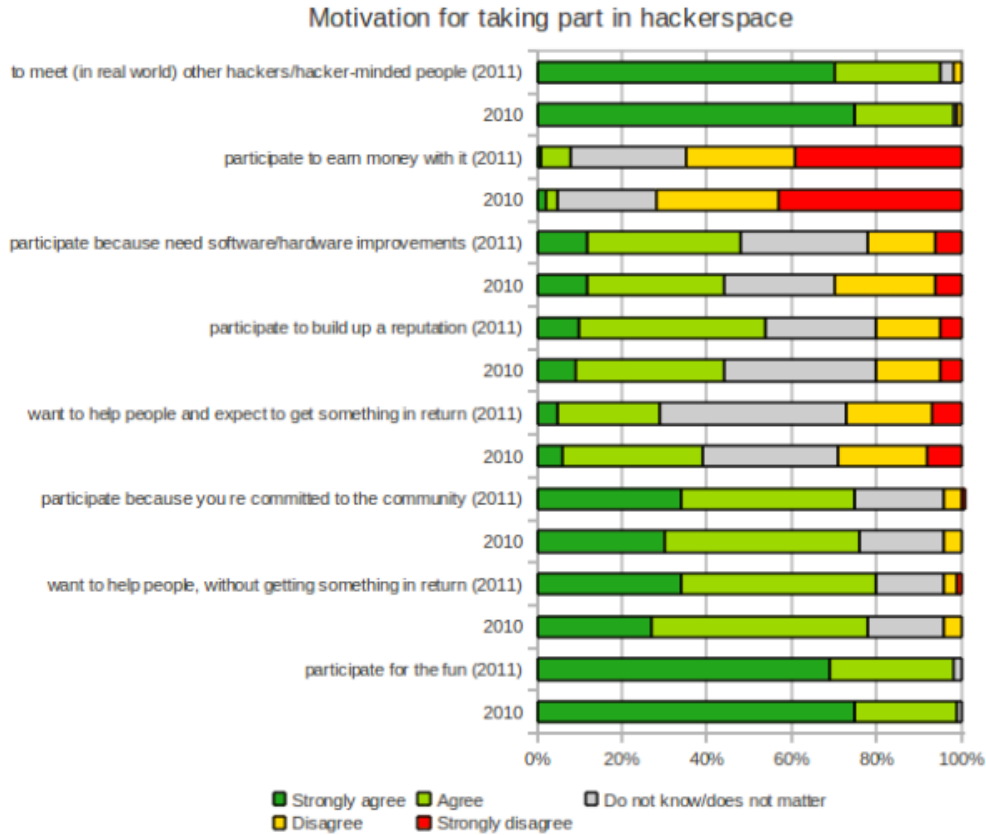


Figure 7: Member motivations in 2010 and 2011 in comparison.

Members – Motivation

Members – time spent on hackerspace related activities

Survey participants were asked to tell how much time they spend on hackerspace related activities in a week. The answers were given in free text format, not as predefined options (which could have been better). The responses were grouped into 2-hour periods and a few answers were dropped away: it seems highly unbelievable (and even impossible) that someone would use 300 hours or more on hackerspace activities in a week.

Roughly, the respondents use the same amount of time as in 2010 (2011:

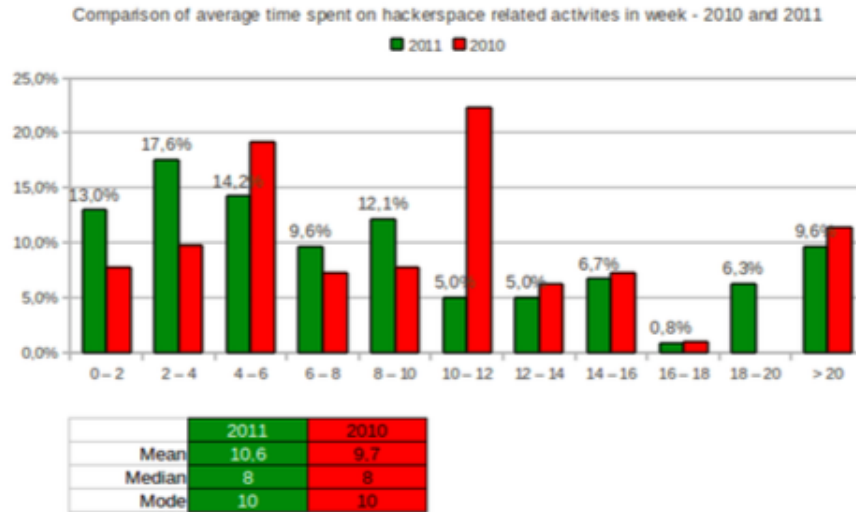


Figure 8: Time spent on hackerspace related activities per week - 2010 and 2011.

10,6 hours and 2010: 9,7 hours). The histogram in Graph 7 seems to suggest some changes. In 2010, two options – 4-6 hours and 10-12 hours – were most common, while other amounts were less popular. In 2011, the distribution is more even. It seems that respondents use either a little time (2-4 hours) or a lot of time (18 hours or more) in hackerspace related activities. The values in the middle got lesser hits. This might suggest that there are two groupings: ‘the mass’ (a few hours) and enthusiasts (high amount of hours).

Members – activity

The respondents participate in community related activities for about 10 hours per week. What kind of things do they do? The answer to this question was sought by asking: “In general my projects in the hackerspace are about ...” which was followed with 7 predefined Likert scale options. The given options were: Software development / hacking, Hardware development / hacking, Website/Web-app development, Management (financial or otherwise), Organize events/nights/sessions etc., Administrative tasks (email lists, servers, etc.) and Mobile device related

hacking.

Results (see Graph 9) suggest that hackerspace members are mostly involved in projects related to software development (over 55%) and hardware development (over 65%). The least popular project contents are Mobile device related hacking (6%) and Organizing events (less than 10%).

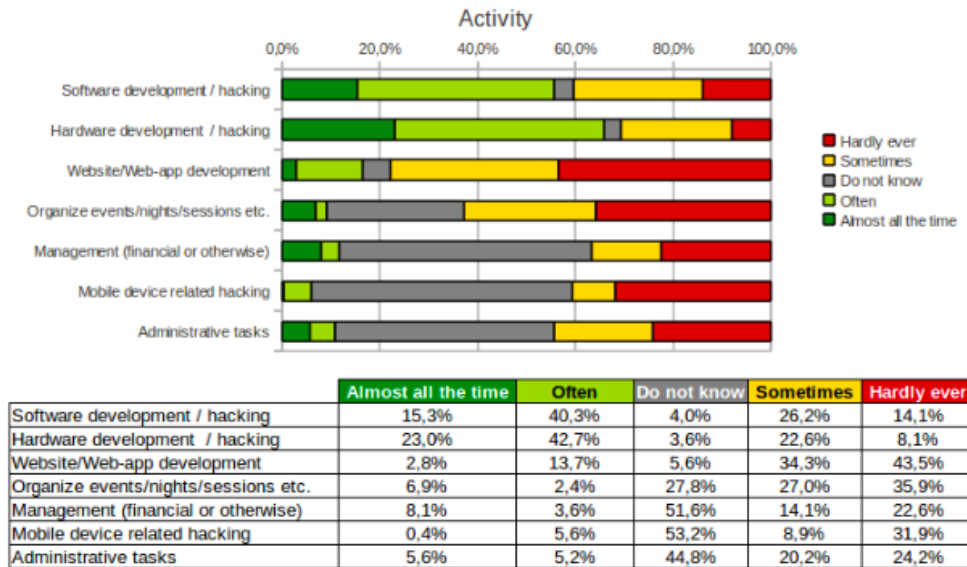


Figure 9: "In general my projects in the hackerspace are about ..." (2011)

Even though the amount of female respondents in the surveys was rather low, some cross tabulation using gender as one factor can be informative. I must stress that gender is not the issue here; it is used just for the sake of research. Keep in mind that hacker ethics does not want to use bogus criteria (such as gender, age or education) in evaluating people. The intention was to find out if there are differences between the genders; what men like to do and what women like to do. The results indicate that women are more often involved in website development and organizing events.

Men are more prone to software and hardware hacking. Women have strong interest in software development and a little less in hardware related projects. Mobile device hacking was not popular among respondents and it is dominated by men. Both genders are equally disinterested in management and administrative tasks.

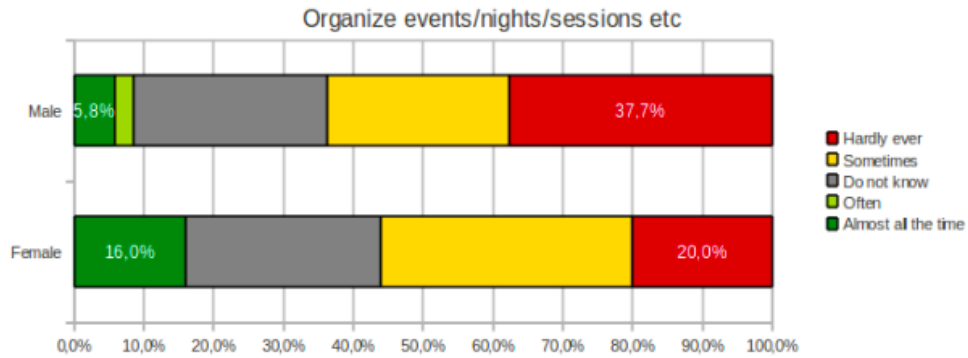


Figure 10: Participation in organizing events by gender in 2011

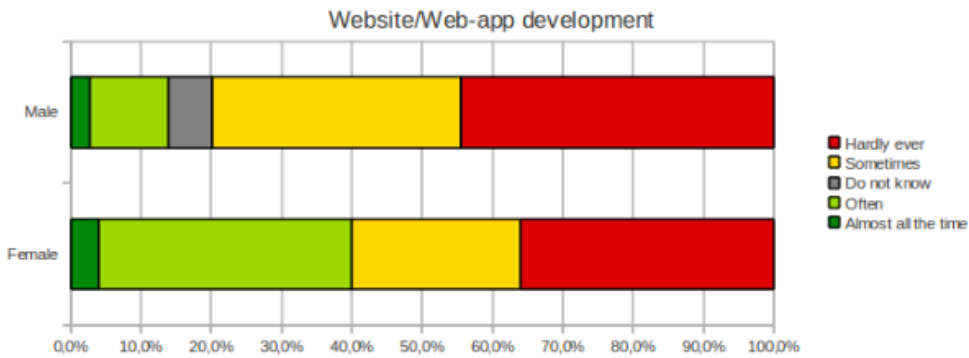


Figure 11: Doing website related development by gender in 2011

Community – amount of members

A few of the questions in the surveys were about the local communities in which the respondents were members. For instance, respondents were asked to give estimated amount of members in their local community. This does not correlate directly to reality, since some respondents might be less aware of the status of their community. In other words, answers are probably mostly given by ‘gut-feeling’. Furthermore, it is somewhat unclear how people understand the term ”member”, who is included and who is not. The question included

predefined drop-down options: 1- 10, 10-20, 20-50, 50-100, 100-200 and 200 or more. These options were constructed based on the 2010 survey results, in which respondents were free to give any number.

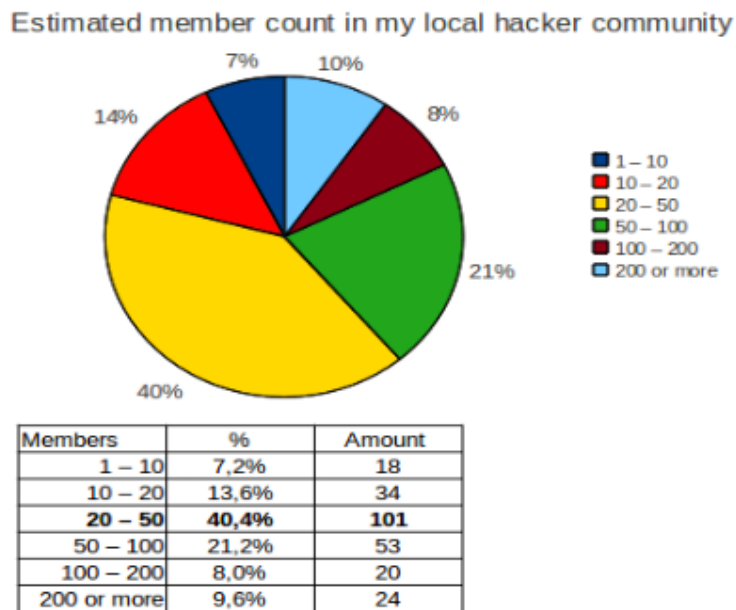


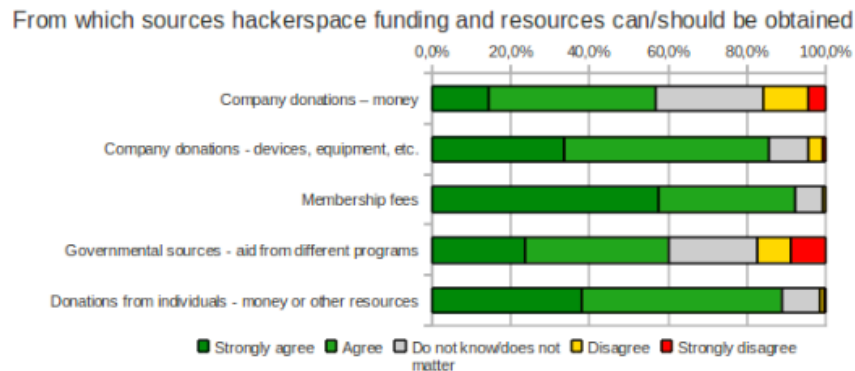
Figure 12: Member count in local hacker community (estimated) in 2011

According to the results 40% of local communities have 20 – 50 members. The second most common size is 50 – 100 members. It must be noted that these figures include all kind of community statuses: planned, building and active.

Community – funding

The topic of funding was added to the survey in 2011. Discussions related to sources of funding have been constantly on the agenda inside hackerspace communities and therefore attitudes towards different funding sources are interesting. The survey participants were given a list with the following possible funding sources (with Likert scale options): company donations (money), company donations (devices, equipment, etc.), membership fees,

governmental sources (aid from different programs which help building and maintaining volunteer activities) and donations from individuals (money or other resources).



	Strongly agree	Agree	Do not know/does not matter	Disagree	Strongly disagree
Company donations – money	14,4%	42,4%	27,2%	11,6%	4,4%
Company donations - devices, equipment, etc.	33,6%	52,0%	10,0%	3,6%	0,8%
Membership fees	57,6%	34,8%	6,8%	0,8%	0,0%
Governmental sources - aid from different programs	23,6%	36,4%	22,8%	8,4%	8,8%
Donations from individuals - money or other resources	38,0%	50,8%	9,6%	1,2%	0,4%

Figure 13: Opinion about sources for hackerspace funding and resources

The results suggest that company donations (money) are less disagreeable than governmental support, but only slightly. Membership fees seem to be the most approved source of funding. Device and other equipment donations from companies and all sorts of donations from individuals gained a lot of support. It must be noted that in some cases, if company donations are accepted, they must be without strings attached. The policy is required in order to maintain community independence from external forces. Nevertheless, it is clear that money or other kind of support in any form coming from individuals is preferred over company or governmental sources.

Discussion and conclusions

According to the survey results the typical hackerspace member is a 27-31 (35%) years old male (90%) with college level or higher education, committed to one hackerspace; he uses in average ca. 10 hours per week in hackerspace related projects, which are commonly software or hardware related. Altruism, community commitment, meeting other hackers in the real world and having fun seem to be the most important factors of motivation. Compared to the motivation models discussed in research on open source development (for example Bonaccorsi & Rossi 2006), hackerspace communities have a strong 'social motivation factor'. The members in the communities have a high interest towards meeting other hacker-minded people in real life. Most communities aim to have a physical space that functions as a community center. They are also known to arrange a lot of real life activities which are often related to learning, education and of course having fun. Having fun is one of the most important motivation factors and having fun is a fundamental part of social life.

Women seem to have found peer-production communities (hackerspaces, makerspaces, fablabs, diybio, etc.). Peer-production communities are still 'man caves', but the amount of women in hacking seems to be rising at least through the hackerspace movement. The emergence of biohacking was also visible in the survey.

Hackerspaces can be seen as hacker versions of 'third places' as defined by Oldenburg (1999). According to Oldenburg 'third places' refer to social settings or surroundings separate from the 'first place' (home and other similar settings) and 'second place' (workplace) (Oldenburg 1999). The third places are 'anchors' of community life that facilitate and foster broader, more creative interaction. These places serve as focal points of community life which has eroded due to commercial chains and unifunctional zoning policy (Oldenburg 2001, p. 3). Third places are needed to reconnect to each other and strengthen community ties. To become a successful third place, a place must be locally owned, independent and small-scale and be based on steady-state business (Oldenburg, 2001, p. 4). Furthermore, the places should be highly accessible, within walking distance, free or cheap and involve regularity. When these criteria are compared to the characteristics of hackerspaces, the similarities become obvious.

