Commons-based Peer-Production of Physical Goods
Is there Room for a Hybrid Innovation Ecology?

Peter Troxler, Square One, Rotterdam, The Netherlands
peter@square-1.eu

This paper examines how in commons-based peer-production of physical goods a hybrid, private-collective innovation ecology is developing. Using the Fab Lab community as the field of investigation, it collates three studies: a survey of Fab Lab business models, an interview study asking Fab Lab managers and assistants about the pain and pride of their Fab Lab, and a selection of cases describing innovation in Fab Lab projects. The paper finds that there is a desire and intention to establish a hybrid innovation ecology in the Fab Lab community, but that Fab Labs have not yet established business models that would e.g. replicate the known models from open source software. However, the studies indicated the possibility of such models. The paper finally puts the results in perspective to the free fabbing ecology, and the wider context of peer-production of physical goods.

Introduction

First there was a digital revolution in communication (from analogue to digital telephony) that eventually cumulated in mobile communication and convergence of media. Then there was a second digital revolution in computation (from analogue to digital computers) that eventually made personal computers possible and lead to a convergence of communication and computing. The next digital revolution, according to Gershenfeld (2005), is in the field of manufactured physical goods with the emergence of digital personal fabrication or 'fabbing'.

In this paper, I'll investigate how this third digital revolution, the emergence of fabbing and its adoption in the commons-based peer-production of physical goods influences how we go about innovation, particularly if and how a hybrid innovation ecology could develop or could be developed.

First, I'll be looking into the world of *fabbing,* commons-based peer-production of physical goods. I'll briefly describe its roots and its analogy to open source software production. I'll show how widespread fabbing is today and I'll propose a conceptual map to describe some of the fabbing communities.

I then go on to ask how *open source and innovation* are related and how far innovation research today understands the contribution of open source to innovation in general, and more specifically, in the area of physical goods, of manufacturing and fabbing.

This leads me to my *research questions, design and methods;* a way to gain more in-depth understanding about business models in commons-based peer-production.

I'll report from *three studies* I carried out in this context, first a survey of Fab Lab business models, second an interview study asking Fab Lab managers and assistants about the pain and pride of their Fab Lab, and third a selection of five case studies describing innovation in Fab Lab projects.

Finally, in a brief *discussion* I'll review the results of these studies, and try to put them into perspective to my research questions, the free fabbing ecology, and the wider context of peer-production of physical goods.

Fabbing

The raise of commons-based peer production, i.e. individuals collaborating in producing cultural content, knowledge, and other information and indeed physical goods, is commonly attributed to 'digital revolutions', the broad availability of new information technologies (see e.g. Benkler, 2006). Benkler (2003) argues that 'in the networked information economy—an economy of information, knowledge, and culture that flow through society over a ubiquitous, decentralized network—productivity and growth can be sustained in a pattern that differs fundamentally from the industrial information economy of the twentieth century in two crucial characteristics. First, nonmarket production (...) can play a much more important role than it could in the physical economy. Second, radically decentralized production and distribution, whether market-based or not, can similarly play a much more important role' (p. 1246f.).

Commons-based peer production is most widely practiced in the area of software development, of which such important programmes as the Linux operating system and the Apache web server are the most prominent examples. Commons-based peer production has also moved beyond pure software and spread into other domains, from culture and education to knowledge discovery and sharing (e.g. the SETI@home project, Wikipedia, Open Street Map, Slashdot, or the Blender movies). Commons-based peer production might be 'born digital', yet it also leaves the purely digital domain. There are quite a number of fabbing projects (fabbing from fabrication), open source hardware projects that aim to produce tangible goods through a peer-production approach. Maybe this is because many 'physical activities are becoming so data-centric that the physical aspects are simply executional steps at the end of a chain of digital manipulation' as Shirky suggests (2007). Or maybe the commons-based peer production model 'provides opportunities for virtuous behavior' and so 'is more conducive to virtuous individuals' (Benkler & Nissenbaum, 2006, p. 394).

Balka et al. went to great length to collect examples of open source hardware projects through their site http://open-innovation-projects.org/ which they then used as basis for their quantitative studies (2009, 2010). They find, 'that, in open design communities, tangible objects can be developed in very similar fashion to software; one could even say that people treat a design as source code to a physical object and change the object via changing the source.' (2009, p. 22), but also that that 'open parts strategies in open design are crafted at the component level, rather than the level of the entire design' (2010, p. 11) and that 'the degree of openness differs significantly between software and hardware components, in the sense that software is more transparent, accessible, and replicable than hardware' (ibid.).

Similarly, Torrone and Fried (2010) collected 13 examples of companies that are selling open source hardware and creating some kind of community around them. Those companies together, the authors estimate, generate a turnover of about US$ 50m. The authors reckon that there are currently about 200 open source hardware projects of this kind. They project the open source hardware community to reach US$ 1b by 2015. Some of these communities have indeed seen an exponential growth recently, e.g. the RepRap community (Rhys et al. 2010).

Next to these single-aim or single-product projects there are other initiatives promoting commons-based peer production mainly through the sharing of designs and the stimulation of 'making things', be it for the fun of it (e.g. the Maker Faire in the USA, the magazines Make or Craft), for easy sharing, distribution and promotion (e.g. Ponoko, Shapeways, Thingiverse), or for the purpose of more serious or more ambitious social experiments, such as the Open Source Ecology with their experimental facility Factor E Farm (Dolittle, 2008).

Finally, there are other initiatives of commons-based peer production that could be summarized under the heading of 'shared machine shops' (Hess, 1979). These workshops are typically equipped with hand tools and relatively inexpensive fabrication machines (e.g. laser cutter, router, 3D mills). Users produce two- and three-dimensional things that once could only be made using equipment costing hundreds of thousands of Euros. They use digital drawings and open-source software to control the machines, or they build electronic circuits and gadgets.

Hackerspaces define themselves 'as community-operated physical places, where people can meet and work on their projects' (Hackerspaces, 2010). Emerging from the counter culture movement (Grenzfurthner & Schneider, 2009), they are 'place[s] where people can learn about technology and science outside the confines of work or school' (Farr, 2009). Activities in hacker spaces evolve around computers and technology, and digital or electronic art. Hackerspaces are founded as local initiatives following a common pattern, becoming a hacker space is predominantly self declaratory. The Hackerspaces ecosystem comprises some 400 member locations, of which roughly half are either dormant or under construction (Hackerspaces, 2010a). Collaboration between Hackerspaces has recently begun in the shape of so-called 'hackatlons' that seem not to extend beyond showing activity at the hacker spaces taking part (Hackerspaces, 2010b).

100k-Garages is 'is a community of workshops with digital fabrication tools for precisely cutting, machining, drilling, or sculpting the parts for your project or product, in all kinds of materials, in a shop or garage near you' (100kGarages, 2010), supported by machine manufacturer ShopBot and the design sharing platform Ponoko. Most of these workshops are located in the U.S.A. and Canada (about 180), with five shops in Europe and two in Australia. As opposed to the other examples, 100k-Garages are providing a professional manufacturing service, rather than offering shop access to makers.

TechShop is a group of workshops that are equipped with typical machine shop tools (welding stations, laser cutters, milling machines) and corresponding design software. Access to the workshop is through monthly or yearly membership, and courses on how to use the tools are offered, too. TechShop started in the California Bay Area, and is present in five more cities around the U.S.A. (TechShop, 2010).

