Making the 3rd Industrial Revolution

The Struggle for Polycentric Structures and a New Peer-Production Commons in the Fab Lab Community

Peter Troxler

Within a decade, Fab Labs have developed from isolated initiatives to a global network of labs that spans all continents. Despite this fast and tremendous growth—or maybe precisely because of it—the global network struggles to define its form and purpose. That network is supposed to provide operational, educational, technical, financial, and logistical assistance beyond what is available within any single lab. Several institutions have emerged and started to provide portions of this assistance: The Fab Academy plays an important role in education. National and international Fab Foundations support operations and logistics of labs. A global user group is developing in the form of an international association. All these institutions are still in their nascent stage, trying to figure out their remit and scope and how to effectively and efficiently work together.

In this chapter, I will place this Fab Lab ecosystem in the context of a larger development in society, one that has the potential to disrupt or revolutionize the way products are manufactured; it is nothing less than the next industrial revolution. The roots of the Fab Lab development are technological and personal digital manufacturing has an important technical side to it. Undoubtedly, developments in manufacturing technology will play an important role in the next industrial revolution. Yet the main disruption that the next industrial revolution will bring is the disruption of hierarchical systems and the emergence of systems of lateral power. Digital manufacturing in a Fab Lab is personal, and the Fab Lab network is primarily a social network with lateral connections established between individuals. It reflects that new paradigm of the third industrial revolution; Fab Labs are places of peer-production. Institutions play important roles in providing support in the network where individual connections are not effective or not efficient. They serve specific purposes and provide specific competences. Within the Fab Lab network, there will be many of these centres of competence. But as of now, such structures have still to fully develop.

In this chapter, I will first outline the concept of the third industrial revolution and explain how Fab Labs relate to it. I will then highlight two specific issues in the development of that revolution: First, the difficulties arising from sharing and collaborative development of hardware as open source and how seeing Fab Labs as a peer-produced commons could help to resolve that issue; second, the institutional challenge that lateral power structures present and how communities and polycentric systems could provide an answer to that challenge. I will then discuss how Fab Labs can help to make the third industrial revolution happen and what I would count as a success in such a revolution. To conclude, I will present a roadmap

To appear in: J. Walter-Herrmann & C. Büching (Eds.), FabLabs: Of Machines, Makers and Inventors. Bielefeld, 2013: Transcript Publishers.

for the future—a set of five central questions around which development will have to evolve, and guidelines how to go about answering these questions.

1 The 3rd Industrial Revolution

Many authors have invoked the next or 3rd Industrial Revolution: Neil Gershenfeld (2005) wrote about ‘Fab. The Coming Revolution on Your Desktop’, Chris Anderson (2010) claimed that ‘In the Next Industrial Revolution, Atoms Are the New Bits and added that ‘Makers [are] The New Industrial Revolution’ (Anderson, 2012). Jeremy Rifkin (2011) described ‘The Third Industrial Revolution—How Lateral Power is Transforming Energy, the Economy, and the World’.

The first industrial revolution brought mechanization, centralized factories and industrial capitalists. Its flagship machine was the steam engine, its social effect the division between labour and capital. The second industrial revolution brought automation, scientific management and management consultants. Its flagship machine was the conveyor belt, its social effect the division between white-collar and blue-collar work. The third industrial revolution is happening right now. Its flagship machines are affordable digital manufacturing tools that are connected to the Internet. That means two things: First, affordable tools do not require huge capital investments, they bridge the labour-capital-divide; the owner-maker is re-emerging. Second, digital tools connect designing and manufacturing, they bridge the white-collar-blue-collar-divide; the designer-producer is having a comeback.

According to Gershenfeld, ‘possession of the means for industrial production has long been the dividing line between workers and owners. But if those means are easily acquired, and designs freely shared, then hardware is likely to follow the evolution of software. Like its software counterpart, opensource hardware is starting with simple fabrication functions, while nipping at the heels of complacent companies that don’t believe that personal fabrication “toys” can do the work of their “real” machines’ (p. 21).