All hacker and other computer related groups or clubs can not be called hackerspaces. Some groups or places that look like hackerspaces don't even

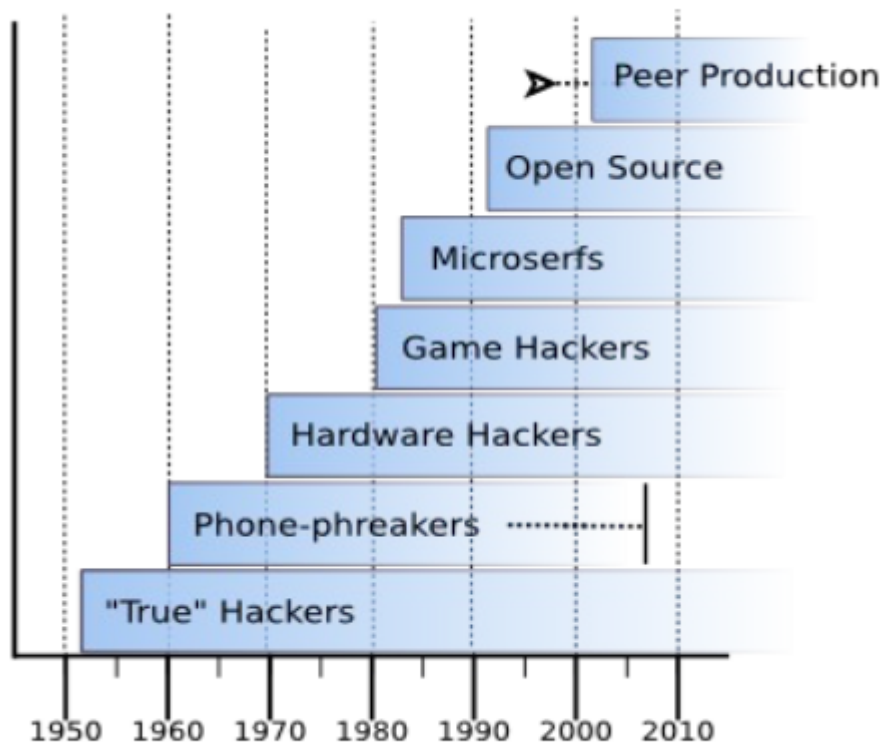
want to be labeled as such. Some hackerspaces avoid using the word itself in the group's name or in the descriptions of the group. Reasons for avoiding the word vary, but the most common is related to the uncertainty of how 'others' will react to any description that includes or refers to the word 'hacker'. This fear of the opinions of others is an example of how communities are shaped, defined and identified also by people that are not members of the communities. The identity is not carved in stone, but constantly evolving. Yet some features can be listed even though the features are not universally agreed upon in the community. The reason for some level of diaspora may lie in the desire not to define hackerspaces rigidly, which in turn is derived from the values of hacker ethic.

Since a shared understanding of how to name the 'fabbing' movement is still missing (not the least in the academic context) and in order to put the movement in a larger context, I suggest that it could be seen as a continuum to the different hacker generations mentioned above. As discussed above, 'fabbing' is bigger than just hackerspaces and therefore I have labeled this new hacker generation as 'peer- production' (see illustration 1) in order to include the different forms described by Troxler (2010, p. 2).

While the above mentioned hacker generations are acknowledged by some scholars (see for example Sterling 2002, Taylor 2005) the descriptions provided so far are missing the latest development, namely peer-production.

The description of peer-production movement as a hacker generation needs more research and thought. Nevertheless, hackerspaces as instances of peer-production have a clear identity and constitute a large, growing and global movement. Hackerspaces and previous hacker generations share some values such as altruism and believe in hacker ethic. As the survey results indicate, hackerspace members are if not obsessed then at least focused to hardware hacking, which was fundamental part of 'hardware hacking' generation. Peer-production generations adapts that obsession and extends it with social aspects. Peer-production generation overlaps with the Open Source generation as well. Both value sharing, collaborative work, openness and transparency. Open source has become part of the main stream in software development. Companies have become part of the open source communities, started to form ecosystems and the border between working hours and contribution has become fuzzy. Hackerspace communities have chosen the other way. They want to stay as independent as possible from external forces such as companies and governments. This might indicate that freedom is more valued than resources. Valuing freedom over resources

Figure 14: Suggested view of hacker generations. Source: Modified from Taylor (2005), peer-production added by the author. Beginning of peer-production generation is debatable. Hackerspaces emerged in small scale around 1995, but breakthrough happened around 2001-2002 and after that other forms of peer-production emerged. Phone-phreakers generation as a movement ends at 2006 because last "phreakable" MF-signalled N2 carrier was replaced with a T1 carrier.



and restraining external (often business related) influences, does not exclude creating new business. Some of the fundamental parts of 3D printing device development (such as RepRap and Ultimaker) have started from peer-production communities.

Yet, hackerspaces are different kind of communities compared to communities formed by previous hacker generations at least in two aspects.

Firstly, hackerspaces focus on social aspects in virtual and physical world. Hackerspace communities organize events, which are about having fun and learning. Examples of virtual events are monthly organized hackathons, in which people gather together to solve technical problems to create something new in collaboration. Physical world events are often educational in nature focusing on different technical issues and skills such as programming languages, soldering skills, 3D printing and biohacking. Furthermore, these events are often open to public. That indicates will to educate 'others', those who are not yet members of the community. Reasons for this free-time based education might be to lure in more members and share the gained knowledge and skills. Secondly, they aim to build and maintain physical spaces which function as community centers. Hackerspaces and alike have taken a significant role in how hackers and hacker-minded people organize themselves and activities.

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6.2 3D printing community and emerging practices of peer production

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Abstract. *Based on the results of a 2012 survey on people doing 3D printing, we present results on the demographics and selfidentification of the community, as well as describing participants' printing activity. Combining results from the survey with insights from research literature, we analyse emerging patterns and practices of 3D printing as a subdivision of a more general trend of physical peer production, and, even, of a revolution in manufacturing, as predicted by several theorists.*

Background

3D printing as an activity has both been growing (see Figure 8, below) and receiving increased attention in the past few years. Viewed from a social perspective, the activity itself has several interconnecting roots. The hacker movement, open source software community and maker culture are

just three of the most prominent socio-cultural backgrounds. While the interconnections between these three are rich and the communities overlap to a large extent, they can still be analytically separated and often the members themselves insist on the separate identities of the communities (see Troxler, 2010; Tocchetti, 2012; Maxigas, 2012; Moilanen, 2012). Therefore one of the purposes of the survey launched in 2012 was to gain insights into the self-identification and background of people doing 3D printing.

One of the reasons 3D printing has intrigued a growing group of theorists is that it can be seen as arguably the most promising phenomenon in a predicted and emerging revolution in manufacturing. Several economists and theorists of innovation have even surmised that a third industrial revolution is at hand (Bauwens, 2005; Benkler, 2006; Rifkin, 2011; see also Bauwens, 2012; McCue, 2012). In this context, 3D printing provides an example of a combination of, first, an organizational innovation, the open source-inspired distributed way of organising design and production, and second, a set of engineering innovations, the 3D printing machines themselves, that together provide a platform for rapid and distributed manufacturing.

Here we adopt Benkler and Nissenbaum's (2006) description "commons-based peer production" to denote a type of production in which the creative energy of large numbers of people is coordinated, usually with the aid of the Internet, into large, meaningful projects mostly without traditional hierarchical organization or centralised decision-making. Commons-based production as "a socio-economic system of production that is emerging in the digitally networked environment" [1] is different from market-based and company-based production in that the resources used and the products produced are shared among the participants in the distributed network. Consequently, the resources form a commons, governed by the social and institutional arrangements of the participation (Ostrom, 2010; Bauwens, 2009). A subset of commons-based production is peer production in which participants are self-selected and decision-making is distributed. Several modes of 3D printing fit under the description, especially because the open source model is widely used in distributing printing and printer designs. Below, we will identify emerging patterns of 3D printing participation and some of the major bottlenecks in terms of creating a commons, as indicated by the survey.

The survey

People engaged in 3D printing can be loosely grouped into the three categories in terms of technology adoption: developers, early adopters and end users. “End users” refers to people who print objects with 3D printers but are not involved in making development either on 3D printing software or hardware. This group contains also people who use 3D printing services. At the same time, these services also represent a kind of peer production since the models and products sold in Web shops are made by a large population of people who participate (at least mostly) voluntarily; they create the content. The second group, early adopters, consists of people who buy 3D printers and assemble and use them with the help of the community, often in the process making contributions, software or hardware, to the communities. An example of community help is assembly instructions related to the Ultimaker 3D printer and the RepRap. Often the help provided goes beyond the assembly instructions and the community produces a lot of information in wikis. The information consists, for example, of test results with different kind of printing speeds [2], experiences of how different printing materials behave on printers [3] and about particular hardware modifications [4]. Finally, developers are people mainly concerned with the developing of 3D printing, either in terms of software or hardware. Of course, the above groups overlap and individuals move from one group to another over time.

The survey launched in May 2012 was directed to all three groups. Developers were approached through developing mailing lists and hackerspaces discussion list. End users were approached with the help of selected 3D printing services and twitter. Service providers Shapeways, Ponoko and Fabbaloo were asked to promote the survey and all three blogged and tweeted about it [5]. Early adopters were assumed to populate RepRap users mailing list and to follow 3D printing related twitter feeds and blogs. Using Twitter and getting publicity from 3D printing service providers, we expected to get some amount of so-called “false respondents”. However, our fear turned out to be false since not a single extravagant answer was found; none of the answers deviated from the most common ones to be obvious spam. In total, there were 358 respondents [6].

Demographics and self-identification

The basic demographics is male-dominated, as one would expect in a technology-oriented community. The average age, 35 years, is somewhat higher than in (stereo)typical open source software communities (Mikkonen, et al., 2007; Ghosh, 2005), conforming well to the pattern where participants in open source hardware have been found to be somewhat older than software hackers (Malinen, et al., 2011). The level of education of respondents is high, with 56 percent having at least a bachelor level degree. Again, this agrees well with earlier results on open source hackers, although the numbers there have been even higher: Mikkonen, et al. (2007) found that 80 percent of respondents in four software communities (Debian, GNOME, Eclipse and MySQL) had a university degree (12.5 percent had Ph.D. degrees); in Malinen, et al. (2011) the number for a hardware community was 59 percent (four percent Ph.D.s).

As noted above, the cultural or ideological background of people doing 3D printing is varied. In order to gain some insight into this, the respondents were asked if they identify with the maker movement or with peer production. Likewise, we inquired about the membership in any type of do-it-yourself (DIY) community and previous involvement in open source projects.

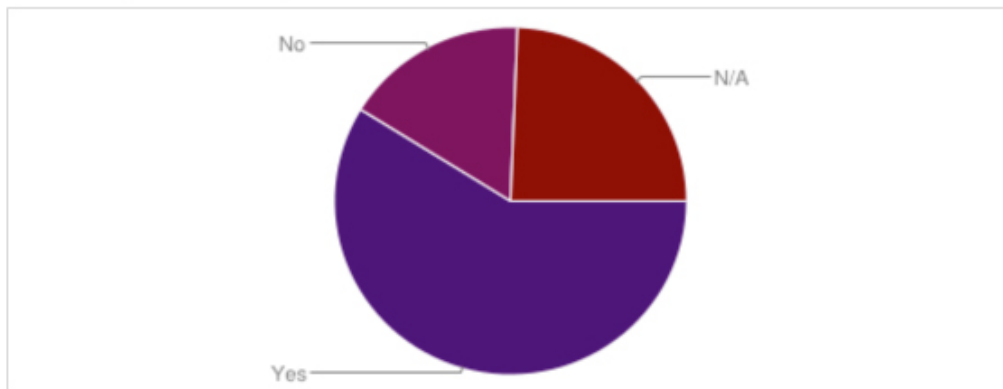


Figure 1: Do you consider yourself a member of the so-called maker movement?

The respondents clearly identify more with the maker movement than with peer production, Especially the high number of “No” answers to the peer production question may indicate an aversion to the “ideological” nature

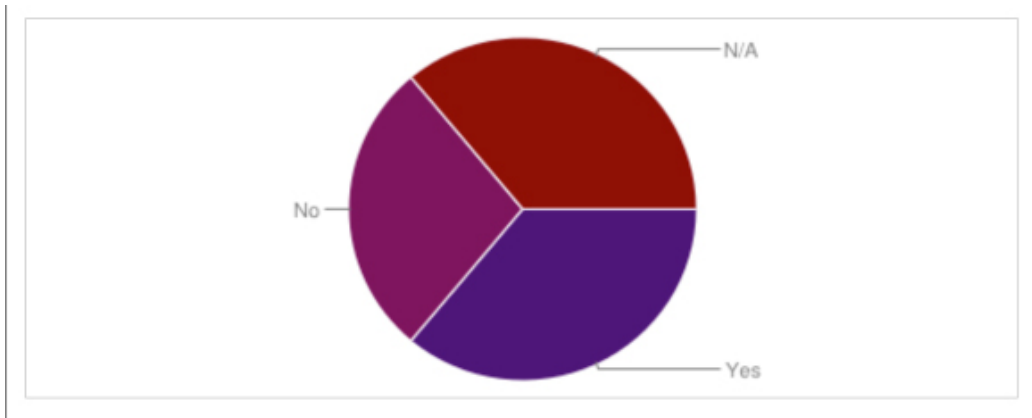


Figure 2: Do you consider your 3D activities a part of so-called peer production?

of the term “peer production” in comparison to the presumably more neutral “maker movement”.

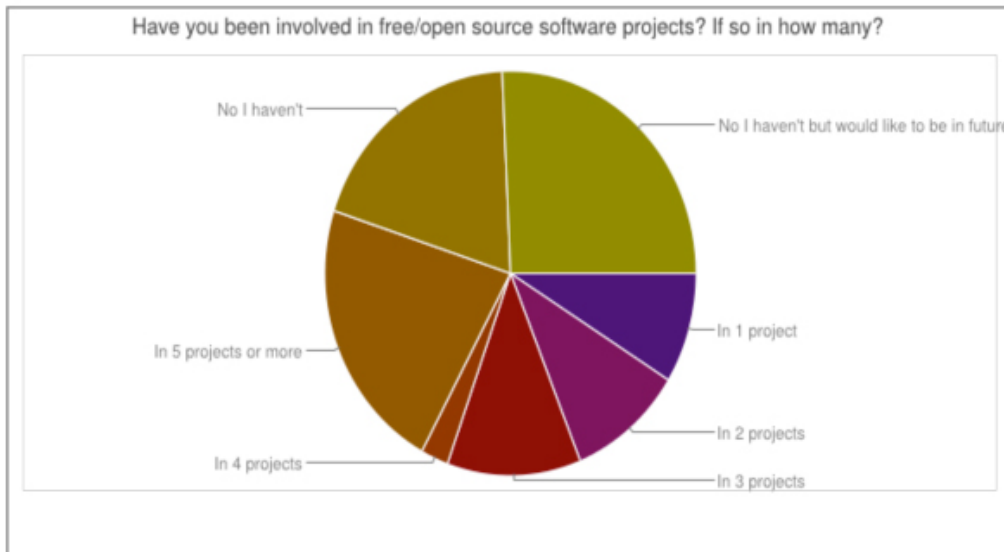


Figure 3: Do you consider your 3D activities a part of so-called peer production?

Fifty-five percent of the participants were involved at least in one open source project. Nearly 20 percent wanted to be involved in the future. Roughly 26 percent did not want to be involved in an open source project.

To us, these numbers suggest that 3D printing can be seen partly as

a continuation of open source. Over half of respondents have previous experience of the open source modus operandi, and bring their knowledge to the printing community. The explicit open source affiliation of the RepRap community — RepRap being the most used printer model (see Figure 9, below) — is one obvious source of the connection.

On the other hand, there are other roots for the community and participants. For instance, the amount of 3D printing done for artistic purposes (the second most common usage, see below) is noteworthy. It would be interesting to know how many of the respondents have a background and motivation in a more hands-on attitude of doing concrete things rather than in “fiddling with software and computers”. The identification with the maker movement may in part indicate this tendency. As seen in Figure 6, below, the amount of participants with a DIY background seems to be on the rise.

In order to gain further insight into the correlation between participation in open source and DIY communities, we cross-tabulated the answers to the questions “Have you been involved in free/open source software projects? If so in how many?” and “Are you or have you been a member of a hackerspace, fab lab or a similar group?”

	Member of DIY community?	
Have you been involved in free/open source software projects? If so in how many?	No	Yes .
In 1 project	6.8% (11)	9.2% (9)
In 2 projects	8.7% (14)	11.2% (11)
In 3 projects	10.6% (17)	12.2% (12)
In 4 projects	0.0% (0)	6.1% (6)
In 5 projects	15.5% (25)	29.6% (29)
No, I haven't but would like to be in future	21.1% (34)	12.2% (12)
No, I haven't	31.1% (50)	11.2% (11)

Table 6: Cross-tabulation between FLOSS involvement and DIY community membership.

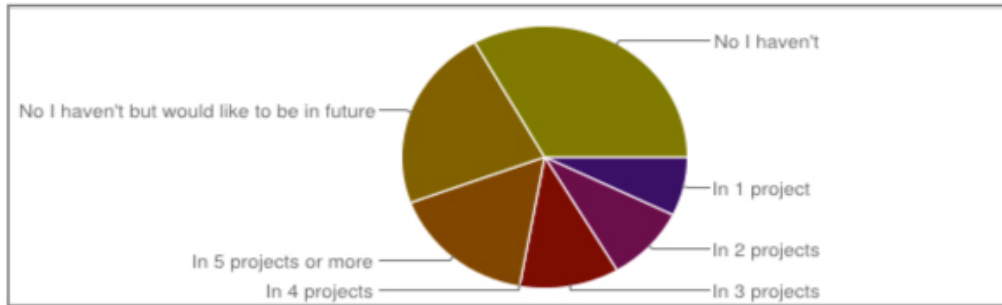


Figure 4: Not members of DIY, participation in open source.

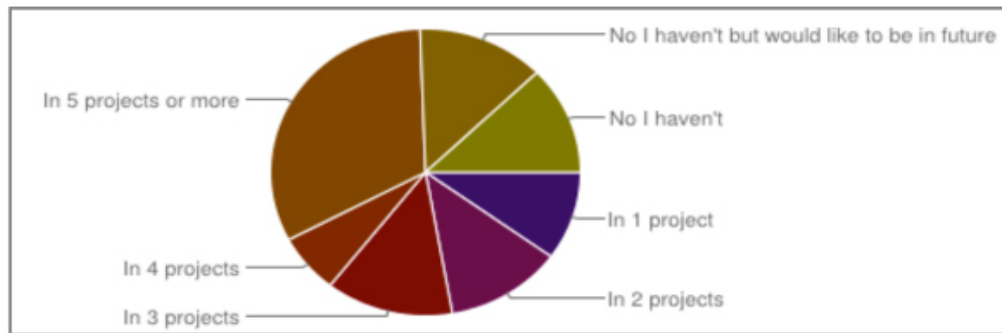


Figure 5: Members of DIY, participation in open source.

The cross-tabulation suggests that there is no systematic difference between people who are or are not members of any DIY community, but participate in open source projects. Both participate in open source about as eagerly. However, there is a difference when the comparison is based on “not participating in open source”. Those who are members of some DIY community, represent smaller portion. The percentage of “In five projects or more” supports that conclusion, since nearly a third of DIY members are involved in five or more open source projects.

Moreover, we wanted to see how the self-identification with the maker movement and peer production correlate with 3D printing activities.