Fab Lab, short for fabrication laboratory, is another global initiative with a growing number of locations around the world. Fab Labs are more conceptually rooted as they emerged from an MIT course entitled 'How To Make (almost) Anything' (Gershenfeld, 2005). While there is no formal procedure on how to become a Fab Lab, the process is monitored by the MIT, and the MIT maintains a list of all Fab Labs worldwide. At the moment of writing, the Fab Lab community comprises 45 labs, with another 45 to 50 labs to open in the not too distant future. There are a few collaborative projects within the community, and a number of initiatives to exchange designs and experience between the labs. Similar to the hackatlons, but on a more structural basis, all the labs around the world are in contact with each other through a common video conferencing system hosted at the MIT which is used for ad-hoc meetings, scheduled conferences and the delivery of the Fab Academy training programme.

In literature, there are a number of examples of Fab Lab projects. Mikhak et al. (2002) report on projects in India, at Vigyan Ashram Fab Lab just outside the village of Pabal in Maharashtra, and at the Costa Rica Institute of Technology in San Jose, Costa Rica. The India projects are about developing controller boards to do more accurate timing of the diesel engines they use to generate electrical power, and developing devices to monitor milk quality not at the collection centres and the processing plants, but at producer level. The Costa Rican projects evolve around wireless sensing modules for agricultural, educational and medical applications, for example the monitoring of a certain skin condition in a rural village.

Gershenfeld (2005) lists examples of what students at MIT made in his course 'how to make (almost) anything', including a bag that collects and replays screams, a computer interface for parrots that can be controlled by a bird's beak, a personalised bike frame, a cow-powered generator, an alarm clock that needs to be wrestled to make it turn off, and a defensive dress that protects its wearer's personal space.

Gjengedal (2006) reports on the early projects at the Norwegian MIT Fab Lab at Solvik farm in Lyngen: the 'electronic shepard' (sic) project that used telecom equipment to track sheep in the mountains, the 'helmet wiper' for clearing the face shield in the rain, the 'wideband antenna' for the industrial, scientific and medical (ISM) radio band, and the 'Internet 0' project (a low bandwidth Internet protocol), the 'perfect antenna', and the 'local position system' for positioning of robots in the lab.

Pfeiffer (2009) describes her own experiments and projects in the context of distributed digital design; the experiments being Lasercut News, Digital Color Studies & Pixilated Images, Lasercut Screen, and Lasercut Bracelets (which she sold at a local shop), the projects: Distorted Chair and Asperatus Tile.

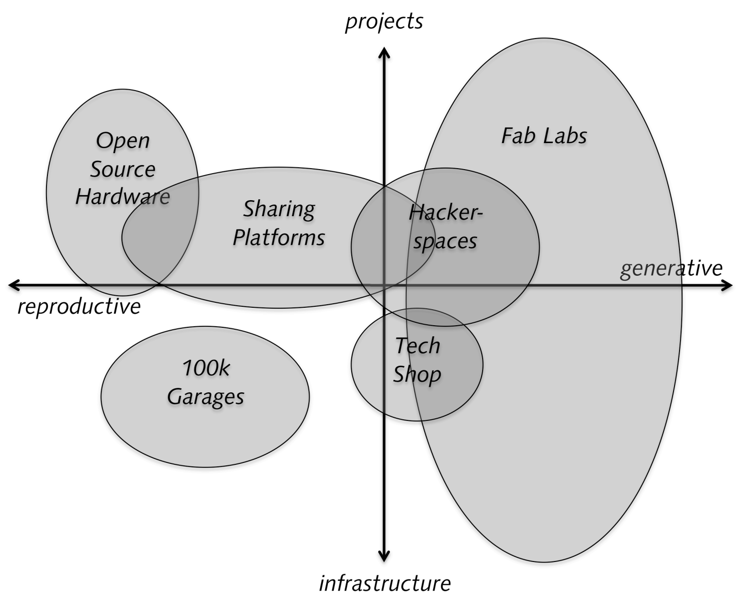

Figure 1: An attempt at mapping the Fabbing world

Hackerspaces, per their name and definition, build on commons-based principles. 100k-Garages and TechShops use dedicated platforms to share (final) designs, yet their commitment to a commons-based peer production philosophy seems to be somewhat weaker. Fab Labs' commitment to some kind of commons is more explicit. The Fab Charter, to which all Fab Labs subscribe, states, that 'designs and processes developed in fab labs must remain available for individual use although intellectual property can be protected however you choose'. And the Charter continues 'commercial activities can be incubated in fab labs but they must not conflict with open access, they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs, and networks that contribute to their success' (Fab Charter, 2007).

Open Source and Innovation

There is a substantial body of research trying to understand the motivational and economical issues for people to choose a commons-based or open source approach, particularly for the Open Source software sector (e.g. Harhoff et al., 2000; Khalak 2000; Lerner & Tirole, 2000, 2002, 2002a; Dalle & Jullien, 2001; Edwards, 2000, 2001, 2003; Kelty 2001; Johnson, 2001; Bonaccorsi & Rossi 2003; Lakhani & von Hippel, 2003; Lakhani & Wolf, 2003; Hemetsberger & Reinhardt 2004; Bessen, 2006; Sauer 2007).

In innovation research, however, it is still relatively early days of accepting the open source way as a mode of innovation of any substantial relevance. von Hippel and von Krogh (2003) proposed the explanation of a 'private-collective innovation model' that combines elements of the traditional private investment model of innovation and the collective action model of innovation of public goods. Participants use their private budget to create innovations they freely reveal as a public good (private investment model). In return they do not want legal protection for the exclusive commercial exploitation of their innovation, but other private benefits such as learning, enjoyment and community participation (collective action model).

Yet in 2005, von Hippel still acknowledged that 'the empirical finding that users often freely reveal their innovations has been a major surprise to innovation researchers'. Also, theories on 'open innovation' (Chesbrough 2003) struggled for quite some time to explain the growth of commons-based peer production: Chesbrough (2003) called it the 'puzzle of Open Source Software'. The major issue was the absence of a business model built around intellectual property rights: 'By construction, open source software is created without any one firm owning the technology. No firm can patent the technology, or exclude anyone else from accessing the software code. Enhancements to the code are available to everyone on an equal basis. Is this simply an exception to the general rule [i.e. that the value of a technology is determined by the business model], is this due to a business model of a different kind, or is there something fundamentally wrong with the above claims of Open Innovation regarding the importance of business model for the behavior of firms?' (Chesbrough, 2006, p. 25). He then introduces 'open source business models' (Chesbrough, 2006a, p. 45 ff.; for an in-depth discussion of open source business models see e.g. Pomerantz, 2000; faberNovel, 2007). Still slightly surprised at the fact, he concludes (p. 47) that 'while open source was created in ways that sought to deliberately eschew the creation of IP rights over its technology, alert companies have nonetheless developed business models that are propelling the [software] technology forward into the market.' faberNovel (2007, p. 13) distinguish four types of business models, all of which are based on complementary services for the products to generate revenue.

Research Questions, Design and Methods

What would these 'open source business models' be with regard to non-software products? How can the transfer of business practices from the software industry to manufacturing be achieved? And what are the difficulties in doing so? Is there indeed a 'next industrial revolution', where 'atoms are the new bits' (Anderson, 2010)? Is there a private-collective, a hybrid innovation ecology in commons-based peer production of physical goods?