For Anderson, ‘the Third Industrial Revolution is best seen as the combination of digital manufacturing and personal manufacturing: the industrialization of the Maker Movement’ (p. 41). This evidently has two aspects to it. First, digital tools and equipment are becoming widely used by makers both for designing and for manufacturing products, which makes sharing of and collaborating on designs over time and distances easier. Second, as files can be directly sent to machines for production (direct digital manufacturing), makers are able to use pooled manufacturing resources that are larger in scale than what any single maker possibly could afford.

In Rifkin’s view, makers and direct digital manufacturing are not the cause but one of the effects of the third industrial revolution. The revolution itself is actually triggered by changes in communication infrastructure and energy generation as it was the case for the first two industrial revolutions which were triggered by the invention of the printing press and steam-powered technology in the 19th century and by electrical means of communication (radio, TV) and electricity (mainly from fossil fuels) as main source of power in the 20th century.

1st revolution	2nd revolution	3rd revolution
19th century	20th century	21st century
Printing press	Radio, TV	Internet
Coal and Steam	Oil and Electricity	Renewable Energies

Table 1: Industrial Revolutions and Their Drivers: Communication and Energy Sources

In the 3rd Industrial Revolution, 'the conventional top-down organization of society that characterized much of the economic, social, and political life of the fossil-fuel based industrial revolutions is giving way to distributed and collaborative relationships in the emerging green industrial era. We are in the midst of a profound shift in the very way society is structured, away from hierarchical power and toward lateral power' (p. 36f).

Also for Rifkin, the 3rd Industrial Revolution includes a shift to green buildings, electric cars—and distributed manufacturing: 'a new digital manufacturing revolution now opens up the possibility of following suit in the production of durable goods. In the new era, everyone can potentially be their own manufacturer as well as their own power company. Welcome to the world of distributed manufacturing' (p. 117).

2 Making: Fab Labs Today

Ever since their first inception in 2002, Fab Labs equipped with digitally controlled machines and made available to ordinary people have started to spread a 'coming revolution on [the] desktop' (Gershenfeld 2005): the revolution of personal digital manufacturing. As means of industrial production became easily accessible and designs were shared freely, hardware was likely to follow the evolution of open source software and that 'a continuum from creators to consumers, servicing markets ranging from one to one billion' would evolve (p. 21), countering the paradigm of mass manufacturing and mass consumption with a peer-produced and community based commons.

In practice, many disciplines have already experienced going open source and community produced as the beginning of that third industrial revolution. Not only the software business was fundamentally changed by the advent of open source software. In music, 'piracy is the new radio' (Young 2012, 17:03); in journalism, blogs and social media have attracted much of the attention that printed papers used to get (Altermann 2008, Newman 2011), and user-generated YouTube videos are displacing corporate news teams (PEJ 2012); in encyclopedia Wikipedia has outgrown printed encyclopaedia in volume, depth, recency and use (Okoli et al. 2012).

For hardware, however, the route to this new world of open source hardware and distributed manufacturing might be somewhat thornier than in software. There are at least two issues to be considered. First, it would be naïve to believe that open source software practices could be simply copied and applied to the manufacturing domain without any alteration or adaptation, ignoring the constraints and opportunities that the materiality of hardware entails (sections 3 and 4). Second, roughly two in three Fab Labs are currently set up and run by institutions rooted in the old world order. These institutions by their very nature are alien to lateral power relationships, struggle to understand polycentric structures and heterarchies, and fail to embrace a peer-production commons (sections 5 and 6).