Both the identification with the maker movement and peer production are increasing over the years, identification with the maker movement more markedly. Historically, the data is too thin to make any claims of the respective influence of the movements, not to speak of the influence of their perceived ideologies.

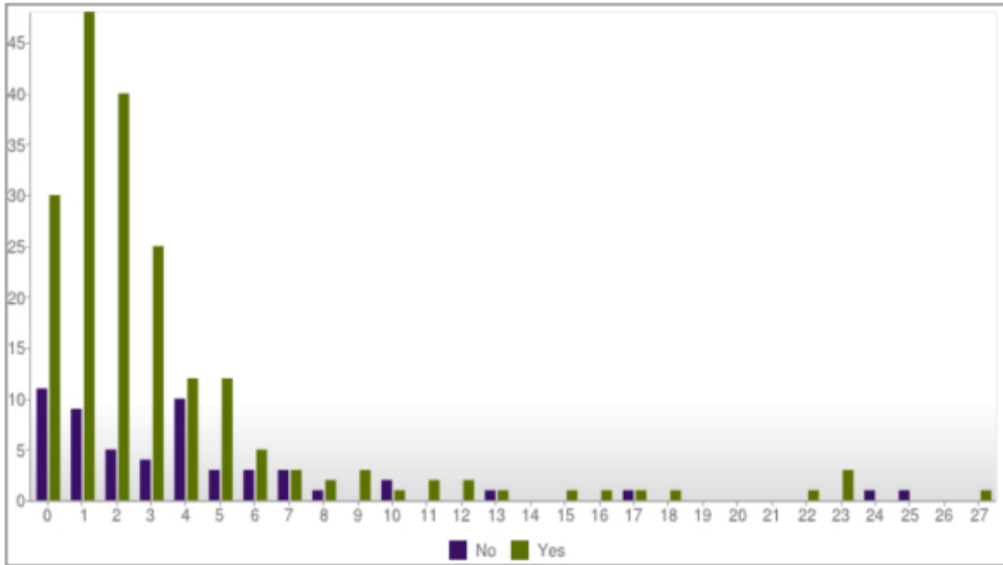


Figure 6: DIY community membership (no/yes) and experience (years) in 3D printing.

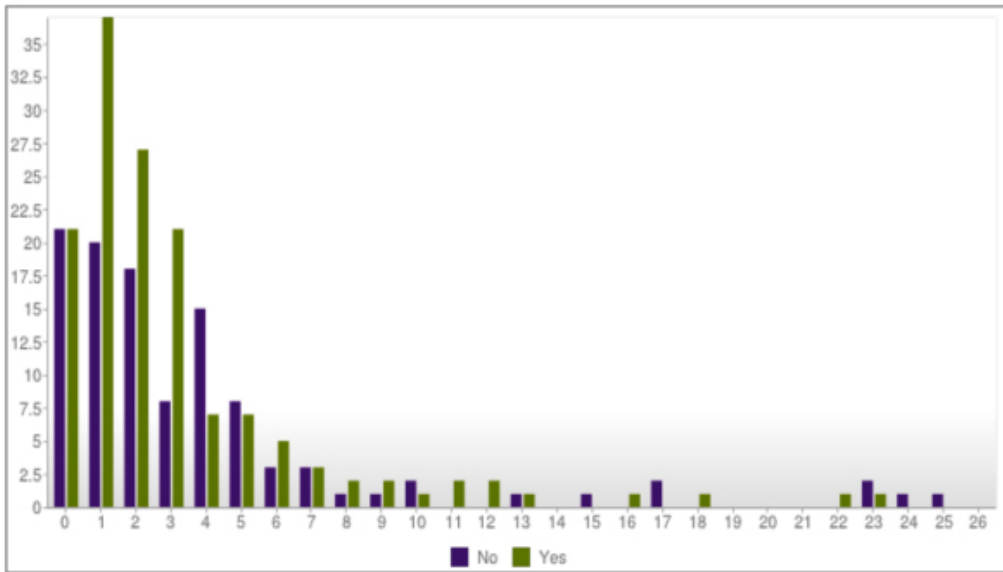


Figure 7: Peer production membership (no/yes) and experience (years) in 3D printing.

3D printing: What, how and why

Survey participants were asked when they used 3D printer/printing services for the first time. Predefined options (years) were listed in a dropdown menu. The amount of 3D printers/printing started rising around 2005–2006 and has been rising ever since, as indicated in Figure 8, below. The growth can be partly explained with the rise of RepRap. The first RepRap, “Darwin”, was finished spring 2007 [7]. The numbers for year 2012 seem to be dropping, but that is an artifice created by the polling schedule. The survey was conducted in May and therefore the amount for 2012 is lower than for 2011.

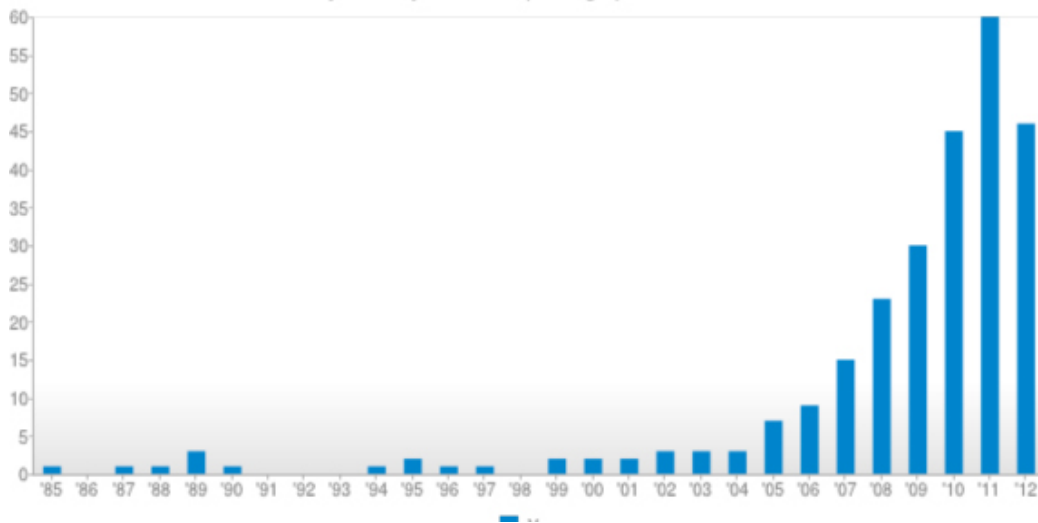


Figure 8: Which year did you use 3D printing/printer the first time?

Participants were asked “For what usage do you use 3D printing?” and given 10 predefined options together with a tick box for “other”. Predefined options were: Spare parts to devices; Covers and such for devices; Artistic items; Visual aids; Presentation models (including architectural models); Functional models; Used for pattern/in molds; For research/educational purposes; Direct part production (custom, short run, series production); and, Furniture and household decoration. The amount of selected items was not restricted.

According to the results, the five most common usages for 3D printed items are:

1. Functional models (144);

2. Artistic items (140);
3. Spare parts to devices (133);
4. For research/educational purposes (128); and,
5. Direct part production (113 times).

If a participant selected “other”, it was instructed that a short description would be provided. Some of the participants (n=42) selected “other”, and gave descriptions containing items and usages such as toys, for fun, (custom) jewelry, reprints (replicating printer), prototyping, reselling, gaming miniatures, tools and medical devices.

Participants were asked “Which printers (which manufacturer) have you used?” and again they were given a predefined option set. Options contained 20 different manufacturers. Three options (Arcam, Blue Printer and Solidoodle) were not chosen at all and have been left out of the figures, below. A few manufacturers were selected only by a few participants (one–six times). Such companies were: Botmill, ExOne, Fortus, Makibot, Printrbot, Solidscape and Envision Tec. Those were also left out of Figure 9.

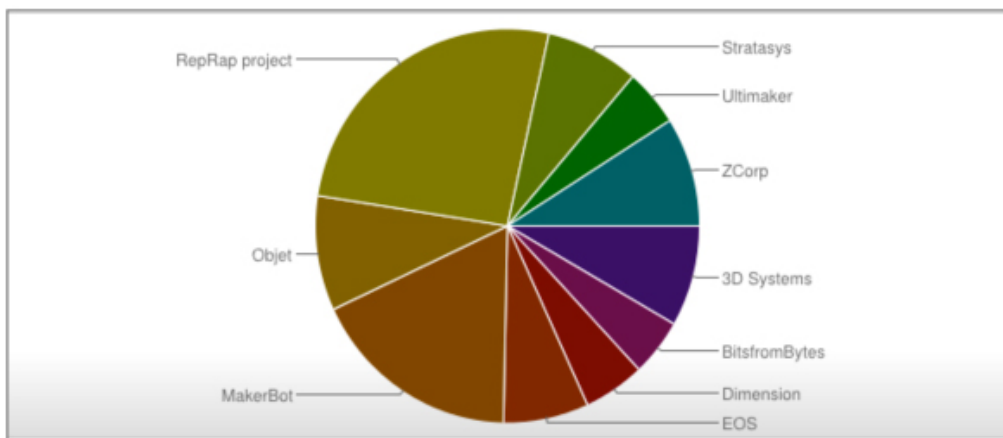


Figure 9: Which printers (which manufacturer) have you used?

RepRap was the most common printer among the participants. RepRap is also the first printer (of the listed “new wave” printers) that was available (since 2007). The relatively low amount of Makerbots can partly be explained with long market entry time, as the Makerbot has been around since early 2009. Some of the printers have just entered or are entering the markets.

3D printing services

The participants were asked: “Which of the 3D printing services have you used?” Again, the question contained predefined options: 3D Creation Lab; 3dprintuk; 3DProParts; Cubify Cloud Print; i.Materialise; Impression-3D; Kraftwurx.com; Ponoko; RedEye; Sculpteo; Shapeways; Solid Concepts; None; and, Other. If participants selected “other”, they were instructed that description would be provided.

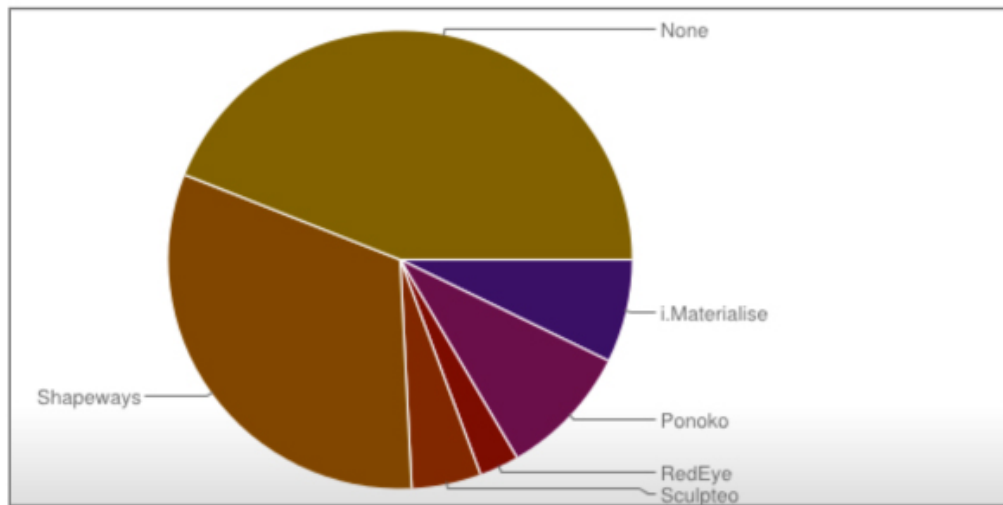


Figure 10: Which of the 3D printing services have you used?

Results suggest that among the participants who have used 3D printing services, Shapeways has taken a major share of customers. Ponoko was second most popular and i.Materialise third. It is notable, however, that a substantial amount of the respondents has not used any 3D printing service.

Several of the available services were not selected at all or only a few times. This result raises interesting questions: Who are those who selected “none” and why is their amount so large? Are they developers and not interested in or in need of printing services? To find some indications for answers, a cross-tabulation was created between this question and whether the respondent’s work was related to 3D printing or rapid manufacturing or not.

Those that do not work with 3D printing or rapid manufacturing seem to use 3D printing services slightly more often than 3D printing professionals. The situation is leveled if the two last lines are calculated together.

Is your work related to 3D printing or rapid manufacturing?	Has used printing services	Has NOT used printing services
No	47.2% (67)	58.7% (71)
Yes	27.5% (39)	20.7% (25)
Yes, but only partly	25.4% (36)	20.7% (25)

Table 7: Cross-tabulation between work relevance and printing service usage.

The same kind of cross-tabulation was created between this question and whether the respondent considered herself/himself to be a developer or end user.

Your involvement in 3D printing. Do you consider yourself:	Has used printing services	Has NOT used printing services
more like 'end user' of 3D printing	64.6% (84)	22.7% (25)
more like developer of 3D printing solutions (not getting paid though)	21.5% (28)	64.5% (71)
more like paid developer of 3D printing solutions	13.8% (18)	12.7% (14)

Table 8: Cross-tabulation between role in 3D printing development and printing service usage.

The cross-tabulation indicates that 3D printing solution developers who do not get paid, are part of the population who are not keen to use 3D printing services.

Why use printing services? The relatively high amount of respondents saying that the reason for using printing services is “to test how the services work” (see Figure 11, below) indicates that the services are still in their early days. The “ecosystem” is, for this part, not yet mature. On the other hand, a large group of respondents use the services for “professional quality printing”, thus confirming a demand for the services. Interestingly, publishing developed apps gets predominantly a “disagree” (as does downloading apps) — this may be another indication of the young age of the 3D printing ecosystem.

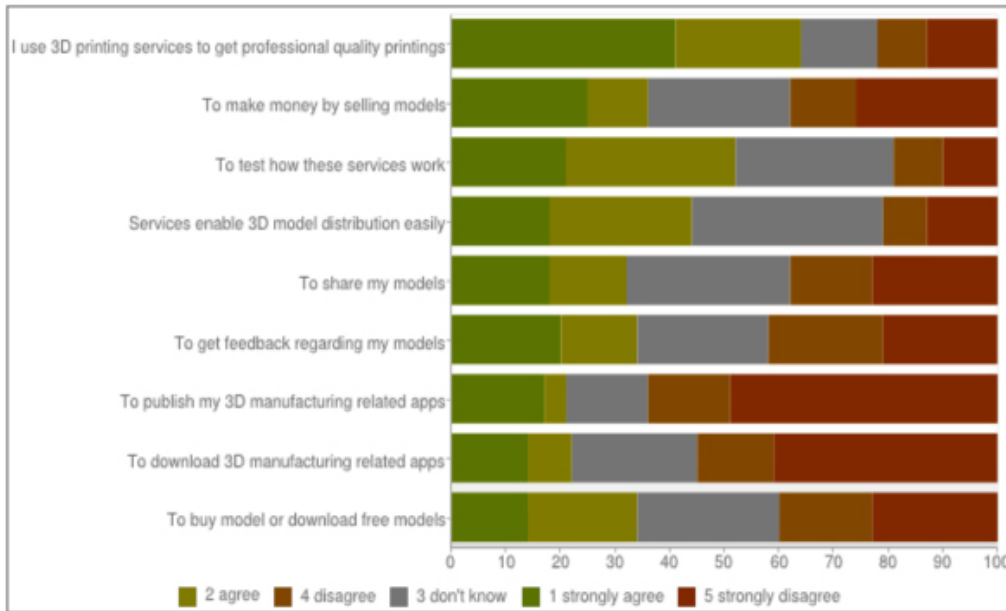


Figure 11: Reason to use 3D printing services.

Bottlenecks in creating a commons and indications for the future

On the basis of a wide review of literature on the sustainability of commons (both in terms of natural resources and in terms of software), Schweik [8] has presented a tri-partite division of variables influencing a developer's commitment to a project and, consequently, the sustainability of the project and the viability of the commons it creates and is based on. The three groups are the 1) technological (including factors like task granularity and modularity, software requirements, versioning system and bug tracking); 2) community (including factors like participant involvement, leadership, social capital, financing, marketing, group homogeneity); and, 3) institutional (operational, collective choice and constitutional level rules) attributes of the project.

The survey participants were asked to name a “most wanted feature” for the future of 3D printing and also to identify bottlenecks. On the basis of the answers, it seems that there are problems on the technological and community levels mentioned by Schweik, while the institutional level was

not mentioned. This is no big surprise, since 3D printing is a field evolving fast, and both the technology and the modes of operation are in flux.

Moreover, the physical nature of 3D printing brings in aspects absent from open source in terms of software. As presented by Malinen, et al. (2011), when peer production is intended to result in a physical artefact, there is more friction in the development cycle compared to open source software production: more time and resources are needed, copies are not perfect, bugs are potentially “deep” and debugging cannot be speeded up at will, and so on. Given identical files and equipment, a skilled and experienced user of 3D printing technology will tend to get better results, i.e., higher quality prints, than a beginner. Typically, the digital designs but not the physical end products are pooled to a commons. The friction and the absence of a commons for the physical end products are the two factors most clearly separating 3D printing from the models of commons-based peer production in terms of software.

Most wanted feature

Participants were asked “What is the most wanted feature you are waiting for to develop further or to emerge?” and given predefined list of options: Multicolored printing; Metal material printing; Glass material printing; Speed; Object quality; Ease of use; Ethernet connected printers; Better printer integration to CAD (or other similar) modeling software; Cheaper printer price; Cheaper material prices; and, Other.

Of the given options the most prevalent were:

1. Object quality (166)
2. Speed (119)
3. Cheaper material prices (115)
4. Metal material printing (108)
5. Cheaper printer price (106)

Comments (n=34) given in option “other” contained several other features such as: multi-material printing; value added services (painting/assembly); ceramic & resin printing; extruder that takes plastic pellets; a broad network supporting the needs of makers and fabbers; feedback loop for self-calibration

for improved quality; mixed material printing; and, bioprinter developments and better shipping (most likely related to printing services).

As mentioned above, unlike in commons-based peer production of software, copies in physical 3D printing are not perfect. The consequences are clearly seen in the answers regarding the “most wanted” feature: all of the items in the top five relate to the physical aspect of the process. This physical friction (to be included in group 1) of technological attributes in Schweik’s classification) also works against the creation of a knowledge commons. However, it can partially be alleviated through information sharing on discussion forums, IRC channels and so on.