To answer these questions, I was looking for a way to gain more in-depth understanding about business models in commons-based peer-production or fabbing. I decided to select one of the communities. For theoretical and practical reasons I chose Fab Labs for my studies. I believe that the Fab Lab network is structurally more developed and better documented than the other communities, and the ambition of Fab Lab is clearly 'hybrid' as stated in the Fab Lab charter. Practically, this was the community to which I had the best access, I was involved in setting up a Fab Lab in Switzerland, and had looked at the Fab Lab business earlier (Troxler, 2009).

I first chose to analyse the business models of existing Fab Labs and to study to which extent they were being able to (economically) sustain themselves as institutions, given their practical and ideological premise of Fab Labs as prime locations for commons-based peer production. Parts of this study were carried out in collaboration with the University of Applied Sciences and Arts, Luzern.

In spring 2010, we studied business models of the Fab Labs around the world in a two-tiered approach. Firstly, a top-level description of the positioning of the Fab Labs was derived through document analysis. Secondly, we selected a subset of seventeen Fab Labs for the study. For the selection, the labs had to be publicly accessible and the main goal of the labs had to be manufacturing-oriented rather than community-oriented. Six labs did not respond, and one lab chose not to take part. The business models of the remaining ten Fab Labs were analyzed more deeply in expert interviews with the Fab Lab managers or, where applicable, with the business managers at their hosting organisations. The interview guideline addressed value proposition, revenue model, processes, resources, marketing, and innovation partnerships.

Second, to gain more insight into the operational business aspects of Fab Labs, I interviewed lab managers and lab assistants of existing and prospective Fab Labs about the 'pain and pride' of their respective labs.

Third, I wanted to investigate if and how users would make use of the open source approach stipulated by the Fab Charter, particularly since literature is mainly focusing on the users of Fab Labs (e.g. Mikhak et al., 2002; Gershenfeld, 2005; Gjengedal, 2006; Pfeiffer, 2009) rather than the labs and their business environment. Therefore, I analysed four projects carried out at Fab Labs based on publicly available documentation. These projects had to show at least some traits of 'openness', such as designs, drawings or documentation made available under some 'free' or 'copyleft' license. Additionally, I report a case of 'closed' innovation where a Fab Lab helped a commercial company.

Study 1
Survey of Fab Lab Business Models

There are currently 45 Fab Labs around the world that use the power of diversity and the disciplinary mastery of their staff to stimulate an innovation ecology accessible to everyone. The first Fab Lab was set up at MIT's interdisciplinary Center for Bits and Atoms, a second one in Boston's inner city. They serve youth, tinkerers, inventors as well as companies and students. Fab Labs can be used by all disciplines in teaching, professional development, applied research and research services. In this study, ten Fab Labs from the United States of America, Colombia, Spain, Iceland, The Netherlands, and Norway took part (see table 1). The labs were analysed in terms of value proposition, revenue model, processes and resources, marketing, and innovation partnerships.

	Americas	Europe
Location	USA (3), Colombia	Spain (2), Iceland, The Netherlands (2), Norway

Table 1. Geographical Sample Description (N=10).

Of the 10 Fab Labs we studied, four were independent entities, the other six were hosted at schools, research or innovation centres (see table 2). All those labs have been founded between spring 2007 and summer 2009. Their funding came typically from public sources or from their hosting institution; however, they were requested to become self-sustaining within 2 to 4 years. None of the labs had yet reached this stage.

	Educational	Research	Innovation	Independent
Fab Lab	2	2	2	4

Table 2. Fab Lab Hosting Institutions (N=10).

Regarding the value proposition, all labs indicated that their envisaged clientele be distributed across the board, including students, researchers, companies and the general public. However, nine labs reported that students were the main users at the labs, only three labs involved the general public, two attracted companies, and only one lab attracted researchers (see table 3).

	Students	Researchers	Companies	General Public
Target user groups	10	6	9	9
Current main users groups	9	1	2	3

Table 3. Target vs. Current Main User Groups at Fab Labs (N=10).

All labs indicated that their core competence was in technology, while five of them explicitly specified IT as additional core competence. Six labs additionally had core competencies in arts and design.

The main contribution to their users' processes was seen equally in education, research, and development and prototyping.

While all labs indicated their main value proposition was providing access to infrastructure that users would have no access to otherwise, seven indicated that access to experts was equally part of their value proposition, and six of the labs saw giving access to knowledge of the Fab Lab network as part of their value proposition (see table 4).

	Infrastructure	Experts	Fab Lab Network
Part of value proposition	10	7	6

Table 4. Value Proposition of Fab Labs (N=10).

Current revenue of the Fab Labs included in this study came mainly from public sources or from a hosting institution. Revenue from sponsoring or from users so far remained the exception. However, all labs indicated that they needed to become self sufficient within two to four years.

Regarding processes and resources, seven of the nine Fab Labs had their own employees, three were run by a faculty of their host university, and five were supported by volunteers. In terms of manufacturing technology, the labs typically adhered to the equipment proposed by MIT, sometimes excluding one single machine; eight labs offered their users extra equipment (such as 3-D-printers or embroidery machines).

Eight of the nine labs included in the study position their offering as 'social-tech', and one as 'green-tech'. None of them, however, positioned themselves as 'high-tech' or 'smart-tech' (e.g. intelligent materials etc.).

In terms of marketing, Fab Labs typically have their own Internet presence, however, only three of the nine labs in this study actively engage in PR.

The innovation ecosystems of the labs were relatively limited with few network and industry partners and few, if any sponsors (see table 5).

	0	1...5	6...10
Network partners	0	6	4
Industry partners	5	1	4
Sponsors	7	3	0

Table 5. Innovation Ecosystem of Fab Labs (N=10)

Also, labs rarely made use of the possibilities the Fab Lab innovation ecosystem offers. Only one lab indicated that nearly all projects required support from the network, two reported that on average every third project required support, while for the remaining labs this was the case on even fewer occasions (N=10).

Conclusions

In summary, the Fab Labs included in this study primarily offered infrastructures to students, and they were relatively passive in reaching out to potential other users. Their funding came from government or hosting institutions. They have so far created a limited innovation ecosystem. This ecosystem, however, gets used rather rarely.

Looking at single labs in the sample, there was a notable tendency that labs that engaged more actively in PR attracted also non-students as users. Also, labs that more explicitly saw themselves as providing access to the knowledge in the Fab Lab network tended to have more network partners in their innovation ecology and were more often asked by users to support their projects. This seems to indicate a distinction between Fab Labs that are focusing on supporting innovation, and those that primarily offer the lab as a production facility.

The study into the business models of Fab Labs finds that the funding for the Fab Labs included in the study came from government or hosting institutions. This is not surprising, given their relatively young age and their requirement to become self-sustaining within 3 to 4 years. The labs were primarily offering infrastructures to students, and they were relatively passive in reaching out to potential other users. They had so far created a limited innovation ecosystem, which got used rather rarely. This also suggests that there are two value propositions, namely labs providing facilities and labs providing innovation support.

Looking at single labs in the sample, there was a notable tendency that labs engaged more actively in public relations activities attracted also non-students as users. Also, labs that more explicitly saw themselves as providing access to the knowledge in the Fab Lab network tended to have more network partners in their innovation ecology and were more often asked by users to support their projects. This again indicates a distinction between Fab Labs that are focusing on supporting innovation, and those that primarily offer the lab as a production facility.