3 Open Source Hardware

Open source hardware is by no means a new phenomenon; and sharing of invention and product manufacturing information has been documented for the 18th and 19th century (e.g. Allen 1983, Nuvolari 2004, Bessen and Nuvolari 2011). James Bessen and Alessandro Nuvolari (2011) even conclude that 'that key technologies at the heart of industrialization…were, at times and places, developed through processes of collective invention' (p. 12) and that '[i]n some cases…aggressive patenting put an end to a period of extensive knowledge sharing' (ibid.). It is ironic that patenting has become blatant normality—to the extent that the number of patents filed in a country is used as the principal measure for its innovation performance—and that hardware has to be made 'open' again when it inherently and historically is open.

Advocates of open source hardware refer to the four freedoms defined in the software world—the freedom to study and use, to redistribute, to modify and to fork (redistribute modifications)—to define open source hardware. And implicitly they often assume that it is relatively straightforward to copy and apply open source software practices—online repositories of 'code' or blueprints, licenses granting those four freedoms, contributing to modules of the end product, widespread use of standard tools to create code—to the hardware domain. However, these practices have to be altered and adapted to account for the opportunities and constraints that the materiality of hardware entails; I see five challenges:

First, hardware is often inherently open, self-explanatory about its composition and ready to be reverse engineered, at least to those with some knowledge in the field. Consequently, the availability of blueprints is not always a requirement for sharing as products 'speak for themselves'.

Second, as hardware often is not IP-protected automatically, to keep that openness intact legally a license might not be adequate. The challenge lies in defeating the novelty requirement of related patent application or design registrations by open design techniques.

Third, breaking up complex systems into simpler modules is not as common in hardware design as in software—despite being promoted as good design practice. Combining modules is potentially more complex as in software as physical forces, mechanical fit and design considerations will have to be taken into account.

Fourth, there are materials involved that may come at a cost and manufacturing processes that may not easily be accessed or require specialist tooling. Different strategies can be employed to overcome such barriers, such as using industrial side-products as raw materials, pooling manufacturing resources or using more universal fabricators.

Fifth, the term hardware spans a much broader field than software and includes such far apart things as integrated circuits, home furniture and ship-to-shore container cranes. The different branches of hardware vary according to materials and technologies involved, manufacturing tools and processes, documentation customs and standards, etc., and the above mentioned characteristics may apply to a different extent.

Various initiatives have been started to define and certify open source hardware and relatedly open (source) design—e.g. the TAPR radio amateur community[1], Open Collector[2], the Open Hardware project[3], the Open Source Hardware and Design Alliance, OHANDA[4], the Open Source Hardware User Group[5], the Open Hardware definition at Freedom Defined[6], the Open Source Hardware Logo[7], the Open Hardware Association[8], host of the annual Open Hardware Summit, and the Open Design working group of the Open Knowledge Foundation[9]. Online repositories of open hardware have been started to appear, too—e.g. Instructables[10], Thingiverse[11], the Open Hardware Repository[12], Qi Hardware[13] to name a few.

4 Peer-Produced Commons

Similar to open source software this emerging ecosystem of open source hardware can be seen as a peer-produced commons—'thousands of volunteers…collaborat[ing] on a complex economic project'—as Yochai Benkler (2002, p. 371) described it, a third model of

1 http://tapr.org, created 1993

2 http://opencollector.org, created 2000

3 http://openhardware.org, created 2002

4 http://ohanda.org, created 2009

5 http://oshug.org, created 2010

6 http://freedomdefined.org/OSHW, created 2010

7 http://oshwlogo.com, created 2011

8 http://oshwa.org, created 2012

9 http://design.okfn.org, created 2012

10 http://instructables.com, created 2005

11 http://thingiverse.com, created 2008

12 http://ohwr.org, created 2009

13 http://en.qi-hardware.org, created 2009

production different from markets (that are orgnanized by price signal) and firms (that are organized by hierarchical command and control). A peer-produced commons builds on lateral relationships.