Bottlenecks

Survey participants were asked what they see as the bottlenecks in development and in general in 3D printing: “What, in your opinion, is the greatest bottleneck for the development in 3D technology right now? — printers — materials — designs — social co-operation — Internet infrastructure — other infrastructure”. Answers were given as free text. Answers were classified to groups by hand. The number of answers was 221, from which a wide range of topics was found. The seven topics discussed below were most common.

Materials and quality. Current low-cost printers use different kinds of plastics as material. For some of the participants that is clearly not enough. Above all, the ability to use different metals for printing is most wanted. One of the participants crystallized this item in one sentence: “Only plastic is a drag, we need metal printers”. Also the quality of plastic prints was criticized “3D printers presently make stuff that looks like the cheapest crap and it is thus not very interesting”. Open source attempts to add metal to the list of materials is according to one respondent already there: “MetalicaRap team! (a electron-beam powder metal printer, in the spirit of the rewrap)”.

Great for hackers, not so much for consumers Usability and ease of use, reliability, lack of “Plug and Play” printers and ease of construction — these terms and concepts kept on coming up in the answers. Printers should be more easy to assemble, more user-friendly and reliable. The learning curve is felt to be too steep or as one survey participant puts it: “The level of knowledge and understanding needed about print quality vs print speed, temperature control of extruder and print bed, is quite an obstacle to new comers and does represent a bottleneck to take-up of 3D printing by people

without an appetite or aptitude for such aspects.” The steep learning curve is partly to blame for the lack of instant gratification. The comments do not relate just to printers, but rather to the whole printing process, which apparently needs to be (or at least needs to be felt) more simple. The solution might be usability related hardware and software improvements.

Software. As noted above, respondents experience hardware hard to use and learn. The same seems to apply to software as well. According to one respondent: “easy to use and open source 3d design software/tools and high/steep learning curve are a definite barrier to entry that requires a lot of research and/or mentoring/hand holding to overcome. Learning curve for 3d modeling for people unskilled in that area, yet still want to design and fabricate items via 3d printing.” Some of the respondents saw a big difference in usability between commercial and open source modeling software: “Open source CAD software that is as powerful and easy to use as the commercial varieties”. The biggest problems with (open source) CAD software is according to one survey participant: “Non-intuitive nature of 3D modeling/CAD tools due to chronically poor user interface design, lack of application-specific design metaphors, and lack of procedural modeling features.”

The lack of access to appropriate models was also seen as bottleneck. The Web is teeming with 3D models, but not all are printable, at least not with all (commonly) used low-cost printers. The software toolchain was also seen as too complicated. Some of the respondents gave examples of toolchain needed to do 3D printing: “I use a combination of SolidWorks, Sketchup, Meshlab, Blender, NetFabb, ReplicatorG, and Skeinforge. That is too many pieces of software” and “the workflow going from computer model to physical print is very convoluted, involving lots of different pieces of software.”

Public awareness. The industry is still seen as a niche, even though it is less and less so every day. A lot of articles have been written about 3D printing and the promise it holds. But has the message been correct? According to one participant the viewpoint could be different: “I think awareness of 3D printing among the general public ... particularly awareness of the cost and availability at the low end, rather than the general ‘look at the future’ articles”.

Lack of social co-operation. Lack of social co-operation was seen as bottleneck. Some of the respondents saw embodiment of poor social co-operation in lack of or insufficient documentation, lack of organization (in the RepRap community), lack of quality control and lack of test plans.

One respondent even said that “there’s an arrogance factor in the community that needs overcoming.” Fragmentation or diversity of solutions and tools was also mentioned by one respondent.

When it comes to fragmentation, it must be remembered that open source normally fosters competition between solutions and that competition (including the possibility and actuality of forking) is considered a sign of a healthy community. Some attempts to increase social co-operation are being made [9].

Patents. Protection of innovation as patents was raised as an obstacle by a few participants. The protection of intellectual rights has negative effect on open source driven development. One respondent formulated this problem as “major patents hold by few 3D printing companies (Open Source 3D Printing companies cannot grow due to patent risks, note for instance Canonical or Red Hat in SW business)”. However, it was not specified what the patents are or which area of development is held back because of patents.

Costs. Cost of printers and materials are too high for consumers. “We need lower prices to democratize 3D printing (and compete with mass manufacture) ... We need a 3d printer you can buy at Target for \$200, with easy to use re-fills”. Low-cost 3D printers should have “better range of material to print with and printers also should be able to print with multiple materials”. One of the respondents noted that there are “still not enough companies and not enough competition on the market.” That might be one reason for situations where it is: “impossible to buy resources/spare parts in local shops”.

In sum. The first three mentioned bottlenecks — materials and quality, usability, software (also the issue of costs, lower on the list) — are, again, related to the physical nature of 3D printing, and, consequently belong in Schweik’s group 1. The next two — lack of public awareness and social co-operation — clearly belong in group 2, i.e., community attributes. Interestingly, issues of the third group, institutional attributes, were not high on the list of concerns. This may indicate that 3D printing as a form of peer production is still in the early days where the institutional level practices and models are being formed and are not yet in the focus of attention.

The influence of the physical aspects of 3D printing on commons-based peer production

It seems that in terms of creating and upholding a commons, the friction introduced by the physical nature of 3D printing does not fundamentally change the mode of operation compared to open source software. The physicality of the production makes things slower and more expensive, but the commitment to open sharing of the designs, improvements on printers and knowledge functions in largely similar fashion. However, the fact that the end results, the printed artefacts themselves, are not pooled into a commons, is a possible game changer. At least for the moment, in order to get good quality prints in a timely fashion, many participants use 3D printing services. In the case of software, people also resort to third-party providers of open source code, such as the Linux operating system, but there the reason is not the quality of the product, but rather additional services. Therefore the prevalence of the use of 3D printing services can be seen as an indication of the way in which the physical nature of 3D printing effects the creation of a commons. It is possible that the gap in quality between the service providers and widely available desktop 3D printers will diminish in the future, so that the role of the printing services will change, but it is also possible that the gap will remain, as both progress. This will be one of the interesting developments to follow, in the future.

Discussion and conclusion

In the survey, the average member of the 3D printing/manufacturing community member is an over 30-years-old male, living in Europe (50.3 percent) or North America (37.7 percent) and has a college degree (56 percent) or at least some college studies.

“Intrinsic” enjoyment (“for fun”) and direct practical benefit (“scratch an itch”) are the two biggest drivers of open source hackers. According to the survey, there is no one predominant “itch to scratch”, rather what we have is a wide variety of purposes and uses. As a whole, the community has a strong open source component (and the basic demographics correspond closely with the demographics of open source communities in previous studies), and many of the participants identify with both the maker movement and peer production. A typical member of the ecosystem identifies himself more strongly with the maker movement than with peer production. Nearly half of

the respondents are not (or have not been) members of any DIY community such as hackerspace, makerspace, or diybio.

Most notably, the use of 3D printers is rapidly growing since 2005. The growth and the corresponding “unsettled” or “early days” nature of the community is clearly visible in the bottlenecks and desired future developments identified by the participants. The fast evolving landscape provides a fertile ground for both social and technological improvements.

Immature “pre-ecosystem”. The buzzword “ecosystem” has been overused during the past few years. However, it is one possible concept to use in order to catch the multitude of 3D printing participants — hardware providers, software developers, volunteer community, service providers and end users — with one word.

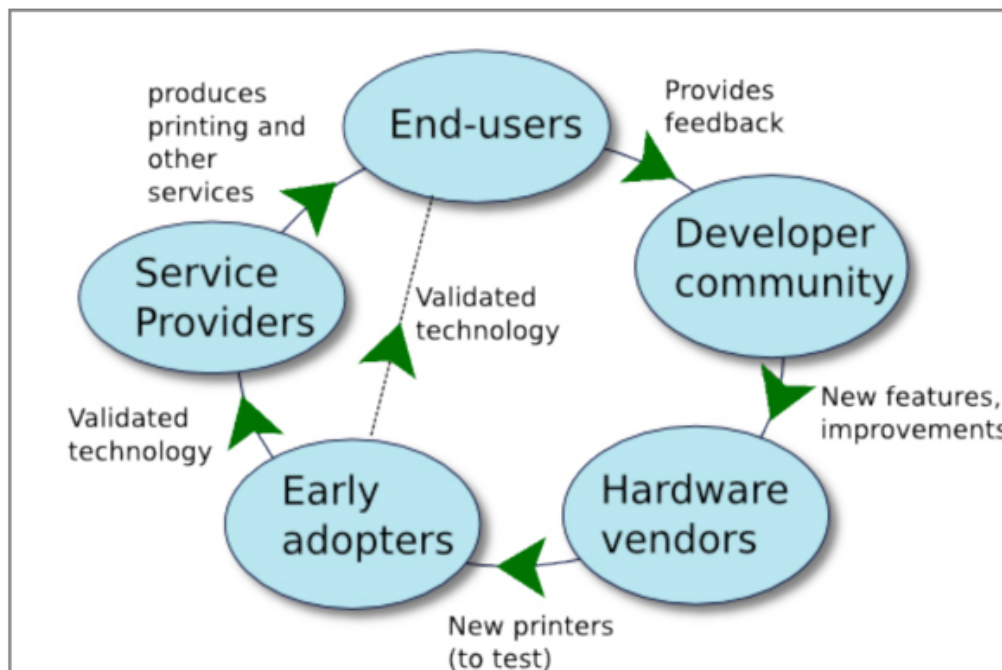


Figure 12: Reason to use 3D printing services.

The 3D manufacturing ecosystem is still immature in nature, as can be seen from the results in several ways. Firstly, some of the participants see lack of organisation (especially in RepRap) as a bottleneck. As argued, e.g., by Schweik (2013), lack of organisation is not just lack of bureaucracy. It causes several other unwanted results such as lack of proper documentation,

lack of quality control and lack of test plans. In other words, implementing additional social co-operation models could solve some of the issues and thereby increase the maturity of the ecosystem. Secondly, 3D manufacturing processes are still too complicated (require too many pieces of at least somewhat separate software). Thirdly, usability and reliability are poor. This is visible in open source CAD/CAM software, which are lagging behind in features and usability compared to commercial software and in the printers themselves, which should be more easily assembled, used and more reliable.

Simple ecosystem model. Based on the survey and observation of the community, a preliminary ecosystem model can be sketched, as seen in Figure 12. The ecosystem parts are: end users, early adopters, developer community, hardware vendors and service providers.

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6.3 Cultures of sharing in 3D printing: what can we learn from the licence choices of Thingiverse users?

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Abstract. *This article contributes to the discussion by analysing how users of the leading online 3D printing design repository Thingiverse manage their intellectual property (IP). 3D printing represents a fruitful case study for exploring the relationship between IP norms and practitioner culture. Although additive manufacturing technology has existed for decades, 3D printing is on the cusp of a breakout into the technological mainstream – hardware prices are falling; designs are circulating widely; consumer-friendly platforms are multiplying; and technological literacy is rising. Analysing metadata from more than 68,000 Thingiverse design files collected from the site, we examine the licensing choices made by users*

and explore the way this shapes the sharing practices of the site's users. We also consider how these choices and practices connect with wider attitudes towards sharing and intellectual property in 3D printing communities. A particular focus of the article is how Thingiverse structures its regulatory framework to avoid IP liability, and the extent to which this may have a bearing on users' conduct. The paper has three sections. First, we will offer a description of Thingiverse and how it operates in the 3D printing ecosystem, noting the legal issues that have arisen regarding Thingiverse's Terms of Use and its allocation of intellectual property rights. Different types of Thingiverse licences will be detailed and explained. Second, the empirical metadata we have collected from Thingiverse will be presented, including the methods used to obtain this information. Third, we will present findings from this data on licence choice and the public availability of user designs. Fourth, we will look at the implications of these findings and our conclusions regarding the particular kind of sharing ethic that is present in Thingiverse; we also consider the "closed" aspects of this community and what this means for current debates about "open" innovation.

Introduction

A growing literature in economics and social science has explored the practices of information exchange among online communities. A strong theme within this literature is that open cultures—characterised by reciprocal sharing, weak IP, and open flows of information among practitioners—are conducive to technological innovation. In Benkler's influential analysis, the end result is 'a flourishing nonmarket sector of information, knowledge, and cultural production... subject to an increasingly robust ethic of open sharing, open for all others to build on, extend, and make their own' (Benkler 2006, p.7). This phenomenon has been the focus of much recent research on collaborative production models, with numerous studies appearing about wikis, open-access publishing, free software and open science (e.g. Chesbrough 2006, Nielson 2011, Suber 2012, Anderson 2012, Hatch

2013).

One lesson from this literature is that sharing practices are context-dependent. Sharing is a social practice shaped by a range of variables, and sharing practices differ from community to community and from technology to technology (Kennedy 2013). Infrastructural issues, cultural factors and legal frameworks, both explicit and implicit, play a role in shaping the way we share information. It is therefore necessary to consider the diverse norms, values, structures and systems that emerge around particular forms of sharing. Scholars in various disciplines have taken up this challenge by documenting specific (rather than universal) aspects of sharing practice, such as the regulatory frameworks that govern conduct and the variable properties of technological platforms (e.g. Berdou 2011, Currie, Kelty and Murillo 2013, Schweik and English 2012, Suzor 2012).

This article contributes to the discussion by analysing how users of the leading online 3D printing design repository Thingiverse manage their intellectual property, and in doing so exchange information. 3D printing represents a fruitful case study for exploring the relationship between IP norms and practitioner culture. Although additive manufacturing technology has existed for decades, 3D printing is on the cusp of a breakout into the technological mainstream—hardware prices are falling; designs are circulating widely; consumer-friendly platforms are multiplying; and users’ technological literacy is rising. Thingiverse, as the leading website for 3D printing design-sharing, is playing a central part in this process.

As a contribution to the emerging literature on Thingiverse and its role in the 3D printing innovation system (Rayna et al 2014, Kyriakou et al 2012, Rideout 2011), this article analyses some recent IP-related controversies within 3D printing communities and examines Thingiverse’s contested position within this community. In particular, we look at how intellectual property, in the form of 3D printing design files, is ‘shared’ in two ‘directions’: ‘horizontally’ among Thingiverse users; and ‘vertically’ between those users and MakerBot, Thingiverse’s parent company. By ‘sharing’ we mean non-monetary exchange, either one-way or reciprocal, of design files between Thingiverse users. Such activities are usually restricted by traditional or orthodox uses of copyright law but the ‘sharing’ of material and software in these ways is a characteristic feature of maker and hacker communities (Coleman 2012).

We conduct this examination of sharing in Thingiverse using two methods: a legal analysis of the intellectual property provisions in

Thingiverse’s terms of use and the disputes which have arisen around them; and an empirical research component comprising an analysis of metadata collected from design files hosted by Thingiverse which reveal the licensing choices made by Thingiverse users. We will discuss what the insights obtained from these two methods may suggest about attitudes towards intellectual property and sharing within this rapidly growing online community of practice.

The paper has three sections. First, we offer a description of Thingiverse and its place in the 3D printing ecosystem. Second, we examine the prevalence of vertical intellectual property sharing between MakerBot and Thingiverse users, noting in particular the issues that have arisen regarding Thingiverse’s Terms of Use and allocation of intellectual property rights. The third section considers horizontal sharing among Thingiverse users. Here we discuss the different types of secondary licences available to Thingiverse users when uploading their 3D printing designs, and present our empirical analysis of Thingiverse metadata. Throughout our discussion we explore the specific kinds of sharing ethics that are present in Thingiverse, the ‘closed’ as well as ‘open’ aspects of its user community, and what all this means for current debates about open innovation: themes that we draw together in the paper’s Conclusion.

Thingiverse’s place in the 3D printing ecosystem

Additive manufacturing technology has long been a feature of aerospace, medical, manufacturing and defence industries. Within the last few years the technology has crossed over into the consumer space, with household-oriented printers coming onto the market at ever-lower prices. The continuing boom in public interest has led to significant commercial investment, venture capital speculation, and consolidation of what was previously a fragmented sector. It has also created a tsunami of hype, with business magazine *The Economist* heralding the arrival of a ‘third industrial revolution’ (21 April 2012).

In this paper, our focus is on one small, yet crucial, part of the 3D printing ecosystem: the online design repositories that allow 3D printing enthusiasts, both professionals and non-professionals, to exchange design files. These

repositories play a crucial role in linking experts with DIY enthusiasts who may not have the necessary skills to create complex Computer Aided Design (CAD) files. Rayna et al (2014) provide a brief typology of online 3D printing platforms after identifying 14 examples. The authors suggest the first mover in the space was Ponoko in 2007, and that the market grew following this. Table 1 provides examples of the diversity of 3D printing sites. These sites perform a mix of functions including design supply, hosting, customisation, co-creation and crowdsourcing, as well as offering print-on-demand and other bespoke manufacturing services.

Thingiverse, owned by MakerBot, is the largest and most important of the 3D printing repositories. MakerBot's own history can be traced back to the RepRap project. Founded in 2007 by Dr Adrian Bowyer, a Senior Lecturer in mechanical engineering at the University of Bath, RepRap was an initiative to develop a 3D printer that could re-print most of its own components. The RepRap project released all of the designs it produced under the GNU General Public licence, in line with free software principles. Designers were free to modify RepRap designs so long as they shared their creations back with the RepRap community.

However, three of the organisers of the NYC Resistor Hackerspace in Brooklyn—Bre Pettis, Zach Smith and Adam Mayer—had other ideas. They 'threw out the self-replication requirement' of RepRap (Courtland 2013), and focused their energies on developing a consumer-friendly printer. Their company, MakerBot Industries, was founded in January 2009, and had sold several thousand printers by 2011. In 2012 it attracted US\$ 10 million in venture capital funding and the following year the company was bought, with much fanfare, by the 3D printing giant Stratsys (Stratasys, along with 3D Systems, is one of the 'big two' 3D printing corporations). Stratasys paid US\$ 400 million in stock, with the consequence that MakerBot's founders became millionaires overnight.