Both models, the innovation support model and the facility model, can be seen in the light of commons-based peer-production. Peer support in the innovation model would ideally form a complete ecosystem that could deliver the experience of effective and fast innovation to participating peers. It would certainly be in the spirit of Fab Labs that such an ecosystem would evolve around a hybrid, private-collective innovation model.

In the facility approach, which would support users primarily during their stay at the lab when using equipment and manufacturing process, the peer-production community would build around the experience of a well-run personal production process. Again, the spirit of Fab Labs would encourage a private-collective model of peer support.

The current business models of Fab Labs were built around external funding covering the (private) budget to create innovations. The challenge for these labs will be to achieve a level of funding—be it public or private—to sustain the hybrid, private-collective model of innovation. Similar to open source business models, the key probably would be to offer complementary services to generate revenue. For the two approaches making things still would remain the core function of the lab. For the Fab Lab as a facility, the complementary proposition would be to provide added value in terms of the digital production processes; for the innovation Fab Lab complementary services could be generated using a mix of ingredients determined by the facilities and (networked) competencies available.

Study 2
The 'Pain and Pride' of Fab Lab Managers and Assistants

During the international workshop and symposium on digital fabrication in Amsterdam (August 2010) I took the opportunity to interview 38 lab managers and lab assistants of existing and prospective Fab Labs. Of the 38 participants, 23 were from existing Fab Labs, 15 from labs that were in planning stages, including one lab that only opened a couple of weeks earlier. Participants were chosen because they attended a one-day workshop dedicated to Fab Lab management and achieving economic sustainability with a Fab Lab. I carried out focused, short interviews, rather than long, narrative ones. Therefore I asked them one question directed at their motivation and challenges at the lab. Methodologically, I borrowed from the critical incident technique (Flanagan, 1954), theoretically from Herzberg's two-factor theory (Herzberg, 1968). I transcribed the answers to our question 'What is your pain and pride at the Fab Lab?' and categorised them according to themes. Below, I first report the answers to the pride part and then to the pain part of the question, since 36 of participants spontaneously answered to pride first.

Pride

	existing lab	planned lab	total	cumulative % (N=38)
effect on users	8	2	10	26.32%
effect on kids	4	1	5	39.47%
community	2	5	7	57.89%
grass-root innovation	3		3	65.79%
innovate themselves	2	1	3	73.68%
innovation	1	1	2	78.95%
open and democratic	1	2	3	84.21%
Other single mention	being chaotic	concept of Fab Labs, educational impact, being local and independent, teaching kids	5	100.00%

Table 6: The pride of Fab Lab managers

Almost 40 % of respondents mentioned the effect a Fab Lab has on its users—in terms of empowerment, in terms of experiencing achievement, or more specifically in terms of mastering technology—as their main pride in the lab.

> 'I think it it it gives me great pride to know that at the end of the day I can change somebody's life directly by using the tools and machineries that are within the fab lab.'
>
> 'The best thing about a fab lab is the smile on the face of a middle-aged, unemployed, African American male who has been very, very discouraged. That's the second best thing. The first best thing is when he holds up the thing he just made and says: What I think: I'm going to play with this and make it better.'

Most of these statements came from existing labs; managers of planned labs referred to talking about their planned lab—'What I found really, really cool is when I'm explaining the concept of Fab Labs to my design friends, and they suddenly get very shiny eyes and see what they can do, and I see what cool projects they can do; and, what cool inventions they can do'—or from experiences they had with lab-type workshops earlier:

> 'There is a pride that we did in a demo workshop which lead up, which is just, you know, the twinkle in the eye of the people when the new world opens up and they see that they can do it themselves, like the artist get this capability to find out how arduino works, I think it will be even more with a fab lab. So I think this is going to be rock-n-roll.'

Community was the second single most important category, as in 'being part of a technology revolution that is not focused completely on commercialisation' or 'The pride is, unlike what some others said, is the community, the fab lab network. I am, I really appreciate all the support and help that I've received from them.' Most of these statements, however, came from people who don't actually have a Fab Lab yet; and sharing and availability of information is also mentioned as a pain (see below).

Innovation was another big topic why managers were proud of their Fab Lab. Some of them named innovation as a relatively general concept: 'imagination is our limit'; others highlighted the fact that a Fab Lab enabled users to innovate themselves:

> 'I would say the biggest pleasure or pride in the fab lab is what I call the fab lab magic, and that is when a young learner or a learner of any age has an idea, something pops in their mind, and all a sudden, minutes or hours later, they're holding in their hands. What happens between having an idea in their minds and holding in their hands is a big hook.'

For others yet the grass-roots aspect of innovation was more important, as in 'letting anyone who has and idea make something'.

Three people explicitly mentioned the open and democratic nature of Fab Labs, and one mentioned Fab Labs being 'local and independent' as their biggest pride. Again, these two topics seemed more important for those who have not started their Fab Lab yet.

Pain

The 'pains' of Fab Lab managers and assistants were more diverse than their prides. Top of the list for both, existing and planned Fab Labs was the question of funding. While for existing Fab Labs it was the question of sustainability—'my pains actually about funding, sustainability'. For planned Fab Labs it was a matter of getting seed funding:

> 'it's actually getting people so that they're more than really really excited, that they are so excited that they are going to give you the money. And it's really easy to get people excited about a fab lab, which is super. But actually getting them to, to write a cheque is a lot more difficult.'

The second important group of pains was about sharing information and finding it—the former was more an issue of existing labs, the latter concerned more the labs in planning:

> 'Biggest pain point is the ongoing challenge and difficulty of trying to find and share projects, I think is the biggest number in the top three issues, and the global fab lab community is to find,

> create the practical infrastructure and means of sharing projects so we can rapidly become an innovation network.'
>
> 'We're doing all this awesome stuff and we've get to document it in a such way that's—you know—accessible and out; that we can actually show people what Fab Labs are—you know—people that don't know; or that we can actually use the information in a constructive way.'

An issue that only managers and assistants of existing Fab Labs mentioned was that they did not get 'enough time on the equipment' themselves and that the learning curve was relatively steep. Finally and relatedly, staffing a Fab Lab with the right people was mentioned twice as an issue.

	existing lab	planned lab	total	cumulative % (N=38)
funding	4	7	11	28.95%
sharing projects/experience	4	1	5	42.11%
public availability of information on Fab Labs	1	2	3	50.00%
little time to spend on own projects	4		4	60.53%
(own) learning curve	2		2	65.79%
staffing	1	1	2	71.05%
Other, single mention	administration, explain the business benefits, knowledge about electronics, Fab Lab as a fashion trend, reminding users of their other responsibilities in life, unity of the community	flawed design of products coming out of Fab Labs, logistics, lack of a central Fab Lab organisation, lacking outreach to society at large, too strong a focus on technology	11	100.00%

Table 7: The pain of Fab Lab managers and assistants

Conclusions

Looking at the whole picture it can be seen that planned labs put more emphasis on the aspects of community and the lab being open and democratic or local and independent, while existing labs more prominently mentioned the effect of the lab on users, and particularly kids, and the innovation aspect when asked about their pride. The aspect of sharing and finding information concerned both existing and planned labs, with existing labs being particularly concerned about sharing. The visibility of community to the outside world, however, was criticised. One participant from a planned lab described it this way:

> 'I couldn't find any list of where all the fab labs in the world were or what a fab lab was or is it an organisation, is it just a name, is it just a casual name, you know, like a ... I don't know, and I still

> don't really know the answer to that, to be honest, but I don't think anybody does. So as a new user searching Google for "fab lab" that was my experience.'