Peer production, according to Benkler (p. 404), builds on four attributes of the Internet-based economy:

1. Information is a non-rival good—it may be 'consumed' (used) by one consumer without preventing others to use it simultaneously. Obviously this is also true for manufacturing information: hardware blueprints, manufacturing instructions, machine settings etc.

2. Information can be produced at dramatically low cost. While producing physical goods will always incur the cots for materials, direct digital fabrication on community-owned machines—as e.g. in Fab Labs—brings down manufacturing costs considerably.

3. Creative talent—the main human input to the process of creation—is best controlled by the creative individuals themselves as they 'possess better information than anyone else about the suitability of their talents and their level of motivation and focus at a given moment to given production tasks' (p. 371).

4. Information exchange and communication—key to the coordination of production processes—are cheap and efficient across the Internet (if used appropriately). Moreover, in distributed manufacturing it is possible to create and distribute information globally and manufacture physical goods primarily locally or regionally, eventually reducing the amount of shipping goods globally.

Open source hardware as a peer-produced commons might at least initially take different shapes in different economic contexts: '[T]he killer app for personal fabrication in the developed world is technology for a market of one, personal expression in technology… And the killer app for the rest of the planet is [to overcome] the instrumentation and the fabrication divide, people locally developing solutions to local problems' (Gershenfeld 2006, 16:52-17:12).

Eric von Hippel, together with Jeroen de Jong and Stephen Flowers (2010) carried out a representative study in the UK and estimated that consumers' annual product development expenditures are £5.1bn or 2.3 times the annual consumer product R&D expenditures of all firms in the UK combined (£2.2bn).

Such peer-production communities—and the Fab Lab community is one of them—are challenging some foundational assumptions about the free market. 'What was formerly taken for granted or minimized in free-market theory—the role of social and civic factors in economic production—is becoming a powerful variable in its own right' as David Bollier (2007, p. 35) wrote. Christian Siefkes (2008) sought to generalize peer production 'into the physical world' and projected a picture of a society where peer production would be the primary mode of production.

Yochai Benkler (2003) cautioned that historically structural economic patterns were determined within a few decades at most after revolutionary technical developments and that '[t]he time to wake up and shape the pattern of freedom and justice in the new century is now' (p. 1276). 'What decentralized and nonmarket information production generally, and peer production in particular, need, is a space free of the laws developed to support market- and hierarchy-based production' (p. 1273). For a 'political economy of information' (Benkler 2003) new ways are needed how to pursue autonomy, democracy, and social justice—the political—and how to organize production and consumption—the economy.

5 Institutional Embeddedness and Institutional Challenge

The second issue—organization of and governance in the Fab Lab community—deserves special attention, not only because peer-produced commons require special forms of governance, but also because there is incongruence in the way makers as users of Fab Labs and institutions as the main providers of Fab Labs approach that issue.

Makers in Fab Labs on the one hand are focused on their own manufacturing projects and make use of their lateral relations as needed but do not normally bother about the organization of those relationships beyond those just-in- time needs. Occasionally they wish for better, more effective access to resources in the network. So far, however, they have only come up with very few sustainable and scalable ways to create new ways of organizing distributed personal manufacturing—organization and governance is not their core interest.

Institutions on the other hand are more concerned about organization, structures and governance, yet their solutions tend to be of conventional, hierarchical, top-down nature: centralized 'cathedral' structures rather than 'bazaars' of co-operation (Raymond 1999). Moreover, those solutions risk counteracting lateral approaches, suffocating emergent peer-to-peer initiatives—and they fail to get accepted by the makers.

Neil Gershenfeld points out that the power of the Fab Lab community is the bottom-up application of technology outside traditional institutions: 'The message coming from the fab lab is that the other five billion people on the planet aren't just technical sinks, they are sources. The real opportunity is to harness the inventive power of the world to locally design and produce solutions to local problems. I thought that's a projection twenty years hence into the future, but it's where we are today. It breaks every organizational boundary we can think of. The hardest thing at this point is the social engineering and the organizational engineering, but it's here today' (Gershenfeld, 2006, 15:36-16:00). However, the solution to 'social and organizational engineering' might not come from the engineers.