Thingiverse plays the role of the design hub within MakerBot's 3D printing ecosystem. Users can post and collaborate on design files for 3D printable 'Things', and find new and interesting uses for their MakerBot printers. Thingiverse has become the leading repository of user-submitted design files and the world's largest online 3D printing community. Unlike some of its competitor sites, Thingiverse is a free site inasmuch as users do not pay a fee to access it nor does it host external advertising. Its commercial function for MakerBot is to add value to printer sales by offering a free and easy way for users to find designs they can print off at home. In the same

Table 9: 3D printing design sites

Thingiverse (http://www.thingiverse.com)	The most popular 3D printing repository. Owned by MakerBot. Designs are free to upload and download. Has received the most media attention for Digital Millennium Copyright Act (DMCA) take-down notices.
Shapeways (http://www.shapeways.com)	A leading commercial site that combines repository and print-on-demand functions. Users can create online shopfronts offering made-to-order products, printed by Shapeways that can be delivered to customers in finished form.
Ponoko (http://www.ponoko.com)	The first website to launch a service in this area, in 2007. Ponoko continues to operate with both free Creative Commons designs, and a paid service for ‘creators and consumers’
Cuboyo (http://www.cuboyo.com)	A commercial site offering paid downloads of user-generated 3D objects. Cuboyo takes a 30 percent cut of the sale price, with the remaining 70 percent going to the seller.
MakeXYZ (http://www.makexyz.com)	MakeXYZ acts as an intermediary between fabricators and end users. The site enables you to ‘find makers in your neighbourhood that are ready to help you make something’.
MyMiniFactory.com (http://www.myminifactory.com)	A mix of free and paid design downloads. The site is connected with iMakr, which opened a physical store in London in May 2013. Offers 3D print on demand, and 3D design requests.
Repables (http://www.repables.com)	Free, open-access repository founded by Gerrit Coetzee. Aims to be a non-commercial alternative to proprietary repositories like Thingiverse.
Fabster (http://www.fabster.com)	A showcase for 3D printing designs, based on a popular Facebook page. Allows companies and artists to display their 3D printed portfolios ‘within a mutual territory for all’. Does not offer downloads.
Yeggi (http://www.yegi.com)	Launched in April 2013 as a ‘meta-library’ or aggregator where makers can search for designs across a number of the other depositories listed above—‘We collect data from all 3D communities and marketplaces offering 3D models to print’

way that iTunes adds value to iPhone purchases, but generates little profit in its own right, the site is ancillary to MakerBot's main line of business—sales of 3D printing hardware.

There is a distinct commercial logic underlying Thingiverse's culture of sharing. Users of the site are part of a thriving, 'open' community of practice, but their activities are organised in ways that align with MakerBot's commercial ambitions. Thingiverse files are 'encouraged to be licensed under a Creative Commons license' (MakerBot 2014(b)). To quote Bre Pettis: '[i]f you're not sharing your designs, you're doing it wrong' (The Economist 2011). The community feel is further espoused on the website: 'We're hoping that together we can create a community of people who create and share designs freely, so that all can benefit from them' (MakerBot 2014(a)). This communitarian aspect to Thingiverse is a major selling point for MakerBot; it markets its hardware on the basis of this vibrant online community.

As our brief account of Thingiverse has demonstrated, the site mobilises a large and growing user base and attempts to align ideas of community, creativity and commerce—framed within the concept of 'sharing'—in ways that are commercially useful to MakerBot. In the following two sections, we will interrogate precisely what this sharing of intellectual property in Thingiverse looks like, in two directions: vertically between MakerBot/Thingiverse and users; and horizontally among users.

Sharing intellectual property vertically

In this section, we examine the sharing of intellectual property taking place between MakerBot/Thingiverse and Thingiverse users via an analysis of the MakerBot's policy decisions regarding intellectual property transfer between the company and users, and the disputes arising around these decisions. These situations of conflict over intellectual property, which are not unusual in the context of for-profit Web 2.0 platforms, suggest that MakerBot's 'sharing' rhetoric is confined to users sharing their 3D printing designs 'upwards' with the company, while MakerBot is much less willing to share its intellectual property 'downwards' with users.

The Replicator 2 controversy

The first sharing controversy involving MakerBot relates to the Replicator 2 3D printer, the infamous fork of the original open-source RepRap project, which MakerBot released in September 2012. Although it incorporated a number of new features compared to its predecessor, the printer was not

received positively by the 3D printing community. Unlike previous MakerBot printers the Replicator 2 was closed and did not follow the principles of open hardware—i.e. that the ‘design is made publicly available so that anyone can study, modify, distribute, make, and sell the design or hardware based on that design’ (OSHWA n.d.). The open hardware movement can be conceptualised as an extension of the free/libre/open source software ideology to physical technological artefacts, designed and disseminated in an ‘open’ fashion. The difference with the Replicator 2 was that MakerBot did not publish details of how the printer was designed. To accompany the new printer, MakerBot also released new 3D printing software that did not comply with open source principles, attracting further criticism.

On the MakerBot blog, Bre Pettis defended the company’s actions: For the Replicator 2, we will not share the way the physical machine is designed or our GUI because we don’t think carbon-copy cloning is acceptable and carbon-copy clones undermine our ability to pay people to do development. (Pettis 2012)

Among the many reasons cited, Pettis focused on the idea that ‘running a business is complicated’ and required MakerBot to keep control of the core technology. It seemed that the Replicator 2 was aimed at a different demographic than those tinkerers involved with the open hardware movement—namely, people ‘who want to make gorgeous models instead of hack the machine’. Unsurprisingly, MakerBot’s actions caused a great deal of controversy within the 3D printing community. The decision to become closed source was criticised by Josef Prusa (2012(b)), a former MakerBot employee, as well as Zach Smith, a founding member of MakerBot who had subsequently left the company. Smith (2012) refers to this departure from open to closed source as the ‘ultimate betrayal’, underscoring the bitter disputes about intellectual property and sharing norms that have become part and parcel of the 3D printing boom.

Occupy Thingiverse

2012 also saw the second controversy involving MakerBot and Thingiverse, the Occupy Thingiverse incident. This controversy has its origins in Thingiverse’s 2012 decision to alter its Terms of Use (to which all users must agree if they wish to open a Thingiverse account) to include the following:

You hereby grant, and you represent and warrant that you have the right to grant, to Company and its affiliates and partners, an irrevocable, nonexclusive, royalty-free and fully paid, worldwide license to reproduce,

distribute, publicly display and perform, prepare derivative works of, incorporate into other works, and otherwise use your User Content, and to grant sublicenses of the foregoing, solely for the purposes of including your User Content in the Site and Services. You agree to irrevocably waive (and cause to be waived) any claims and assertions of moral rights or attribution with respect to your User Content. (MakerBot (c))

This marked a significant departure from the previous Terms of Use, which had a more narrow scope, were revocable in nature, and concerned Thingiverse's rights to use the content uploaded by users across its platforms:

However, by posting, uploading, inputting, providing or submitting your content to Thingiverse.com, you are granting Thingiverse.com, its affiliated companies and partners, a worldwide, revocable, royalty-free, non-exclusive, sub-licensable license to use, reproduce, create derivative works of, distribute, publicly perform, publicly display, transfer, transmit, distribute and publish that content for the purposes of displaying that content on Thingiverse.com and on other Web sites, devices and/or platforms (Walter 2012).

One major difference in the wording is that the previous Terms had a more narrow scope than their replacement, and seemed to restrict the use of user designs to similar platforms to Thingiverse. The consequence of this appears to have been that MakerBot was limited in its ability to incorporate designs uploaded to Thingiverse into 'closed' hardware products, such as their 3D printers. The change in language, however, seemed to allow Thingiverse to use those designs for its own commercial purposes, as well as to assert moral rights over any design uploaded to the platform. One of Thingiverse's lawyers defended the moral rights waiver, stating that these rights were not part of American copyright law and that the purpose of the waiver was to 'lend certainty' to the licences upon which MakerBot relies to operate Thingiverse—to prevent, for instance, users claiming that their moral rights against the 'mutilation' of a work had been infringed (McCarthy 2012). Interestingly, Thingiverse's actions were also framed within a discourse of sharing: they suggested the assertion of moral rights by the original users would be 'fundamentally inconsistent with the intention of Thingiverse, which is to share things and their derivatives'. Reference was also made to the fact that these updated Terms of Use were 'structured similarly to any large website that hosts user-content'.

Yet Thingiverse's assertion that moral rights were not part of US copyright law was inaccurate—some operation of moral rights had been recognised in case-law, and then statutorily in the Visual Artists Rights

Act 1990 (Rosenblatt 1998), which was enacted to implement some moral rights provisions of the Berne Convention that was eventually signed by the US in 1989. However the bigger issue was the widespread disquiet within Thingiverse’s maker community, many of whom took to the Internet to argue that Thingiverse was no longer ‘open’, and that the new Terms betrayed the community ethos. This user backlash came to be known as Occupy Thingiverse. The movement was initiated by the aforementioned former MakerBot employee Josef Prusa (2012(a)), who wrote an open letter to Bre Pettis which drew attention from other Thingiverse users (Prusa 2012(b)). The Occupy Thingiverse meme quickly gained traction, and many users chose to remove their designs from the Thingiverse site so that they might retain more control over them. Following Prusa’s suggestion, many of these users reposted their designs at GitHub, a popular data repository for open-source projects (Molitch-Hou 2013). Forums were created to discuss alternatives (RepRap 2013).

It is worth noting that Thingiverse’s Terms of Use take precedence over any of the more ‘open’ licence choices that users make on the site. While Thingiverse still gives users a choice of licence (a point we will discuss in more detail shortly), this is a secondary licence on top of the primary licence over uploaded content that this language in the Terms of Use grants to Thingiverse. The licence with Thingiverse is a standard form, non-negotiable contract—users must sign up to Thingiverse and accept these terms, or not have a Thingiverse account at all. The offending language which led to the Occupy Thingiverse movement is still present in Thingiverse’s Terms of Use at the time of writing.

Ongoing patent problems

The Replicator 2 and Occupy Thingiverse controversies demonstrate MakerBot’s willingness for users to share their creations ‘upwards’ as well as horizontally between users, as the MakerBot business model requires. This can be seen plainly in another recent controversy regarding MakerBot patents.

In mid-2014 it emerged that MakerBot had filed various 3D printing-related patent applications in the US (Benchoff 2014). The two patents that received the most attention related to technical improvements in 3D printer hardware—specifically, a quick-release extruder mechanism and a plate-leveling device. While the fact that MakerBot is patenting new elements of its hardware design angers many within the 3D printing community, who remember the open-source roots of the RepRap project, in the context of

MakerBot’s increasingly aggressive IP policy such patent applications are not particularly surprising. However, there was an added degree of intrigue in this instance because similar innovations had previously been published under open licences by enthusiasts. Ironically, one of these—the quick-release extruder—appeared on Thingiverse months earlier. This prompted accusations that Makerbot was stealing the ideas of its users. MakerBot was quick to defend itself, however, arguing in a blog post that its patent applications predate the user-designed versions. It offered no apology for its patenting practices, acknowledging that filing patents was not ‘optimal’ but was an intrinsic part of ‘being a competitive company’.

The general reaction from community members to these revelations again was predictably negative, with some members advocating a boycott of Thingiverse, and others resisting the call to boycott the site (Molitch-Hou 2014). Those who were against a boycott noted that the process of posting design files on Thingiverse generated evidence that the user had created and uploaded that design on a certain date—which could be used to oppose patent applications such as those by MakerBot.

Applications for patents are not the same thing as the grant of a patent. The patent may not be granted on a number of grounds. Specifically, successful patent applications must fulfil various conditions, including the elements of novelty, non-obviousness (in the US — ‘inventive step’ in Europe) and usefulness (in the US — ‘susceptible of industrial application’ in Europe). However, chronology here is key. While these allegations of MakerBot ‘stealing’ users’ designs in order to patent them may well turn out to be a red herring, this course of action that MakerBot is taking by filing patent applications demonstrates a further distancing from the company’s ‘open’ roots and another point of conflict with its user community.

Together, these three examples — the RepRap controversy, Occupy Thingiverse, and the hardware patents — demonstrate the vertical sharing of intellectual property that goes on in Thingiverse between MakerBot and users is largely one-directional. While users are encouraged to upload and share their designs on Thingiverse using a Creative Commons or free software licence (discussed in more detail in the following section), MakerBot is no longer sharing its intellectual property in the form of 3D printing design files back with the community, and indeed has even been accused of misappropriating the creations of Thingiverse users.

Sharing intellectual property horizontally

So far in the article we have considered various aspects of intellectual property regulation on Thingiverse, including some recent controversies related to this issue. Some of these aspects relate to Thingiverse as a platform—how it is organised, how it mobilises certain kinds of practices, and its role within MakerBot’s sphere of commercial ambition. These aspects are all bound up with what Gillespie (2010) calls ‘the politics of platforms’. We now turn to the question of user practices on Thingiverse — specifically, what kinds of licensing options users choose when they upload their 3D printing designs to the site. In this section we explore what these choices tell us about how cultures of sharing are framed, understood and practiced among Thingiverse users, i.e., in the horizontal, peer-to-peer dimension of sharing, as opposed to the vertical sharing dimension discussed in the previous section.

For users to upload a design to Thingiverse, they must firstly have a Thingiverse account, and agree to the Terms of Use (as discussed above). The Terms of Use are a standard form agreement and there is no scope to negotiate with Thingiverse: users must either take them or leave them. When uploading a 3D printing design file to the platform, the user can add various pieces of information about the design, such as: its name; a brief description of the Thing; a category from a drop-down list, including such terms as art, fashion, gadgets, hobby and learning; and instructions as to how the creator made the Thing. The user can also link their creation to another, pre-existing Thing if it was ‘inspired by, derived from, or a remix of’ that other Thing. Finally, the user also has a choice of secondary licence to attach to the Thing from a drop-down list so that the user can ‘choose how you want your thing to be used by others’.

These secondary licences chosen by users are the focus of our discussion here. Creative Commons licences feature heavily in the drop-down list of options presented to users. Indeed, Thingiverse actively encourages users to list their designs under one of these licences, stating that licensing under this banner means ‘that anyone can use or alter any design’ (MakerBot 2014(b)). While such an arrangement seems conducive to open sharing among users, there are a number of issues here that warrant attention.

Creative Commons (CC) licensing provides a unique combination of conditions giving users a form of copyright that is more tailored to their personal needs. They can be seen as a level to which the user wishes to free their works into the public domain, reflecting the extent to which they

reserve, or do not reserve, their rights. In this sense, CC licensing can be seen as an unorthodox use, or ‘hack’, of intellectual property law. Traditionally, copyright has worked by granting the creator of a work a bundle of exclusive rights over that work, governing how the work is shared, copied and modified — and usually this cannot be done without the permission of the copyright holder (which is not necessarily the original creator as these rights can be assigned to others). CC licensing differs from this model inasmuch as the copyright holder can choose to allow the future distribution of copies and modified versions of the original work without users needing to ask specific permission, while requiring that these same rights are preserved in any future modified versions.

As mentioned above, when uploading a file, Thingiverse contributors are asked to attach a secondary licence to their design file, which includes the core suite of six CC licences (Creative Commons n.d.(b)). This possibility to choose a licence acts as a flexible tool to respond to the needs of creators and the demands of consumers. The licences are grouped under four ‘modules’, each representing the extent to which certain rights are (or are not) withheld. The four modules are: Attribution (there are no restrictions on what others can do with the creation so long as the original creator is acknowledged); Non Commercial Use (the original creation can be used in any way so long as it is not commercial); Share Alike (the original creation can be used in any way so long as derivative creations are licensed under the same terms); and No Derivatives (the original creation can be redistributed so long as it is passed along unchanged and in whole). Combinations of these four modules result in six unique licences: Attribution (CC BY); Attribution-ShareAlike (CC BY-SA); Attribution-NoDerivs (CC BY-ND); Attribution-NonCommercial (CC BY-NC); Attribution-NonCommercial-ShareAlike (CC BY-NC-SA); and Attribution-NonCommercial-NoDerivs (CC BY-NC-ND). As previously noted, when uploading a file on Thingiverse, users select this secondary licence from a drop-down menu. The default option is CC BY and the second option down on the list is CC BY-SA. Interestingly, as can be seen on the table below, these are the two most popular licences chosen by users in our sample, and it may well be that many users simply go along with the pre-selected option or the second choice, rather than considering the other options.

The CC licences display varying degrees of ‘openness’. The most open CC licences (based on the extent to which intellectual property is licensed in a non-restrictive way) are those which only require attribution to the original

creator when using or remixing the material—the CC BY (Attribution) licence. Accordingly, the most restrictive CC licences would be those that do not allow derivative works (no adaptations and no changes) and do not allow the works to be used for commercial purposes. Also important is the ‘Share Alike’ restriction permitting derivative works but only if they are further licensed under the same terms as the original work. For example, if the original work is not to be used for commercial purposes, then neither is the derivative. This kind of licence is known as ‘sticky’ as it ‘sticks’ to all future, modified versions of the original work. The two least ‘open’ licences with the lowest ‘sharing’ factor would be CC BY-NC-SA (Attribution-NonCommercial-ShareAlike) and CC BY-NC-ND (Attribution-NonCommercial-NoDerivs).

Thingiverse also gives its users the choice to use a CC-Public Domain Dedication licence, although CC has officially ‘retired’ this licence. Its successor is the CC0 ‘No Rights Reserved’ dedication, by which creators of copyrighted material can waive their interests in those works and ‘place them as completely as possible in the public domain, so that others may freely build upon, enhance and reuse the works for any purposes without restriction under copyright or database law’ (Creative Commons n.d(a)).

Moreover, Thingiverse users can choose from a number of other, non-CC, licences, which are derived from free software licences: while broadly similar to CC licences, these are designed to deal with different situations. CC licences typically apply to ‘traditional’ or ‘conventional’ types of copyrighted material such as music, film, photography and literature—and also apply to websites. Free software licences typically apply to software, which has been protected by copyright in the US since 1980 when computer programs were defined as falling within the ‘literary works’ category. The inclusion of software code in categories of copyright protection has been controversial (Samuelson 1988), as has the recognition by US courts since the 1970s that software could also be patentable (which is not the case for more conventional literary works). In response to this software ‘land grab’, free software licences have been created and used to make the works accessible and allow others to build upon them. Thingiverse offers a choice of three free software licences for uploaded files in addition to the CC options: two GNU licences—GNU General Public Licence (GNU-GPL) and GNU Lesser General Public Licence (GNU-LGPL)—and the BSD (Berkeley Source Distribution) licence.