Both existing and planned labs mentioned funding as their number one concern. It was experienced as difficulty because it required to find some kind of balance between generating enough funds to survive—maybe even with some more commercial ventures—while at the same time keeping the spirit of being grass-roots, creative and inventive. A manager of a planned lab nicely expressed this struggle in his statement as he corrects himself twice when using more 'business' language:

> 'the pain is the business model because we have to profit...we have to survive; so we have to make...to think about money. It's like something that does not match with the imagination and the creativity.'

Overall, this interview study created the picture that managers and assistants at Fab Labs saw and experienced their labs very much as being part of a community that comprised elements of commons-based peer production and of grass-root, user-driven innovation. The labs and the community at large seemed however to struggle with the hybrid aspect when looking for funding to sustain their ability for private investment while keeping the results open—i.e. gratis and accessible—to the community.

Study 3
Selected Fab Lab Innovation Projects

To illustrate how hybrid innovation actually could happen at Fab Labs, I selected five recent cases that are publicly documented and cover various aspects of innovation (see table 8).

Project	Innovation aspect
'Walking robot' by Edwin Dertien	sharing the project lead to 'serendipity' commercialisation
'Scottie' by Waag Society and Utrecht School of Arts	prototype development at Fab Labs
'50-$-leg' by Alex Schaub, Fab Lab Amsterdam, in co-operation with the House of Natural Fibre (HONF) and Yakkum Rehabilitation Centre, Yogyakarta, and MIT Fab Lab Norway	large collaboration project innovating the production and fitting of lower leg prostheses
'Chocolate letter Pi' by Hans Wisbrun	creating production equipment at a Fab Lab
'Pop-out card stand' by Fab Lab Manchester for It's Unique Ltd.	product innovation at a Fab Lab

Table 8: Selected Fab Lab innovation projects

One of these examples is the walking robot, developed by Dutch robot researcher Edwin Dertien. He created a little robot at the Fab Lab in Utrecht, the Netherlands. Because staff there liked the robot very much, they encouraged him to describe it on the lab's website (Dertien, 2009). He also added it to the website at instructables.com (Dertien, 2009a). Two days later he received an email from a manufacturer of flat-pack robot building kits. They wanted to add his robot to their programme. Edwin never thought about this possibility, and yet, a week later he started to earn money with his product which he just shared online (van Tubergen & Wijnia, 2010).

In a project named 'Scottie', Amsterdam-based media-lab Waag Society and Utrecht School of the Arts researched the possibilities of using information and communication technology to create virtual immediacy between long-term hospitalised children and their parents or grand parents. Scottie is a puppet that can communicate via the Internet with a similar puppet or mobile device that is used at home. Communication is non-verbal by using lights and colour codes (Lubsen, 2009). For a prototype, the puppet itself and its electronics were produced at Fab Lab Amsterdam and Protospace Utrecht. The making of the Scottie puppets is documented extensively online:

> 'We went to ProtoSpace Utrecht to make some 3d prints of positive models for Scottie. Siert set up the batch the night before, but the next day all of the parts were printed out stacked on top of each other. Here's what the print chamber looks like after the parts have been printed. You vacuum away the excess dust to find your parts. Once you've vacuumed out your parts, you place them in the other chamber for de-powdering.
>
> The finished prints contained a flange around the edges to make two part moulds. There are two separate pieces for the interior and exterior of the body. Unfortunately these prints were not used to make final moulds. We settled on using a 3D print that uses the whole model instead of creating boxes around the model. This uses less material and takes less time to print.' (Pelletier, 2009)
>
> 'I've been making PCB's for the Scottie Project for some time now, and recently I've started to make a board that contains all the sensors and actuators we're using. The sensors it contains/connects to are an accelerometer and four touch sensors. The actuators are six high brightness RGB LEDs and four solenoids. From this board a long cable runs to the 'brains' of the scotty, a GPRS-modem. Power and communications must go from the brains to the sensor-board, so a thick multi-core cable was chosen to do the job. Originally I was also running the output from the touch-sensor trough this cable, but there seems to be too much disturbance in this signal over this long distance.' (Withagen, 2009)
>
> 'Here they are! Good looking Scottie parts in PU! They have been casted in the fablab, without vacuum chamber. The moulds were pre-heated to 100 degrees before casting, which really helped to get a smooth finishing.' (Lubsen, 2009a)

The third example is an ongoing collaborative project between Fab Lab Amsterdam, the House of Natural Fibre (HONF) and Yakkum Rehabilitation Centre, Yogyakarta, and MIT Fab Lab Norway. The goal of the project is to develop a cheap, high-quality lower-leg prosthesis and the corresponding manufacturing and fitting tools and techniques.

> 'On the surface, there appears to be little difference in the design and manufacturing of prosthetic solutions between the approaches of "Western" and "third world" countries. However, considering the availability of materials, economical resources, skilled personnel, cultural, social and geographical differences, it seems that "third world" prosthetics might need a different approach. Direct translation of Western prosthetics technology into developing countries has, so far, proven insufficient due to many reasons' (Schaub, 2009).

In two workshops, HONF and Fab Lab Amsterdam established the requirements for such prosthesis and verified that the actual manufacturing cost would be around US$ 50 (Schaub & Pelletier, 2009; Agrivina et al. 2010). In the mean-time, Schaub et al. (2010) started to develop a 3D scanning system to facilitate the fitting process of a lower leg prosthesis. The stomp socket is the most important part of the prosthesis, because it has to sustain half the body weight and transfer walking forces between the body and the implement. In collaboration with the MIT Fab Lab Norway and other partners, Schaub and Berndtzen (2009) started to develop a low cost prosthetic alignment laser system that should almost meets the specifications of commercial scanners (such as Otto Bock's L.A.S.A.R system). This cheap D.I.Y. kit, made in a Fab Lab, would allow prosthesis makers in developing countries to have a professional tool to improve the alignment of limb prosthetics on their patients.

While the project is still under way, it is the most prominent example of several labs working together on one project, sharing knowledge, using personal digital manufacturing technology and developing a solution that can benefit a large population.

Another maybe slightly amusing example that initially started in a Fab Lab is the 'chocolate letter Pi'. Dutch natural scientist Hans Wisbrun combined his fascination as a mathematician with the constant π and the Dutch tradition of chocolate letters that are traditional gifts for St. Nicholas day. To produce π chocolate letter he made his very first steps making a mould at the Amsterdam Fab Lab:

> 'It all started off with an idea in December 2005: to produce chocolate letters with mathematical symbols. The letters would be sold, at a price to cover the costs, to the public attending the yearly Reunion of the National Organisation of Mathematics Teachers in the Netherlands (NVvW). The idea stayed in my sub-conscience for quite a while, but in July 2008, at the end of a Sabbatical Year, it sprang out again.
>
> Doing an Internet search I found out that a mould could be produced at Fab Lab Amsterdam. A couple of days later the work started. We (Mike Pelletier, a Fab Lab volunteer, and me, Hans Wisbrun, Wisc) started off with the mould for the mathematical symbol Pi.' (Wisbrun 2009)

In March 2009, coinciding with the international π-day (March 14), the chocolate letters were made available to the readers of one of the country's major newspapers, NRC (2009).