To successfully develop the digital manufacturing ecosystem beyond a mere collection of individual tinkerers, a common understanding is needed of how such an ecosystem would function. Such a common understanding could build on a suitable theory. However, canonical knowledge in business administration, industrial engineering and organization science on ‘how to run a factory’ and the collective wisdom of practitioners and consultants alike will only tell us the old story of hierarchies. Their ‘imagery of the centralized, rationalized bureaucracy is increasingly unable to capture the empirical world’ (Clemens 2005: 352), and insight has to be found outside those disciplines. Indeed, there is a substantial body of knowledge about collective action, self-organization and inverse infrastructures, and about peer-production and governing the commons. One has to turn to organisation science, social movement theory and ethnography to learn about and understand communities and polycentric systems.

6 Communities and Polycentric Systems

Communities, movements and collective action have been of research interest in social movement theory (see also chapter 2 in this volume). More recently the topic has gained interest in organizational analysis and design (see e.g. Davis et al. 2005). Siobhán O’Mahoney and Karim R. Lakhani (2011) discuss the impact of communities on organizations and find it can take four forms:

- Communities help organizations emerge
- Communities mediate the performance and growth of organizations
- Communities can pose competitive threats to organizations
- Communities outlive organizations

The Fab Lab community today might well be both threatening pre-existing organisations built around the provision of and education about technology, and helping new organizations emerge. Given the preference for lateral structures in the 3rd Industrial Revolution, new organizations will develop polycentric or heterarchical forms as defined by David C. Stark (2001), ‘with distinctive network properties (…) and multiple organizing principles’ (p. 71). A polycentric approach may be needed to solve the governance problems of the common-pool resources and the peer-produced commons of Fab Labs. Elinor Ostrom (2008) showed, that polycentric systems are one approach to solve collective-action problems related to the governance of public goods (commons) and common-pool resources.

Leonard Dobusch and Sigrid Quack (2010) compared the development of Wikipedia and Creative Commons in the years 2001 to 2008 and found that both started as relatively non-participatory, centralized organisations and developed into more participatory, decentralized structures. Creative Commons followed a strategy of decentralized first, participatory later; Wikipedia of participatory first, decentralized later. Mayo Fuster Morell (2011) found that Wikipedia also adapted organizationally over time to the changing needs of the community, and that it adopted a hybrid model for its infrastructure governance—the central Wikimedia Foundation adapted a traditional, representational democratic logic, while the community remains an innovative, elaborate, organizational model—similar to the successful open source initiatives of the Linux kernel and the Apache http server development projects (Lanzara & Morner, 2004).

These findings were also confirmed by recent research into ‘inverse infrastructures’—infrastructures that are formed bottom-up by means of many small private investments—in other than only the ICT sector (Egyedi and Mehos 2012). As Wim G. Vree (2003) poined out, inverse infrastructures require different thinking at the administrative level: ‘The words “design”, “construct” and “implement” used in the classical approach could be replaced by “bring about”, “cause to happen” or “create optimum conditions for growth”’ (Vree 2012, p. 276). Moreover, Tineke M. Egyedi (2012) portrayed inverse infrastructures as disruptive in the current institutional context and requiring more adaptive and robust infrastructure agreements, policies and regulation on national, regional and international level (p. 259f.).

The policy recommendations proposed by the European Design Initiative (Thomson & Taipo, 2012) acknowledged this development: Design innovation in the 21st century, they argue, is characterized by social-based developments and collaboration in networks of designers and stakeholders; and open source design is based upon European values of diversity, low power distance and democracy (p. 38). Hence they include as recommendation number 8: ‘Create guidelines, codes of practice, legal frameworks and experimental spaces to promote the use of Open Design’ (p. 45).