In addition to the choice of secondary licence, Thingiverse users also have the ability to make their files ‘public’ or ‘private’. ‘Public Things’ are publicly available to see and download from Thingiverse’s website. ‘Private Things’

are Things which have not yet been officially published, because they are still in draft form or because the person uploading the file does not wish to make it publicly available for some other reason. There is also a box that can be ticked to signal that a Public Thing is a Work in Progress, to alert others to the fact that it may be updated in some way in the future but is still available publicly in its current form.

By analysing these user choices, both of secondary licence and whether a Thing is public or private, we can gain some insight into the motivations of Thingiverse users through revealed preference, and thereby assess the prevalence of horizontal sharing practices among Thingiverse users. To this end, in 2013 we conducted an empirical analysis of the metadata of 117,450 Thingiverse Things, primarily to discover information about users' choices of secondary licence and the prevalence of Public and Private Things. Thingiverse has an open API which can be used to collect metadata about Things, but in practice it proved complicated to use for our purposes, mostly due to a lack of code examples and insufficient documentation; so we chose to screen-scrape with a custom-built Ruby program, which extracts information from the site by parsing its web pages.

Figure 1 shows how the number of designs on the site has grown since 2011, as determined by the upload date of Things. There is a noticeable increase around Jan-Feb 2013. One reason for that, aside from growing popular interest in 3D printing technology, might be the fact that in January 2013 Thingiverse launched a new online application, MakerBot Customizer, which allowed users to create easily new things from parametric designs.[1] Another possible reason is the counter-effect of the negative publicity around Thingiverse discussed above.

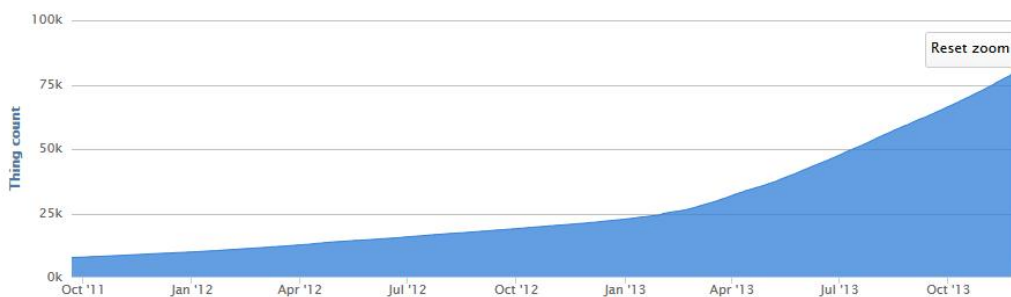


Figure 1: Number of Things in Thingiverse

The data scrape, conducted between 16 and 18 August 2013, collected and

stored metadata about 117,450 Things—both Public and Private—dating from Jan 2009 to Aug 2013. Private Things could be coded for their status only, while Public Things offered a wealth of other data, including the database identifier, author handle, secondary licence choice, creation date, how many times the Thing had been commented on, how many times it had been viewed, and any tags the creator had attached to it. This scrape also revealed number of ‘makes’ (how many times other Thingiverse users have reportedly printed the item), the number of collections (how many collections, i.e. user-curated categories like ‘Keys’ and ‘Vases’, in which the given Thing appears) and number of remixes (how many times the Thing has been used as starting point for derived works). There are of course limitations to such an approach, which provides a wide-angled overview of IP practices rather than the deep analysis that might result from other methods, such as community ethnographies or sample studies.[2] These limitations notwithstanding, the scrape uncovered a number of insights into Thingiverse’s operation and use.

Table 10: Top 5 secondary licence choices among Thingiverse users, 2013

Attribution (CC BY)	36%
Attribution- ShareAlike (CC BY-SA)	36%
Attribution-NonCommercial (CC BY-NC)	10%
Attribution-NonCommercial-ShareAlike (CC BY-NC-SA)	8%

Our first finding, based on an analysis of metadata from the 68,618 Public Things hosted on Thingiverse, was that the CC licences were by far the most popular licences used. The top 4 licences were all CC, representing 89.84 per cent of all Public Things (see Table 2). Interestingly, the two most popular choices—Attribution (CC BY) and the ‘sticky’ Attribution-ShareAlike (CC BY-SA)—both allow commercial usage. As mentioned above, the order of popularity here is fairly similar to the order in which licence options are listed in Thingiverse’s licence drop-down menu, so it is possible that many users do not venture far down the list or are happy to go with the initial options.

Further analysis of the remixed objects tells us more about how these licence choices interact with user practices. Licence choices for these objects are illustrated in Figure 2. Note that, while the number of CC BY (blue

circle) and CC BY-SA (grey circle) licensed Things are almost the same, CC BY licensed Things are remixed far more often (10,569 times) than CC BY-SA (7,225) Things. Conversely, many more CC BY-SA (grey circle) licensed Things have been made than CC BY (blue circle) licensed Things. In other words, non-sticky licences seem to be preferred when it comes to remixing 3D printing designs. This would be in line with the ‘experimental’ quality of these designs, whereas sticky licences may be associated more with finished works ready for presentation to, and construction by, other users.

The most frequently remixed item we found was a customisable iPhone case, licensed under CC BY, which had been remixed 2,153 times. The licence used in the example is not sticky, but does require attribution. In theory this gives remixers more freedom in selecting other licences for their work, particularly compared to the commonly used CC BY-SA licence, which requires that derivative works be licensed under ‘same or similar’ terms.

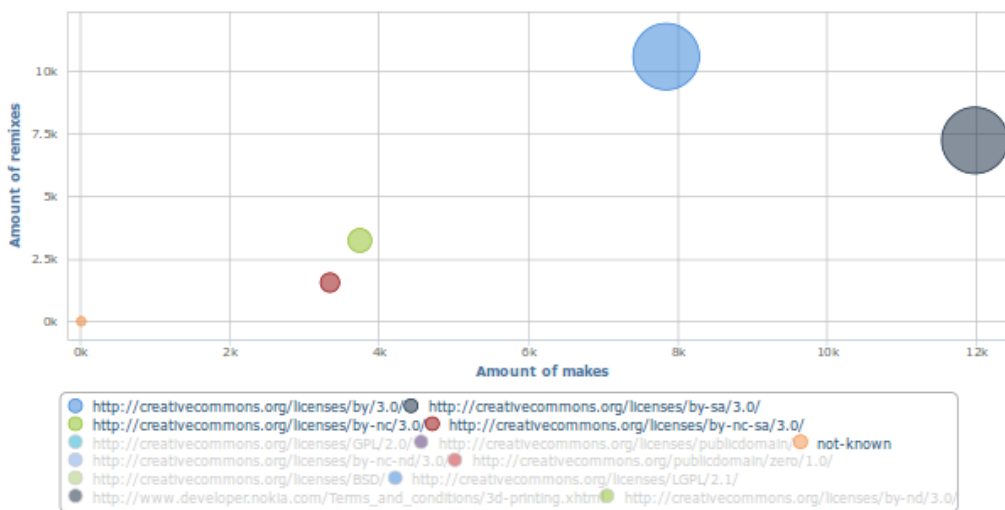


Figure 2: Licence choices—by makes and remixes

This remixing pattern can be compared with use of the ‘collection’ function. CC BY (blue) and CC BY-SA (grey) licensed Things are almost equal in terms of how many times they are included in user collections, suggesting that choice of licence here does not play a major role in which objects users find most interesting to add to their collections, unlike the situation with number of makes and number of remixes discussed above. In comparison, BY-SA licensed items (11,964 times) are significantly more

frequently printed out than BY items (7,833 times). Licence choice does not seem to make a difference to the likelihood of a Thing being added to a user’s collection. It is hard to discern what the users’ motivations behind adding a Thing to one of their collections is without more information from those users, but this finding may suggest that it is users’ view of a particular Thing as being innovative, useful or otherwise interesting to them which is important here, rather than the secondary licence attached to that Thing. Moreover, it may well be that a collection constitutes different components of a complex creation—or preliminary attempts at such a creation—created by different users using different licences for each part.

In terms of actual reproduction using a 3D printer, however, ‘sticky’ licenced models are far more likely to be made than BY items. It is possible that there is a link between a Thing’s quality and the licence chosen by the creator, with high quality Things appearing under more restrictive licences than low quality Things due to the time and effort involved in creating the former.

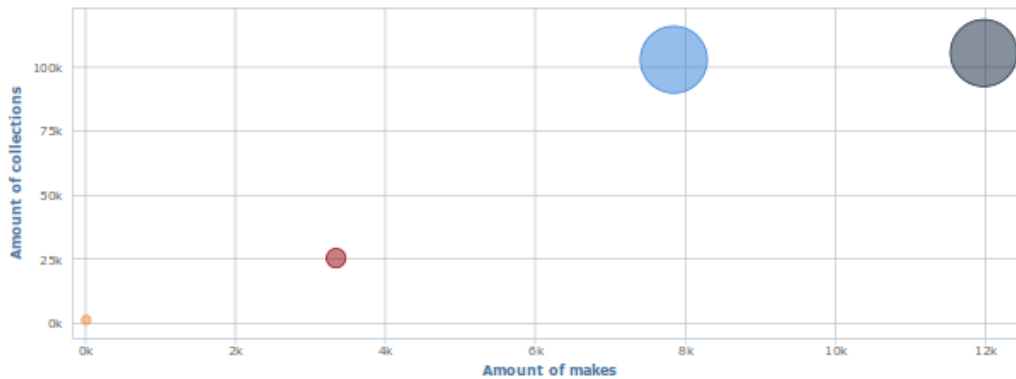


Figure 3: Licence choices—by makes and collection count

Analysis of Thingiverse tags can also reveal insights into intellectual property norms on the site. These are listed in Figure 4 below. The most common tag that users attach to Things is customized (19,206 times). This tag would seem to refer to Thingiverse users handling Things in a way closer to ‘remixing’ than ‘building from scratch’, although overall few Things use this tag in what is framed as being an iterative, collaborative platform. Nevertheless, strong conclusions cannot be drawn from this finding given tagging Things is optional rather than mandatory.

The findings so far broadly conform to the image of Thingiverse as a platform dominated by derivative works and collaborative projects among users. All this supports the notion of Thingiverse as an open sharing service, in the horizontal peer-to-peer sense at least. Yet other findings from our study tell a different story.

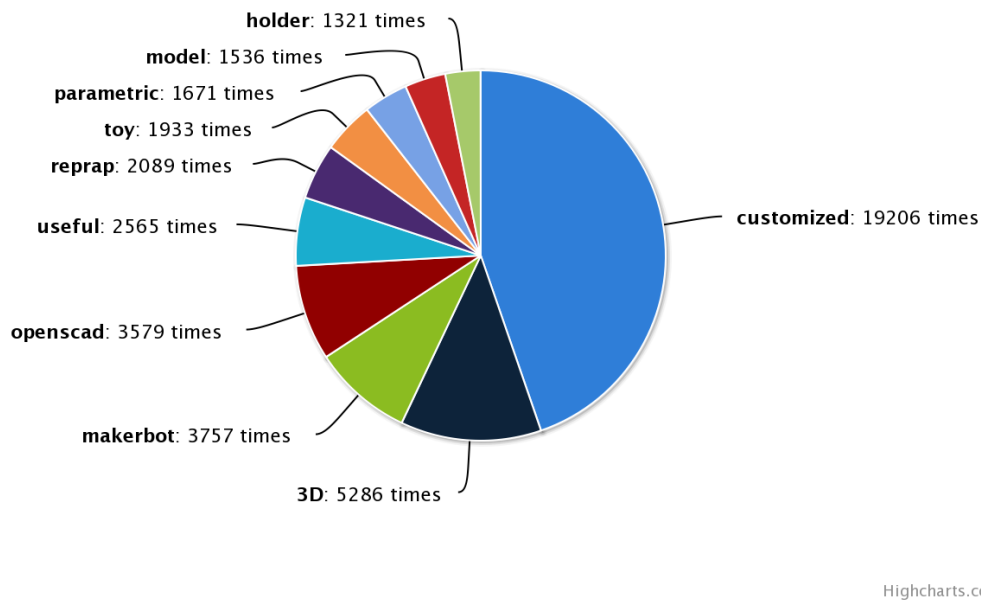


Figure 4: Most common tags used with Thingiverse objects

Our scrape of the site revealed that nearly 42 per cent of the files hosted on Thingiverse are Private—in the sense that they have not been made available to internet users according to the process described above, whereby a user selects a ‘Public’ status for their creation and the file is published on Thingiverse. In other words, they are not shared through the Thingiverse platform—or if they are shared, the sharing is limited to a small group of collaborators who have access to the login and password details of the particular Thingiverse user account, or via other, non-Thingiverse channels.

Why are there are so many Private Things? One explanation may be that many people are experimenting with the platform and are not ready to release their work to the community. If a user does not fully complete

the upload process their item will show up as a Private Thing. However, we should bear in mind another conflicting finding from our scrape: only 6 per cent of Things have an in-progress status.[3] We also note that over time the ratio of Private Things to all Things has been growing slightly, although this may be a random fluctuation. More longitudinal research is needed to determine whether this increase in Private Things is significant.

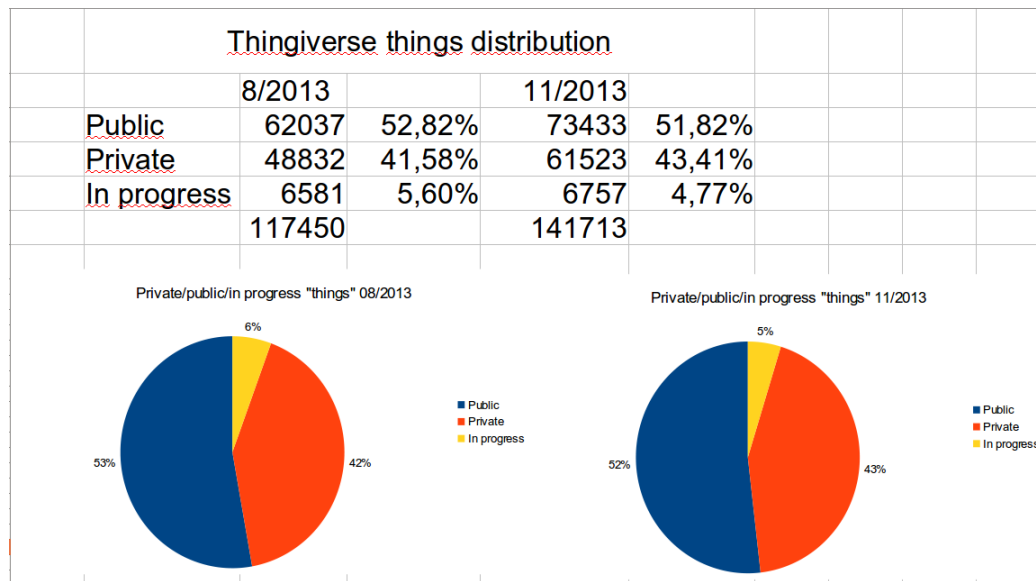


Figure 5: Types of Thingiverse Things

We were unable to collect any more information about why Thingiverse users were marking their Things as private, despite our efforts to contact individual users. Further qualitative research would be useful here. From the information we have, it seems that sharing by Thingiverse users among themselves may not be as prevalent or dominant a practice as the rhetoric suggests, and should perhaps be considered within the wider context of MakerBot's commercial strategy: as mentioned earlier, the company is keen for its users to share yet less willing to share back since it transitioned to 'closed' design and software.

This finding that a large proportion of total Thingiverse Things are actually 'Private' and not shareable by other users is not entirely isolated from other horizontal, peer practices. For instance, Thingiverse has been the object of various Digital Millennium Copyright Act (DMCA) takedown

notices regarding files its users had uploaded to the site which allegedly infringed the intellectual property of others (Rideout 2011; Weinberg 2013, Thompson 2012, Brean 2013, Andersen and Howells 2014, Kahler 2013). While some of the entities issuing these notices were large companies, in one case the notice came from another 3D printing user who had uploaded his design to rival design repository Shapeways. The very existence of these DMCA takedown orders shows another limit to horizontal sharing on Thingiverse. Even if Thingiverse users are happy to share their designs via CC licences, this does not mean that others are also happy for this to happen.

The empirical analysis presented here demonstrates that while it is true to say a great deal of intellectual property sharing occurs among users in a horizontal fashion in Thingiverse, the picture is complicated by the fact that a large proportion of Things overall uploaded to the site remain ‘Private’, and thus cannot be shared with other users via the platform.

Conclusion

The design repository Thingiverse has had a rapid and spectacular rise, and is now a vital component in global 3D printing culture and practice. As our study of the site has demonstrated, Thingiverse sits at the nexus of a number of intellectual property tensions and disputes. As such, it is a useful site from which to view wider IP power struggles within peer production arenas.

We have demonstrated that Thingiverse’s IP policies are profoundly contradictory. On the one hand, Thingiverse and the practices it enables are the ultimate by-products of user innovation, fertilised by open-source culture. On the other hand, Thingiverse is a commercial, proprietary platform, owned by a large, global corporation, which has been widely criticised for its own intellectual property misdemeanours. Recent controversies around Terms of Use reveal the contentious nature of Thingiverse’s actions, and the ethical gulf that divides MakerBot and Thingiverse from their users.

Yet the behaviour of Thingiverse users is also somewhat contradictory. As our analysis has shown, only a proportion of users license their content in ways that take full advantage of open licensing norms. Creative Commons licences are used for 89 per cent of all Public Things. Yet users also keep a surprisingly large proportion of their designs private. Whether by accident or design, this adds a thick layer of ‘off-stage’ activity to what is intended, at least judging from MakerBot’s rhetoric, to be an open, transparent system

dedicated to sharing.

Looking into the horizon, we anticipate a number of future developments for Thingiverse. Digital Millennium Copyright Act takedown notices, which suggest some kind of unauthorised sharing has taken place, are likely to become an increasingly common occurrence, and the site is likely to deepen its reliance on the kind of complex, automated regulatory systems that characterise other major user generated content platforms, notably YouTube. This is, in part, a natural consequence of the 3D printing boom. As awareness of the technology rises, hardware gets more sophisticated, and design options proliferate, the level of concern among rights holders is likely to increase. The rise of 3D scanners is another factor to watch. Take-up of scanning technology, and its integration into handheld devices, will likely reduce the reliance on user-created designs, thus relocating (although possibly not reducing) some of the existing IP tension, with ethical choices being devolved to software rather than human designers.