Finally, Fab Lab Manchester reported a case in August 2010 when they were able to help a local manufacturer, It's Unique Ltd, of pop-up greeting cards to design little devices that would help to keep the cards opened, showing their pop-up content—particularly in the case of the sport-themed stadium cards, such as pop-up football and sport stadia. These cards needed to be displayed in a somewhat different way to traditional 3-D greeting cards. The cards sat horizontally on the surface, and to display the stadium in correct perspective, they needed to be propped open as one would a hinged box lid. The existing plastic stand pairs were costing £2, which was too expensive for customers, taking into account the card was sold for only £4.99. They also had a relatively large carbon footprint, and most importantly, they could damage the greeting card when included with it in an envelope. The Fab Lab Manchester developed a simple, laser-cut design from cardboard that was equally suited to do the job.

'I can only describe the environmentally-friendly, laser-cut, pop-out card stand Fab Lab came up with as ingenious' Mike Smith, managing director at It's Unique, was reported saying (Kirkby, 2010).

Conclusions

The 'Walking robot' project shows the most prototypical business model for hybrid innovation in a commons-based peer-production environment. The product (i.e. the robot) was developed with private investment—but probably building on robotics knowledge that was already shared among peers—it was made available to the community as an open source product. On top of this, a commercial manufacturer of building kits is able to sell the product.

'Scottie' and '50-$-leg' impressively demonstrate the innovative power of commons-based peer-production. Both projects are set-up as research projects. 'Scottie' was funded through research and development grants, commercialisation options are currently being considered (Waag Society, 2007). The '50-$-leg' mainly lives from volunteer enthusiasm and contributions that could be made in the context of student internships. So it could be seen as a true private-collective innovation project while leaving the question open how infrastructure and out-of-pocket costs would be paid for.

'Chocolate letter Pi' and 'Pop-out card stand' show ways of commercialisation of work done in the peer-production environment of a Fab Lab. 'Chocolate letter Pi' is not yet a fully commercial proposal that would pay money back to the Fab Lab where it initiated. However it demonstrates the value of the services offered at a Fab Lab. 'Pop-out card stand' shows an obvious way how these services could be sold to commercial partners.

Discussion

In this paper, I portrayed the 'free fabbing' ecology and identified some of its important communities. To understand commons-based peer-production and the possibility of private-collective (hybrid) innovation in the fabbing context, I studied Fab Labs on three levels. First, in a survey analysis of the business model of 10 Fab Labs, I found two types of Fab Lab models, the innovation support model and the facility model, that both represent a way of commons-based peer-production. I also found, that all of the observed business models were built around external funding, and that none of the labs had yet found a way to the hybrid, private-collective model of innovation in the long term.

In focused interviews with 38 managers and assistants at existing and planned Fab Labs I found that they understood themselves as being part of a commons-based community of grass-root innovation. I also found that they struggled with the hybrid aspect and with finding a balance between attracting funding to sustain the lab while keeping the results open to the community.

Finally, I described five cases of Fab Lab innovation projects to illustrate three aspects of the hybrid innovation ecology. One case illustrated—through serendipity rather than planning—how a commercial offering could be built on top of an openly shared product. Two cases demonstrated the innovative power of the Fab Lab innovation ecology; however, one projects was more conventionally funded while the second indeed built on a private-collective model. The last two cases showed possible ways of commercialising Fab Lab services—one keeping at least parts of the results open source, the other as an example of a commercial, closed solution that builds on the open Fab Lab infrastructure.

I started out by asking, if there is room for a hybrid innovation ecology in commons-based peer-production, room for private-collective innovation models. In literature I found a number of studies that address this overall theme and give evidence that the hybrid economy actually is happening out there, at least in the open source hardware business. However, the literature was inconclusive regarding hybrid and open source innovation; and the contribution of 'free fabbing' (as in TechShops, Hackerspaces and Fab Labs) was hardly covered. In my studies I was able to show that there is a desire and intention to establish a hybrid innovation ecology in the Fab Lab community. Yet I also found that Fab Labs do not currently have established business models that would replicate the known models from open source software, i.e. selling complementary services to generate revenue for funding free fabbing. The interviews illustrated the desire of Fab Lab managers and assistants to find those solutions. Some of the case studies at least indicated the possibility of such models.

Limitations and future research

The three studies into the Fab Lab community used different sources of evidence; yet the approach is lacking at least one fourth element, the study of actual users of Fab Labs. Such a study based on participant observation and other methods should be able to clarify attitudes and behaviour of Fab Lab users as important stakeholders of a hybrid innovation model.

Limiting myself to the Fab Lab community helped to focus the research and to find consistent themes across the three layers of studies. To better understand the fabbing phenomenon and its hybrid, private-collective aspects, however, a comparison with other fabbing communities would lead to more insights and produce a wider picture.

Finally, I did not extend our research to include other known examples of peer-based innovation, e.g. the work on regional innovation clusters in the USA, Italy, Portugal (e.g. Porter, 1998) and elsewhere, or immigrant networks in the Silicon Valley and their transnational extensions (e.g. Saxenian, 1996, 2002). These examples would also include elements of reciprocity characteristic of hybrid, private-collective innovation models and could indeed convey valuable insights for the Fab Lab community. This is certainly an area worthwhile investigating.

Acknowledgements

I would like to thank the three anonymous reviewers for helpful comments on an early draft of the manuscript. I would like to extend special thanks to Kristina Lauche for her valuable suggestions on an earlier version of the paper. I would also like to thank the colleagues who helped undertake the three studies, particularly Marcel Scheidegger for collecting the data for study 1 and the many Fab Lab users for documenting their work which formed the basis of study 3.

References

100kGarages (2010). 100kGarages. Available online at http://www.100kgarages.com, accessed 30 August 2010.

Agrivina, Irene, Agus Tri Budiarto and Alex Schaub (2010). HONF Prosthetics Workshop II. 31 January 2010. Available online at http://amsterdam.fablab.nl/node/2626, accessed 10 August 2010.

Anderson, Chris (2010). In the Next Industrial Revolution, Atoms Are the New Bits. *Wired,* Feb. 2010. Available online at http://www.wired.com/magazine/2010/01/ff_newrevolution/all/1, accessed 4 June 2010.

Balka, Kerstin, Christina Raasch, Cornelius Herstatt (2009). Open Source beyond software: An empirical investigation of the open design phenomenon. Paper presented at the R&D Management Conference 2009, Feldafing near Munich, Germany 14-16 October 2009.

Balka, Kerstin, Christina Raasch, Cornelius Herstatt (2010). Open Source Innovation: A study of openness and community expectations. Paper presented at the DIME Conference, Milano, April 14th-16th, 2010.

Benkler, Yochai (2003). Freedom in the Commons: Towards a Political Economy of Information. *Duke Law Journal,* vol. 52, pp. 1245-1276.

Benkler, Yochai (2006). The Wealth of Networks. How Social Production Transforms Markets and Freedom. New Haven and London: Yale University Press.

Benkler, Yochai, and Helen Nissenbaum (2006). Commons-based Peer Production and Virtue. *The Journal of Political Philosophy.* Volume 14, Number 4, 2006, pp. 394–419.

Bessen, James (2006), Open Source Software: Free Provision of Complex Public Goods. In: Bitzer, Jürgen and Philip J. H. Schöder (eds.) The Economics of Open Source Development. Amsterdam: Elsevier. pp. 57-81.