7 Making the Revolution

Understanding developments of common-pool resources and inverse infrastructures and policy recommendations aimed to promote more collaboration and networks is not sufficient. There is a need for more practical guidance: How to create communities and polycentric systems? Charlotte Hess and Elinor Ostrom proposed to use the Institutional Analysis and Development (IAD) framework for analysing knowledge commons (Ostrom & Hess 2007, p. 41). This primarily analytical framework comprises three clusters of broad variables:

1. The basic underlying factors or resource characteristics are the biophysical-technical characteristics, the attributes of the community and the rules-in-use (position of participants, boundary rules, authority, aggregation, scope, information availability and pay-off rules).
2. The action arena made up by action situations and actors.
3. The outcomes: patterns of interactions, outcomes, and the evaluation criteria that allow assessing these outcomes (see next section).

This framework can also serve as a guide for development. According to Ostrom and Hess, ‘the action arena…is an appropriate place to start when trying to think through the challenges of creating a new form of commons’ (p. 45). From the envisaged action situations likely patterns of interaction and outcomes can be estimated. Physical and material conditions, community conditions, and rules-in-use can then be derived that are likely to bring about those actions.

In the case of Fab Labs, the action arena would be a nested cluster of individual labs, regional networks and the international community.

Action situations would include small groups or even individual users working on projects, sharing information, machining parts etc., different individuals or groups co-ordinating machine access in a lab or labs working together on projects or common infrastructures, such as an interconnected system for project documentation. Fab Academy would be a specific action situation, the annual Fab Lab workshop and symposium, and so on.

Patterns of interaction would concern issues of over- and underuse of resources—laser cutters likely being overused, documentation repositories underused. They would address free riding, productive and conflict behaviour, etc.

Possible outcomes would be cohesion or secession in the community, growth of reciprocity or conflict, recognition or ridicule. As basic underlying factors for Fab Labs one could identify the geographical and social location of labs, their users, user communities and institutional embedding, and implicit and explicit rules such as the Fab Charter.

As part of its third set of variables, the IAD framework includes evaluative criteria. Of course they would need to be established before starting an analysis and development exercise as sketched above. But what would be those criteria in the case of Fab Labs? Beyond the apparent exponential growth of the number of labs and users, what are measures of success?

8 Measures of Success

For the Fab Labs as a peer-produced commons in the Third Industrial Revolution, I propose three measures of success:

1. The protection of interests and creative freedom of makers—makers should be able to protect their interest, such as being acknowledged as the originator, being able to produce and sell their products; and they should be able to freely create new products as they wish.

2. Wide access to new knowledge, processes and products—the heritage and knowledge of the community, things that others made, processes that others used, experience that others built need to be freely accessible to anyone in the community in order to gain inspiration and build upon on it.

3. The extent to which it is possible to appropriately and effectively create and capture value—the value of what makers create is two sided, the value it presents to the makers themselves, and the value it presents to others; this value forms a basis for transactions between individuals within the community and with the outside world.

Positive outcomes according to these criteria would be those that have a beneficial effect for makers in Fab Labs: in a working peer-produced commons they will have the authority to decide for themselves whether to contribute to the commons or not; they will be able to associate themselves and be associated with what they produce, they will be allowed to use and build upon what others made; they will be able to build a reputation, establish productive relationships with peers, and economically sustain themselves.

For Fab Labs, or whatever infrastructures the community would eventually use collectively, positive outcomes possibly would include: that they will sustain their key enabling role for the community, that they will be able to stay at the forefront of developments that further the development of the community and the spread of the Third Industrial Revolution, that they will become hubs for transactions in the community, and that the community will look after that collective infrastructure, also financially.