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Footnotes

[1] Parametric design is a design method in which the output is generated by a set of rules or an Algorithm, normally by using a computer program.

[2] Since data collection was not continuous, the collected data offers only a snapshot view at a particular point in time. Our selected method enables automated processing of large data sets with minimal human intervention and resources, lending itself to generalisations and a broader view; however, the downside is that data often is shallow and does not capture fine nuances or hidden meanings. Community-based ethnographies could offer a more in-depth view, but not at the same extent and certainly not with same small amount of resources and time. Sample studies would also enable detailed exploration of selected items, but the generalisation of results gained would be difficult or impossible.

[3] These are not included in the 'Private' status percentage

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6.4 Possibility-Driven Spins in the Open Design Community

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Abstract. *This case study is a description of the open design community. The study identifies the main characteristics and methods of operation that frame and drive activities in the community. Qualitative research methods were mainly employed to gather and analyse the data. Work in the open design community is collaborative; it is a symbiosis of interests between profit-making companies and members of the community resulting in win-win situations. A word spin in the title of this paper indicates fast turns in the practices of the open design community. The study also proposes a potential direction for the future development of self-sufficient design and production of artefacts, platforms and services in an almost untouched area of scientific research.*

Introduction

3D printing has enabled members of the 3D printing community to create, develop and produce artefacts, platforms and services in new ways, and this case study sheds light on the nature of the open design community through

the window of the 3D printing community (Figure 1).

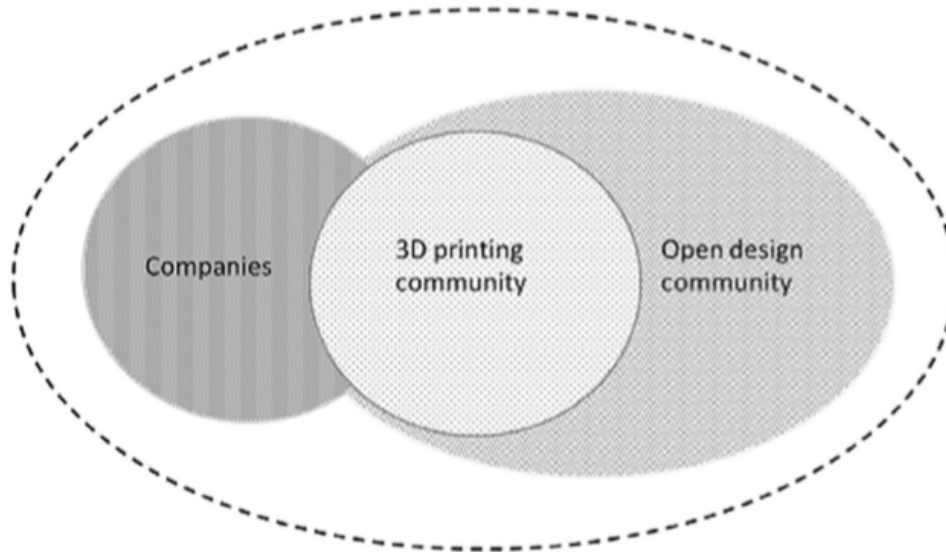
3D printing is intriguing a growing number of theorists because it can be seen as one of the most promising phenomena of the predicted and emerging ‘revolution in manufacturing’. Economists and theorists of innovation such as Jeremy Rifkin (2011, 2014), Yochai Benkler and Helen Nissenbaum (2006) and Michel Bauwens (2005, 2012) have concluded that the Third Industrial Revolution is at hand. Peer production based 3D printing enables activities that can be termed ‘prosumerism’, as put forward by Alvin Tof er (1980). Prosumer is normally regarded as a portmanteau of the words ‘professional’ and ‘consumer’, although, in this context, ‘producing consumer’ is more accurate as it refers to manufacturing enabled by 3D printing.

In the early 1970s, Victor Papanek claimed that all men are designers, as design is basic for all human activity (Papanek, 1972). Open design and open design processes can be compared to the early days of computing. According to Eric Raymond’s (1999) ‘cathedral-bazaar’ analogy, design is conventionally performed in cathedrals where designers employ expensive devices and software, and all design and knowledge are kept hidden from the public. Lately, design has moved from cathedrals to bazaars. In a bazaar model, design is open, 3D models are shared publicly and derived work is a normal activity. While design activities have become possible for all, simultaneously, the production of artefacts has changed. Although 3D printing has existed for more than 30 years, acceleration in the development of features and usability of software programs, applications and sharing platforms began in 2007 (RepRap, 2013). This development has enabled the evolution of novel design methods, business models and a new design community that is populated by a new generation of designers. The purpose of this case study is to shed light on the main characteristics and novel methods of operation within the open design community. The goal of the study is to propose a potential direction for the future development and production of artefacts and diverse functionalities that support the new and self-sufficient methods of operation. A word spin in the title of this paper indicates fast turns in the practices of the open design community.

Theoretical Approaches

Some research has been conducted in the area of product design in 3D printing (Hague et al, 2003), although the main focus has been

Figure 1: The open design community viewed through the lens of the 3D printing community.



on prototyping in the early phases of product development or different technologies (Campbell et al, 2012). For the sake of clarity, the words ‘producing consumer’, ‘end-user’ and ‘user’ are grouped under one term, ‘customer’. In this paper, ‘peer’ is understood as an autonomous agent, an individual participating in a peer-to-peer (P2P) network (French, 1985). Sharing platforms such as Thingiverse.com, Github.com, Ponoko.com, i.Materialise.com, Shapeways.com and Cubehero.com are understood in line with Michel Bauwens et al (2012): ‘Corporate platforms create the possibility for users to share their own creative work, or what they have found, but no common code or knowledge base is created. The platforms are owned by corporations, and the attention and behavioural data are sold to advertisers. Regulations over these platforms are established by the corporate owners.’

Design methodologies

In this section, as an overview on existing methodologies of design, we discuss the different methodologies in the order of increasing levels of user

participation. The aim of user-centred design (Norman and Draper, 1986) is to understand the core needs of a user and convert them into an appropriate design of a product or service for the customer. User-centred design can also be described as a market-oriented approach from a company perspective. Contextual design (Beyer and Holtzblatt, 1998) takes situational factors into account in product design. Experience design (Pullman and Gross, 2004) is more inclined towards service design as it focuses on creating an experience; for example, an emotional experience for the user through a particular type of design. Empathic design can be regarded as being part of experience design as it tries to understand user experiences in the early phases of the design process (Mattelmäki and Visser, 2011). The focus of participatory design is on people participating as co-designers in the design process. Participatory design, also termed cooperative design, can be regarded as a way to involve users in the design phase of an artefacts (Redström 2006, 2008) and also as empowering, because those who are affected by design have the opportunity to influence it. Participatory design merges the decision-making and work practices of users and designers, so that the artefacts is designed with the customer. Co-design is conducted with a collaborative mind-set and is a process that is grounded in the user-centred and emphatic design approaches. Co-creation activities take place within the co-design process and focus on the collective creativity of involved users and stakeholders (Koskinen et al, 2003: Sanders and Simons, 2009). Co-design concerns openness, collaboration and partnership with the customer. The role of designers is to facilitate creative processes among users who create the finished solution. As such, open design can be regarded as a continuation of participatory design. However, the users produce the objects themselves (von Busch, 2012); thus, an artefact's design is performed by the customer.

Possibility-driven design in the 3D printing community

Possibility-driven design

The possibility-driven approach lies in the background of many researchers in the design area (e.g. Norman, 2006, 2011: Verganti, 2006, 2011). Possibility-driven design, an alternative to the problem-driven approach (e.g. Roozenburg and Eekels, 1995), is based on the theory that people want to design future technologies because the activity and its outcome generate happiness, while the established culture of human innovation brings direct

improvement to people's lives (Desmet and Hasselzahl, 2012). Possibility-driven design, or the creation of a possibility to contribute to the flourishing of humans, is associated with well-being and what makes us happy beyond being neutral, whereas problem-driven design focuses on removing prevailing problems (Desmet and Hasselzahl, 2012). Current research on well-being has two perspectives: hedonic and eudemonic (Ryan and Deci, 2001). The hedonic approach focuses on happiness in terms of pleasure cultivation and pain avoidance in well-being, whereas the eudemonic approach focuses on happiness through meaningful activities and self-realization that might be caused by an intervention, an abnormal act or exception to routines (Ryan and Deci, 2001). Positive design stems from possibility-driven design, contributing to people's subjective well-being. The main aim of positive design is to support the flourishing of humans (Desmet and Pohlmeier, 2013).

Desmet and Pohlmeier's (2013) framework of positive design comprises three main components: design for pleasure, design for personal significance and design for virtue (Figure 2). In an ideal framework, there are no incongruities between the components, each person has his or her own fit with the components depending on personal preferences, values, skills, and aspirations. People strive for active user involvement, and the framework provides a means for a long-term perspective and planning.

Open design

According to van der Beek (2012), open design is disruptive and embodies a paradigm shift in which the design object in itself has no fixed identity; instead, it is something that is an ongoing process, along which the fixed identity of the consumer changes to that of a 'prosumer'. Therefore, design in an open design process is found 'in-between', in the space between individuals. It is different from traditional design thinking, whereby the object and subject are clearly separated. As 3D printing is also considered disruptive, the combination of open design and 3D printing can be perceived as doubly disruptive, containing disruption in both the design and manufacturing processes. In contrast to more conventional collaborative design processes (Lahti et al, 2004: Rahman et al, 2013), the methods of working can shift in many ways in open communities as projects progress from the initiation phase to the printing of the physical artefact; the reason for change might be, for example, a project maintainer or an individual designer. A group of people working with the same artefact can also decide

to change the employed design tools or digital environment where the 3D models are shared and stored (Moilanen and Vadén, 2012). In decreasing order of magnitude, the main reasons for utilizing 3D printing are to create functional models, artistic items and spare parts for devices, or for research and educational purposes, or directly to participate in production (Moilanen, 2013a).

There are four interlinked layers in the preliminary model for an ‘open/commons design economy’: the individuals, a tool/design layer, community and sharing platforms, and manufacturing/production (Moilanen and Vadén, 2012; Moilanen, 2013b).

Values of an open community

Communities can usually be characterized by a common connection between all members; for example, an occupation or common interest (McAlexander et al, 2002). In this paper, by building on the definitions of West and Lahkani (2008) and Gläser (2001), an open design community is defined as a community of voluntary actors united by openness as a value and the shared instrumental goal of creating, adapting, adopting or producing models and artefacts. The communities recognize the bounds of what is correct and appropriate and what is wrong and inappropriate behaviour (Muniz and O’Guinn, 2001). Moral responsibility also includes helping other members of the community. While people can share different things such as cognitive, emotional and material resources, the thing that is most frequently shared is the creation and negotiation of meaning (McAlexander et al, 2002).

Values of an open community act as ‘glue’ that keeps the community together. Active members of the 3D printing community are often brilliant engineers and scientists who share an ethical belief in the value of collaboration over proprietorship, and access over ownership (Rifkin, 2014). Transparency, volunteerism, self-selection, self-direction and the freedom to act in accordance with self-articulated goals and principles are essential features in commons-based peer production (Benkler and Nissenbaum, 2006; Castells, 2007). The values appeal to those engaging in do-it-yourself, libertarians, social entrepreneurs and communitarians by bridging ideological borders and also their common abhorrence of hierarchical power and fierce commitment to P2P lateral power (Rifkin, 2014).

Prosumer involvement – from customer to producing consumer

Massimo Menichinelli (2008), one of the long-term open design researchers, has added the term P2P to open design. Menichinelli employs the term open P2P design to emphasize the need to co-create a community that collaborates in a common activity. In other words, Menichinelli has added the aspects of with and for the community to open design, which can embody the acts of designing, developing and managing participatory public services, creating businesses based on communities or managing interactions between business and communities.

An open community offers a medium for co-creatively contributing, for example, thoughts, knowledge, know-how and designs toward a solution or product (Benkler and Nissenbaum, 2006; Menichinelli, 2008). Members of the open community are active participants and also consumers in the community (Benkler and Nissenbaum, 2006; Moilanen and Vadén, 2012). The work in open communities is mainly performed to satisfy needs of the developer, who also acts as a project maintainer or leader along the development process (Mikkonen et al, 2007).

According to Manuel Castells (2007) the socialized communication mode of network societies is termed mass self-communication, which is different from the industrial society's traditional communication system that is centred on mass media, whereby a message is conveyed from one to many. Socialized communication content is self-generated, and emission and reception are self-selected by many who communicate with many. Multimodal exchange means the sharing of files by employing advanced social software and P2P networks that enable the global circulation and reformatting of digitally formatted content based on an open source. Participants in the network act locally but think globally (Castells, 2007 ; Rifkin, 2014).

Research Methods

There were two independent phases in this research; First, an inductive case study employing qualitative research methods was conducted. Based on the findings of the first study, the second deductive case study was performed utilizing both qualitative and quantitative research methods. The case study approach was chosen to examine the methods of operation in the 3D printing community due to the exploratory nature of the research and the aim

of gaining insights on each case (Eisenhardt, 1989; Yin, 2009). In the first study, the data were gathered in semi-structured interviews and email correspondence, whereas the complementary data for the second study were part of a quantitative web survey within the open source area. The gathering of data was conducted in 2012–13 and the findings of both data sets were combined to create this paper.

In the first study, data collection began with an email pilot to verify the questions' relevance. Feedback on the pilot indicated that members of the 3D printing community did not understand the questions or the research aim; therefore, the format of the questions was changed. The community members were asked to draw their design process. The final questions were sent to participants in an open design contest. Semi-structured interviews were continued with the designers until saturation was reached after eight interviews. Some interviewees provided sketches of their design process while others only briefly answered the study's questions. Some data were also received through email correspondence between the second author of this paper and well-known experts in the open source area. Emails strengthened the internal validity of the data (Eisenhardt and Graebner, 2007). All data were first analysed within their respective case and subsequently across the cases (Eisenhardt and Graebner, 2007 ; Yin, 2009).

The second study was built on the first study's data and findings. The qualitative data were revisited with a possibility-driven design approach and complemented with quantitative data of an ongoing longitudinal 3D printing survey (Moilanen, 2013a). The quantitative web survey was targeted at people who use 3D printers, develop 3D printers and related software or use 3D printing services. There were 344 respondents in the quantitative survey conducted in 2013. It is not possible to count the response rate for the survey due to its open nature: the invitation to the survey was sent via twitter, to developed mailing and hacker spaces, discussion lists and also by several companies providing 3D printing services which promoted the survey. The findings of the quantitative 3D printing survey were supported by both the results of the qualitative survey and the possibility-driven theory.

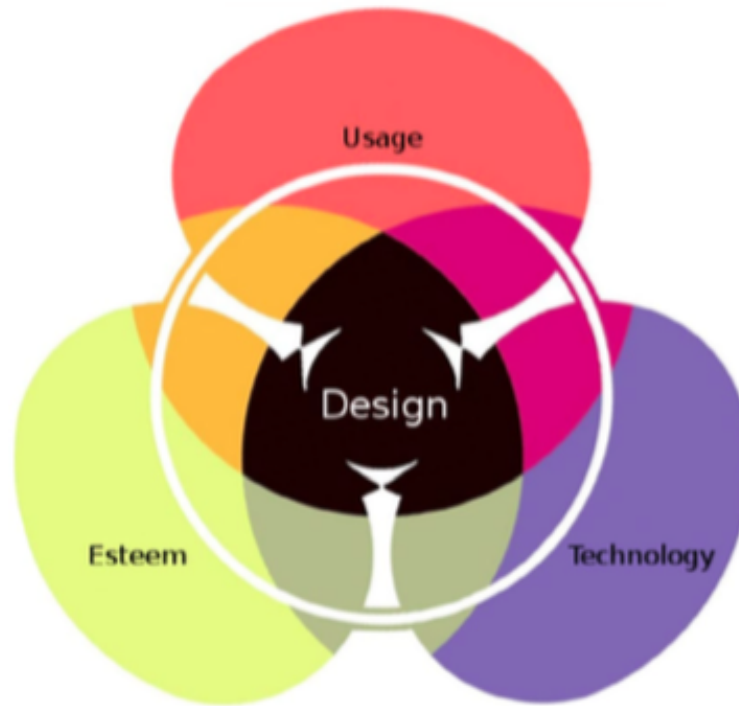
Results

Global approach of open design practices

Activities and outcomes of the open design community can be regarded as practical examples of a possibility-driven design. The possibilities are rooted in the fundamental philosophy and working practices of the community; anybody can be a member and participate in the community's activities when, where and how it is most suitable. Design activities stimulate people's awareness of their abilities to create meaningful artefacts, that is, a eudemonic perspective on well-being, and the outcome contributes to happiness by mediating positive experiences; that is, a hedonic perspective on well-being (Desmet and Hassenzahl, 2012). An illustration of a personal design framework presented by one of the interviewees (see Figure 3) resembles Desmet and Pohlmeier's (2013) positive design framework. Virtue, or being a morally good person, in Desmet and Pohlmeier's framework (see Figure 2) can be regarded as esteem in the open designer's model (Figure 3). Respectively, pleasure, or experiencing a positive effect, is shown in Desmet and Pohlmeier's framework (Figure 2) as usage (Figure 3), and personal significance and pursuing personal goals (Figure 2) are shown as technology in the open designer's model (Figure 3).

Results of a web survey conducted in 2013 (see Graph 3) indicate that the main reasons for people to participate in 3D printing projects is to have fun and learn new skills. Sixty-six per cent of the respondents agreed strongly that they participate in 3D printing projects because they find it fun. The result is in line with Ryan and Deci's (2001) hedonic approach, and the design for pleasure attribute in Desmet and Pohlmeier's model (2013). Fifty-one per cent of the respondents agreed strongly that they participate in 3D printing projects because they learn new skills, which is in line with the eudemonic perspective (Ryan and Deci, 2001) and an attribute of design for personal significance (Desmet and Pohlmeier, 2013). Sixty-two per cent of the respondents agreed or strongly agreed that they participate in 3D printing projects because they want to share their own knowledge and skills with others, which can be both a hedonic and eudemonic experience by giving an immediate good feeling of being able to help and also a deeper meaning of increasing the general level of knowledge and personal respect in the community. Sharing of a member's own knowledge and skills can also have many effects on subjective well-being; it can be a virtue, it can increase

Figure 2: An open design framework of one of the interviewees.



the feeling of personal significance and the member can feel pleasure while sharing. Sixty-one per cent of the respondents agreed or strongly agreed that they participate in 3D printing projects because they want to express themselves. Self-expression is part of subjective well-being, and it can be identified in each of the triangles in Desmet and Pohlmeier's (2013) positive design framework. Fifty-seven per cent of the respondents agreed or strongly agreed that they participate in 3D printing projects because they want to help others, which is similar to the reason of sharing their own knowledge and skills with others.