Bonaccorsi, Andrea , and Cristina Rossi (2003). Why Open Source can succeed. *Research Policy,* 32(7): 1243-1258.

Chesbrough, Henry (2003). Open Innovation. The new imperative for creating and profiting from technology. Boston, MA: Harvard Business School Publishing.

Chesbrough, Henry (2006). New puzzles and New Findings. In: Chesbrough, Henry, Wim Vanhaverbeke, Joel West (2006): Open Innovation Researching a New Paradigm. Oxford: Oxford University Press, pp. 15-34.

Chesbrough, Henry (2006a). Open business models: how to thrive in the new innovation landscape. Boston, MA: Harvard Business School Publishing.

Dalle, Jean-Michel, and Nicolas Jullien (2002). 'Libre' Software: Turning Fads into Institutions? *Research Policy,* vol. 32, 1, January 2003, pp. 1-11.

Dertien, Edwin (2009). Lopend robotje met twee servo's. Available online at http://www.protospace.nl /node/583, accessed 6 June 2010.

Dertien, Edwin (2009a). SimpleWalker: 4-legged 2-servo walking robot. Available online at http://www.instructables.com/id/simpleWalker-4-legged-2-servo-walking-robot/, accessed 6 June 2010.

Dolittle, Joseph (2008). OSE Proposal – Towards a World Class Open Source Research and Development Facility. Available online at http://openfarmtech.org/OSE_Proposal_2008.pdf, accessed 6 June 2010.

Edwards, Kasper (2000). When Beggars Become Choosers. First Monday, vol. 5, 10 (October 2000). Available online at http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/795 (cached at http://pascal.case.unibz.it/retrieve/3589/, accessed 10 August 2010).

Edwards, Kasper (2001). Epistemic Communities, Situated Learning and Open Source Software Development. Working paper, available online at http://citeseerx.ist.psu.edu/viewdoc/download ?doi=10.1.1.24.7873&rep=rep1&type=pdf, accessed 10 August 2010.

Edwards, Kasper (2003). Technological innovation in software industry, Ph.D. Thesis, Department of Manufacturing Engineering and Management, Technical University of Denmark. Available online at http://edwards.dk/thesis.pdf, accessed 10 August 2010.

Fab Charter (2007). The Fab Charter. Available online at http://fab.cba.mit.edu/about/charter/, accessed 1 June 2010.

faberNovel (2007). Modèles économiques des logiciels open source et logiciels libres: quelques points de repère. Available online at: http://www.slideshare.net/faberNovel/research-paperles-business-models-de-l-open-source-faber-novel-consulting, accessed 30 August 2010.

Farr, Nick (2009). Respect the past, examine the present, build the future. 25 August 2009. Available online at http://blog.hackerspaces.org/2009/08/25/respect-the-past-examine-the-present-build-the-future/, accessed 30 August 2010.

Flanagan, John C. (1954). The critical incident technique. *Psychological Bulletin,* vol. 51, 4, pp. 327–358.

Gershenfeld, Neil (2005). FAB: The Coming Revolution on Your Desktop. From Personal Computers to Personal Fabrication. Cambridge: Basic Books.

Gjengedal, Arne (2006). Industrial clusters and establishment of MIT FabLab at Furuflaten, Norway. Paper presented at the 9th International Conference on Engineering Education. Available online at: http://www.ineer.org/Events/ ICEE2006/papers/3600.pdf, accessed 3 March 2010.

Graham, Marty (2007). Hackers Space: the Final Frontier. 20. October 2007. Available online at http://www.wired.com/threatlevel/2007/10/hackers-space-t/, accessed 30 August 2010.

Grenzfurthner, Johannes, and Frank Apunkt Schneider (2009). Hacking the Spaces. *monochrome.at.* Available at http://www.monochrom.at/hacking-the-spaces/, accessed 30 August 2010.

Hackerspaces (2010). HackerspaceWiki. Available online at http://hackerspaces.org/wiki/, accessed 30 August 2010.

Hackerspaces (2010a). List of Hackerspaces. Available online at http://hackerspaces.org/wiki /List_of_Hacker_Spaces, accessed 30 August 2010.

Hackerspaces (2010b). Synchronous Hackathlon. Available online at http://hackerspaces.org /wiki/Synchronous_Hackathon, accessed 30 August 2010.

Harhoff, Dietmar, Joachim Henkel and Eric von Hippel (2000). Profiting from Voluntary Information Spillovers: How Users Benefit from Freely Revealing Their Innovations. MIT Sloan School of Management Working Paper #4125.

Hemetsberger, Andrea and Christian Reinhardt (2004) . Sharing and Creating Knowledge in Open-Source Communities. The case of KDE. Paper presented at The Fifth European Conference on Organizational Knowledge, Learning, and Capabilities, Innsbruck, Austria.

Herzberg, Frederic (1968). One more time: how do you motivate employees? *Harvard Business Review,* vol. 46, 1, pp. 53–62.

Hess, Karl (1979). Community Technology. New York: Harper & Rowe.

Hippel, Eric von (2005). Democratizing Innovation. Cambridge, MA: MIT Press.

Jewell, Mark (2005). Imagine, Make It Real in Fab Lab. *Wired,* 6 November 2005, available online at http://www.wired.com/science/discoveries/news/2005/11/69495, accessed 3 March 2010.

Johnson, Justin Pappas (2001). Economics of Open Source Software. Available online at http://opensource.mit.edu/papers/johnsonopensource.pdf, accessed 10 August 2010.

Jones, Rhys, Erik de Bruijn & Adrian Bowyer (2010), : The Law and the Prophets/Profits. Presentation given at FAB6: The Sixth International Fab Lab Forum and Symposium on Digital Fabrication, Amsterdam, 15-20 August 2010; available at http://cba.mit.edu/events/10.08.FAB6/RepRap.ppt, accessed 30 August 2010.

Kelty, Christopher M. (2001), Free Software/Free Science. *First Monday,* Vol. 6, 12, available online at http://firstmonday.org/htbin/cgiwrap/bin/ojs/index.php/fm/article/view/902/811, accessed 10 August 2010.

Khalak, Asif (2000), Economic Model for Impact of Open Source Software, Available online at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.13.4269&rep=rep1&type=pdf, accessed 10 August 2010.

Kirkby, Eddy (2010). It's Unique: Innovation Diary. Available online at http://www.fablab.is/w/images /7/7a/Fab_Lab_Case_Study_Its_Unique.pdf, accessed 13 August 2010.

Lakhani, Karim R., Eric von Hippel (2003). How open source software works: "free" user-to-user assistance. Research Policy 32, 923-943. Available online at http://citeseerx.ist.psu.edu/viewdoc/download ?doi=10.1.1.110.8172&rep=rep1&type=pdf, accessed 10 August 2010.

Lakhani, Karim R. and Robert G. Wolf (2003). Why hackers do what they do: Understanding motivation and effort in Free / Open Source software projects". MIT Sloan Working Paper No. 4425-03. Available online at http://ssrn.com/abstract=443040, accessed 10 August 2010.

Lerner, Josh, and Jean Tirole (2000). The Simple Economics of Open Source, Working Paper 7600, National Bureau of Economic research, Cambridge, MA. Available online at http://citeseerx.ist.psu.edu/viewdoc /download?doi=10.1.1.145.3577&rep=rep1&type=pdf, accessed 10 August 2010.

Lerner, Josh, and Jean Tirole (2002). Some simple economics of Open Source. *Journal of Industrial Economics,* 50, 197-234.

Lerner, Josh, and Jean Tirole (2002a). The Scope of Open Source licensing. MIT Working Paper. Available online at http://opensource.mit.edu/papers/lernertirole2.pdf, accessed 10 August 2010.

Lubsen, Astrid (2009a). Scottie Casting With PU. 2 February 2009. Available online at http://amsterdam.fablab.nl/node/1653, accessed 10 August 2010.

Mikhak, Bakhtiar, Christopher Lyon, Tim Gorton, Neil Gershenfeld, Caroline McEnnis, Jason Taylor (2002). Fab Lab: An Alternative Model of ICT for Development. development by design (dyd02). Bangalore: ThinkCycle. Available online at http://citeseerx.ist.psu.edu/viewdoc/download ?doi=10.1.1.72.315&rep=rep1&type=pdf, accessed 10 August 2010.

NRC (2009). Chocoladeletter. Available online at http://selectie.nrc.nl/product.php?productid=709, accessed 20 February 2009.

Pelletier, Mike (2009). Scottie 3d Prints. 16 Feb 2009. Available online at http://amsterdam.fablab.nl /node/1809, accessed 10 August 2010.

Pfeiffer, Diane (2009). Digital Tools, Distributed Making & Design. Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfilment of the requirements for Master of Science in Architecture. Blacksburg, VA: Virginia Polytechnic Institute and State University.

Pomerantz, Gregory M. (2000). Business Models for Open Source Hardware Design. Available online at http://pages.nyu.edu/~gmp216/papers/bmfosh-1.0.html, accessed 30. August 2010.

Porter, Michael E. (1998). Clusters and the new economics of competition. *Harvard Business Review*, vol. 76, 6, pp. 77-90.

Sauer, Robert M. (2007). Why Develop Open Source Software? The Role of Non-pecuniary Benefits, Monetary Rewards and Open Source Licence Type. *Oxford Review of Economic Policy*, Vol. 23, 4, pp. 605-619

Saxenian, AnnaLee (1994). Regional Advantage: Culture and Competition in Silicon Valley and Route 128. Harvard University Press.

Saxenian, AnnaLee (2002). The Silicon Valley Connection: Transnational Networks and Regional Development in Taiwan, China and India. *Science Technology Society*, vol. 7, 1, pp. 117-149.

Schaub, Alex (2009). Fab Prosthetics. 22 June 2009. Available online at http://amsterdam.fablab.nl/node /2094, accessed 10 August 2010.

Schaub, Alex, and Berndt E. Berntzen (2009). Prosthetic Alignment Laser. 9 July 2009. Available online at http://amsterdam.fablab.nl/node/2221, accessed 10 August 2010.

Schaub, Alex, and Michael Pelletier (2009). HONF - Prosthetics Workshop. 4 May 2009. Available online at http://amsterdam.fablab.nl/node/1943, accessed 10 August 2010.

Schaub, Alex, Miguel Jimenez Gimenez and Oscar Gerritsen (2010). Open Source 3D Scanning System. 26 January 2010. Available at http://fablab.waag.org/node/2609, accessed 10 August 2010.

Shirky, Clay (2007). Re: [decentralization] Generalizing Peer Production into the Physical World. Forum post, 5 Nov, 2007 at http://finance.groups.yahoo.com/group/decentralization/message/6967, accessed: 30 August 2010.

TechShop (2010). TechShop is the SF Bay Area's Only Open-Access Public Workshop. Available online http://techshop.ws/, accessed 30 August 2010.

Torrone, Philip and Limor Fried (2010). Million Dollar Baby. Businesses Designing and Selling Open Source Hardware, Making Millions. Talk at the O'Reilly foo camp east, 1 May 2010. Available online at http://blog.makezine.com/archive/2010/05/million_dollar_baby_-_businesses_de.html, accessed 30 August 2010.

Troxler, Peter (2009). Open Content in the Creative Industries: A Source for Service Innovation? In: Wolf, Patricia, Sami Kazi, Peter Troxler and Ralf Jonischkeit, (eds.). Supporting Service Innovation Through Knowledge Management. Bristol: KnowledgeBoard, Zurich: Swiss Knowledge Management Forum. pp. 187-206. Available online at SSRN: http://ssrn.com/abstract=1597357, accessed 10 August 2010.

van Tubergen, Joris, and Elmine Wijnia (2010). Joris van Tubergen talks on open innovation and FabLab. Available online at http://vimeo.com/9677277, accessed 6 June 2010.

Von Hippel, Eric A. and Von Krogh, Georg (2003). Open Source Software and the 'Private-Collective' Innovation Model: Issues for Organization Science. Organization Science, Vol. 14, No. 2, March–April 2003, pp. 209-223. Available online at http://opensource.mit.edu/papers/hippelkrogh.pdf, accessed: 30 August 2010.

Waag Society (2007). Pilot Healthcare (GATE). Remotely play with loved ones. Available at http://waag.org/project/gate, accessed 10 August 2010.

Wisbrun, Hans (2009, 12 February). ChocoPI: Mathematical Symbols In Chocolate. Available online at http://amsterdam.fablab.nl/node/1719, accessed 15 February 2009.

Withagen, Bas (2009). Scottie Sensor-Pcb Design And Bits Of Trouble. 4 July 2009. Available online at http://amsterdam.fablab.nl/node/1916, accessed 10 August 2010.

Author Bio

Peter Troxler is an independent researcher at the intersection of business administration, society and technology. His interest and expertise are in management systems, such as quality and knowledge management, in the application of technologies, particularly Internet and Web 2.0 technology, and in the overall architecture and design of the social, technological and commercial aspects of enterprises. He is equally intrigued by the challenges of investigating models that explain and applying these models to both companies as permanent and projects as temporary organisations. One current topic is how structural and societal conditions influence and are influenced by various forms of co-creation, for example the current intellectual property and copyright regimes.

Peter has worked as a research manager in knowledge management and technologies at the University of Aberdeen (Scotland, UK; 2001-2004) and he has been a researcher in industrial psychology at ETH Zurich (1993-1999). Peter has also worked in business as a senior consultant for Akronym GmbH , Switzerland, (since 1997), as a senior project manager at Waag Society, The Netherlands, (2007-2009) and for GEC Alsthom (now Areva T&D) Switzerland as an industrial engineer (1988-1995).

Next to his business and academic assignments, Peter has helped to initiate various interdisciplinary cultural and artistic projects—in Lucerne (Switzerland) and Melk (Austria) he co-founded the group p&s (2000) that is responsible for the European project readme.cc virtual library (funded by the European Culture 2000 programme), and in Aberdeen (Scotland, UK) he initiated the project Oil and the City (2004/5) discussing the impact of the oil industry on the social life an cohesion in the city. Peter's contribution was in bridging the gap between culture and entrepreneurship. His interest in these projects was integrating arts, academia and media, and bringing about public involvement and public discourse.

Peter holds a Dr. sc. techn. and an MSc. in industrial engineering from ETH Zurich, he received a certificate in International Copyright Law from the University of Amsterdam, and he has received formal training in online journalism, in educational video production, as a facilitator for Local Agenda 21 and for Future Workshops, and in audio engineering.