However, thirty-six per cent of the respondents strongly disagreed that they participate in 3D printing projects because of money. The basic philosophy is that sharing conflicts with monetary values, which is shown in the results. However, findings from the interviews indicate that business-

Figure 3: Motivation factors of the 3D printing community members who participate in the 3D printing activities (Moilanen, 2013a).

	1 strongly agree	2 agree	3 don't know	4 disagree	5 strongly disagree
I participate in 3D printing projects because of money.	14	14	22	13	36
I participate in 3D printing projects because I want to develop 3D printing tools and practices.	29	19	32	9	11
I participate in 3D printing projects because I learn new skills.	51	23	8	5	12
I participate in 3D printing projects because I like collaborative development	27	24	24	13	12
I participate in 3D printing projects because I like to share my knowledge and skills with others.	30	32	16	12	10
I participate in 3D printing projects because I get more respect	12	17	27	21	23
I participate 3D printing projects because it gives me better job opportunities in the future	18	24	25	18	15
I participate in 3D printing projects because it is fun.	66	12	6	4	13
I participate in 3D printing projects because I want to help others.	28	29	24	12	7
3D printing projects are a way to express myself.	32	29	16	14	10
I do 3D printing because I think all software and hardware should be free.	18	15	25	15	27
I participate in 3D printing projects because I want to give back to the community.	19	23	24	19	15
I develop 3D printing because I need it for doing something else.	29	22	18	15	16

orientated thinking is accepted while it is transparent. Open community members believe and have experienced that if they contribute to open community activities, they will benefit from it ‘sooner or later in surprising ways and on a larger scale than ever expected’.

A typical way to become a member of the 3D printing community is to begin open design work gradually and progress to being an expert. A designer described the evolution of his career: ‘it all started first as an interesting hobby, then finally modded [sic] the machine and finally designed a new one’. The importance of the social aspects and sharing of common values within a community is clear:

[T]here are nice people and then, in addition, if sometimes one succeeds in designing something really useful ... that every- body can benefit from.

The above statement by a designer can be perceived as eudemonic, inducing happiness through a meaningful activity and self- realization, and is also aligned with Desmet and Pohlmeier's (2013) framework of positive design.

Based on the findings, the open design community is a heterogeneous group of people. Nevertheless, the values of openness to and transparency of knowledge and processes are shared by all community members, and trust is the glue that keeps the collaboration and derived work ongoing, as one of the interviewees stated:

[We are] better able to meet people in real life, people with whom we can work, especially when it's someone who understands our values and shares our beliefs in the concept by which we will be able to achieve our current projects and implement future ideas.

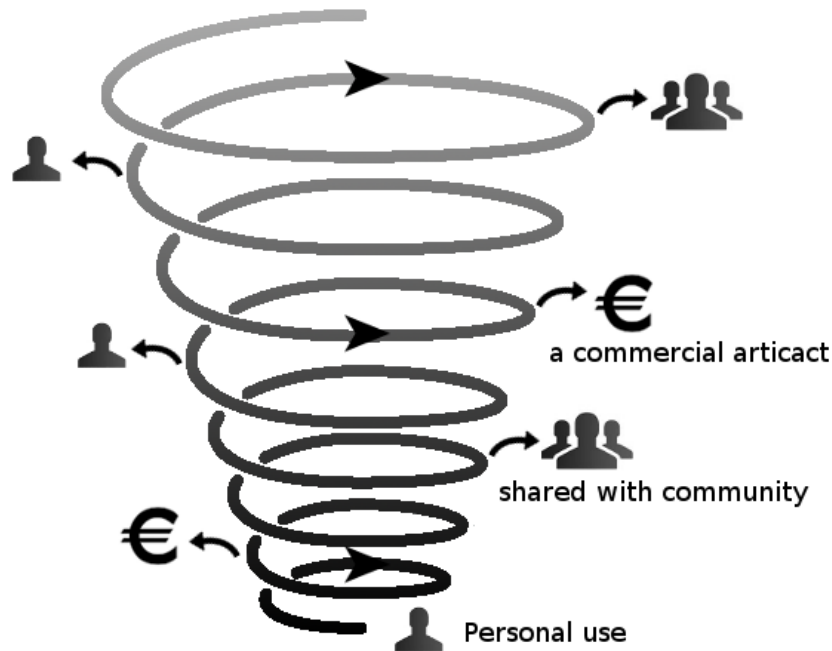
The 3D printing community can be regarded as a bridge that links two worlds: makers and engineers, who are problem-solvers, and solution-focused designers who also take into account the usability and aesthetics of the artefacts.

Possibility-driven spins

The findings indicate that open design projects are dynamic, and there are many ongoing parallel projects in different phases at the same time. A spin with several inputs and outcomes describes the development and production methods employed by the 3D print- ing community (Figure 4). The development of artefacts happens through collaboration and iteration; that is, sharing existing models with all community members and allowing them be involved in the creation and production process of the solution.

An artefact can be taken for personal use and not shared with the community as objects intended for personal use do not need to be shared. Quite often, a member is pleased with his or her design and wants to share it with the community, add his or her name to the artefact's license and get the community's recognition. A design can also be developed for commercial

Figure 4: Spin model of the method of operation in the open design community.



markets. Forks with commercial goals can cause philosophical conflicts in the community due to possible abuse of designs that members created under some commons licenses for others to use and modify; as such, sudden ‘hijacking’ of the designs is not well received. A fork is an incident in which part of the development team, or a third party not involved in the project, starts an independent development line based on the project’s source code (Robles and González-Barahona, 2012).

An example of a business-oriented fork in the recent history of the 3D printing community occurred during a RepRap project in 2012, when MakerBot independently created a new 3D printer termed Replicator 2. The incident created a lively discussion in the 3D printing community; those whose designs under commons license were employed for profit-making purposes were especially displeased. However, Replicator 2 is a 3D printer targeted at the layman and is relatively cheap and easy to use. In hindsight, MakerBot’s fork has brought benefits to the whole 3D printing market: there is an affordable 3D printer available in the market and 3D printing community members have gained insights, for example, on commercial

aspects of open designs. Also, revenues of companies selling 3D printers and 3D printing material have increased.

One of the designers participating in the research explained the design process utilizing open design terminology. The process is similar to a traditional design process, although the interaction with other people creates more complexity and unpredictable changes.

I – Ideation phase

The sources of ideas can be grouped into three categories: ‘scratch an itch’, ‘think outside the box’ and ‘derived work’. ‘Scratch an itch’ refers to a personal need for which a solution has not been developed by someone else (Rifkin, 2011). As explained by an interviewee, motivation to create an idea can be two-fold: ‘I design for customers and for myself. But mostly the products I designed ... I first designed it because I wanted to have it.’ Willingness to ‘think outside of the box’ enables innovation. An interviewee described this way of thinking as ‘I look at everything as a possible brick that could be used in something else.’ One aspect of finding new ideas and solutions is the ability to ‘synthesize all the good ideas I seen [sic] in things around.’ This refers to thinking by which ‘we never start from scratch as we are inspired by all the things we see’. Derived work refers to utilizing previous inventions and models, whereby the designer begins with existing items and redesigns them. The need for modification might be personal, ‘scratch an itch’ or the designer wants to make the solution slightly different and more efficient. In the latter case, the results are more often contributed back to community: ‘You find many things that could fit, but not exactly the way you want, I import the .stl in sketch [sic] up and work beside it to make my version’ (.stl is the file format used by 3D printers).

II – Opportunity seeking

When the initial idea and goal of the design are clear, designers can discuss the topic with each other. An interviewee described this phase as ‘filling the tank’. Reactions can occur in online asynchronous discussions in, for example, Internet Relay Chat (IRC) channels or other technology-related peer communities. While ‘the IRC is the Petri dish where you can observe the bleeding edge of the development,’ it is also a place where design-related issues, ideas, perspectives, implementation techniques and development tools

are discussed.

III – Sketching and sharing of working designs

Being an active member in an open design community requires that sketches, digital 3D models and related items are exposed to the community. There are several sharing platforms, and designers' have personal preferences: 'with the GUI [i.e. graphical user inter- face] for windows it's easier to update the models, the Thingiverse thing is more a link to the repo[sitory].'

IV – Prototyping

When the design has been created as a digital 3D model, it needs to be produced. A designer has at least four options to get an object printed: (1) the designer can have his or her own 3D printer and 3D print the object; (2) The designer can utilize a local DIY community if it has a 3D printer. This is natural evolution as the open design community, 3D printing and local hacker spaces have a common history, and the development of low-cost 3D printers began in hacker spaces; (3) The designer can employ 3D printing services. The time span between order and delivery can be weeks, while 3D printing in a local DIY community can be performed more rapidly; (4) Many members of the open design community can 3D print a physical artefact and even test it. This is termed peer-prototyping.

Derived work and sharing

The intrinsic complexity in the methods of operation emerges from the derived work mode; a design created by a member can be utilized and modified several times by other members, and the original purpose of the design can also change. Several components can be combined and related discussions in the network help with design work as the development is time consuming in the 'component and design jungle' of the open design community.

Local sharing of 3D models, knowledge, skills, and resources for development and production takes place, for example, in physical maker spaces, hacker spaces and open design events; people discuss, ideate, browse, touch and 3D print products themselves.

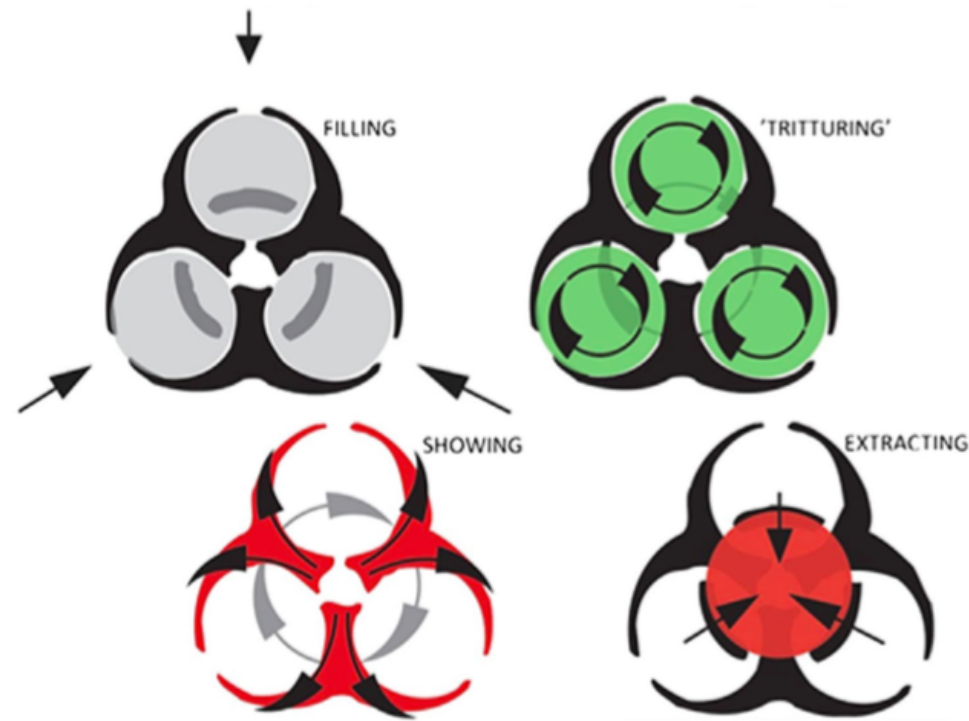
The amount of tacit knowledge in local spaces and events varies depending of the enthusiasm and expertise of the active participants. There are no ‘global people’ in the community, but local activists initiate things to be shared also at the global level. Fundamentally, anything shared online is global: ideas, designs, knowledge, skills, resources and activities which are shared through, for example, blogs, Wikipedia projects and discussion forums such as the Thingiverse 3D printing website. There can be constant changes in, for example, methods of operation, roles taken by the community members, employed tools and platforms, and even targets of the development projects. If a member of the 3D printing community has a need for a particular feature or function of an artefact, a potential model to fulfill the need is quite often found in a global sharing platform such as Thingiverse. The quality of the designs varies depending on the maturity level of the model; that is, the number and quality of the iteration rounds conducted to develop the model. As one of the interviewees stated:

The attitude is that we collect the pearls of what has already been developed, and make our own thing on the side of it in a way.

Local approach of the open design practices

One of the interviewees, a designer focused on hardware development of an open source driven RepRap 3D printer, identified four phases along the design process and emphasized that they are not sequential but intertwined and parallel. Due to limitations of 2D images and for the sake of clarity, a preliminary process model has been drawn to include distinct phases (see Figure 5). The four ‘cycles’ are not separate chronological phases, but ‘can repeat over and over or the four phase simultaneously’ and ‘each small circle is at a different stage’. The process description also reflects the ideology and values of the designer who perceives ‘design as a “good virus” to spread change’, and therefore employs a biohazard symbol as the theme behind all thinking. The ‘filling’ is an ideation phase in which the designer collects ideas and ‘start[s] by diving into a subject, learning more and more about it [i.e. filling the tank in this analogy]’. It can be part of a co-creation process: ‘Today I’d say that these ideas/concepts can be enriched by other people’s view[s]’; however, the work is mostly performed alone.

Figure 5: A design process of one of the interviewees.



The publishing of results (e.g. sketches in the early phase) enables others to join if they find it interesting. In the second phase, designers ‘triture’ [free translation in English: ‘Cogitate on’] ideas and thoughts: ‘you start to mix the things that inspire you with your own ingredients’. In the ‘extracting’ phase, excess is removed and a ‘meme’ is formed which ‘describe[s] [the] minimum component[s] that compose a concept’. The results are ‘shown’ in the last phase to gain, for example, more contributions to and shared knowledge on ongoing projects. The process is unending; it is ‘always in evolution, but sometimes we have to make an iteration such as a picture of its current state’. Open source designers employ methodology similar to that in software development without knowing it until they become familiar with it, or as an interviewee stated: ‘later when I discovered agile methods, I was able to put words to what I was trying to achieve’.

Discussion

The findings suggest that the open design community seeks widely accepted forms and applied processes. It is a nascent community; however, there are indications of more coherent practices and shared understanding on what open design is and how it works. Licensing of designs in open communities is another area that needs global understanding, acceptance and agreement. It seems that the majority of designs in the open design area are under creative commons license (Moilanen, 2013c).

The number of interviews within the open design community was rather limited; as such, the characteristics of the community might need more detailed descriptions and deeper understanding.

Nevertheless, the proposed design processes and characteristics offer an interpretation of the open design community and act as a starting point for further research. 3D printing and open design and communities are not bound to any country borders; therefore the results should have global validity.

As the number of 3D printers increases, so also does their potential impact on the environment in a way similar to the notion of paperless offices, which eventually proved to be the wrong conclusion because the popularity of paper printers increased as people still wanted to read their documents in a physical paper format. Open design community members are conscious of the situation and actively seek environmentally friendly materials and technologies and also think of recycling processes to reduce waste. Nevertheless, if people's behaviour does not change and they print artefacts that are not finalized, the number of deformed items to be thrown away increases. Building on the strengths of open design practices and the well-being it provides to the community members, the open design community can be an interesting platform for attractive future working modes. Due to the early adopter phase of the 3D printing technology, services and applications, there remains plenty of scope for further research.

Conclusion

Those who succeed in today's fast changing markets screen and seize appropriate opportunities, and, by thinking differently from competitors, gain competitive advantage. In recent years, the design process has

often been outpaced by social, economic or technological changes (Lawson, 2005). As Manuel Castells (2000) pointed out, the process of revolutionary technological change needs to be located in the social context in which it occurs and by which it is being shaped, as understanding on a global transformation requires a global perspective. A 3D printer is an innovation and the way it is employed by the open design community can revolutionize the design and manufacture of customized products in a way similar to how the assembly line changed production of goods during the industrial revolution due to near zero marginal costs in the creation, production, marketing and distribution of products.

Possibility-driven design focuses on finding solutions and follows the same line of thought as Nigel Cross' (2004) statement that expert designers are solution-focused; both approaches want to improve the state of the future. Possibility-driven design with an open-minded way of thinking can lead to disruptive solutions that are not based on the notion of solving problems. Community members' motivation to participate in 3D printing projects can be explained by subjective well-being (Ryan and Deci, 2001) and a positive design framework (Desmet and Pohlmeier, 2013). The open design community is inherently very dynamic; there are many parallel project spins with simultaneous related sharing activities and ongoing discussions. The directions of developments are very difficult to predict due to the disruptive nature of the work.

Designs shared among the open design community are not standardized in the way commercial companies legitimate their products. Designs are tested, commented on and discussed by open design community members; only 'the fittest survive'. The lack of official standardizations requires end-users to be more responsible and careful when utilizing open design products, especially if the safety of people or the environment is at stake. Direct, honest and timely feedback that comes from an end-user motivates the developers and keeps the development cycles short in open design community, because the work can be done in '24/7 mode' in a similar fashion to open source communities. People working in companies work for dedicated projects from seven to eight hours a day, five days a week, so the clock speed is faster and the development more effective in the open design community. Learning happens quickly in the community, since the more skilful members help out and support the ones who need advice. Trust acts as the glue that facilitates openness and transparency in the open design community. Social relationships of the community members create the foundation for

enjoyable and interesting projects. Companies would benefit of similar drivers and methods of operation, especially in today's competitive markets where reduction of costs, employees' well-being and cutting edge innovations are key factors of successful companies. The 3D printing community can be regarded as a bridge that links the strengths of a maker or an engineer with the strengths of a designer, who also perceives the importance of usability and aesthetics. Nevertheless, agile and dynamic methods of operation, combined with the community members' goal of improving their personal lives or those of the whole community, can create a unique and competitive edge in situations where business companies fail.

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Supplement data and research materials

Supplemental data for this article can accessed at <http://surveys.peerproduction.net/>

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