On the level of the community as a whole positive outcomes would be in the internal and external workings of the community: Internally the Fab Lab community will show cohesion without being sectarian, control of disruptive behaviour without the need for heavy policing, diversity in any respect without the constant threat of falling apart. Externally the community will be seen as one that not only provides access to direct digital manufacturing equipment to nerdy makers but as one that also sparks innovation, empowers individuals and groups from all walks of life and contributes to a thriving economy and the human condition in general.

9 Conclusions: A Roadmap for the Future

There is a lot of change in the cards—making hardware open source, creating a peer-produced commons, overcoming incumbent institutional structures and corresponding mind set, developing strong, living and interconnected communities and their institutions, and achieving an appropriate balance of interest, influence and importance in a polycentric system demand some quite fundamental rethinking of how to organise the world.

As Jeremy Rifkin (2012) points out, the 3rd Industrial Revolution will require 'a wholesale reconfiguration of the economic infrastructure' and 'a massive retraining of workers on a scale matching the vocational and professional training at the onset of the First and Second Industrial Revolutions'.

Fab Labs can contribute to both, the reconfiguration of the economic infrastructure and the (re)training of workers. Fab Labs have the potential to tell a compelling story that can become part of the overall narrative of the Third Industrial Revolution that Rifkin is missing in EU policy.

To be able to tell that compelling story, the Fab Lab community has to stop being preoccupied by machines and making only and wake up to the challenges of 'the social engineering and the organizational engineering' (Gershenfeld 2006); it must start working on how to organize the ecosystem, too. I propose that this development could evolve around a roadmap of five key questions:

- How to build effective forms of collective action and self-organisation for Fab Labs?

- How to break free from traditional systems of manufacturing and creating value and creatively design new systems that tap into the capabilities of Fab Labs?
- How to protect the interests and creative freedom of makers while also ensuring wide access to new knowledge, processes and products?
- How to appropriately and effectively create and capture value?
- How to achieve equity and fairness?

However, it is crucial that the community itself takes responsibility for the study of these questions and the development of answers. The contributions by external professionals such as social scientists and management consultants can be crucial at times; any relevant development in a peer-to-peer community will have to come from within, from peers who are actually part of the community and contribute to that community and its commons.

Research will have to be participative, not purely observational; researchers are expected to involve others in their research and leverage their different kinds of knowledge ('engaged scholarship', van de Ven 2007, p. 9). Collaboration and a multiplicity of views are important, as is the question how to evaluate development and monitor progress.

Design has to be emergent, not prescriptive. While theory can and should inform practice, practice also refines theory. There is a need to put forward new hypotheses and develop new knowledge through 'research action' (Heller 2004, p. 352).

Making the 3rd industrial revolution is not an easy engineering or design task: learning and exploring the unknown will be required, a journey of on going trial and error over a several decades. In software, this is termed 'perpetual beta' (O'Reilly 2005)—which might loosely equal the notion of the 'learning organization' (Senge 1990) in management.

On this journey we have to be prepared to get surprised, we must dare to fail, and we will have to disagree, but constructively.

References

Allen, Robert C. 1983. Collective Invention. *Journal of Economic Behavior and Organization, 4,* 1: 1–24.

Altermann, Eric (2008). Out of Print. The death and life of the American newspaper. New Yorker, 31. March 2008. Online at: http://www.newyorker.com/reporting/2008/03/31/080331fa_fact_alterman (accessed 20. September 2012).

Anderson, Chris (2010). In the Next Industrial Revolution, Atoms Are the New Bits. *Wired Magazine, 1,* 25.

Anderson, Chris (2012). Makers. The New Industrial Revolution. New York: Crown Publishing Group.

Benkler, Yochai (2002). Coase's Penguin, or Linux and the Nature of the Firm. *Yale Law Journal, 112:* 369–446. Online at: http://www.yalelawjournal.org/images/pdfs/354.pdf (accessed 20. Sept. 2012).

Benkler, Yochai (2003). Freedom in the Commons: Towards a Political Economy of Information. *Duke Law Journal 52:* 1245–1276. Online at: http://scholarship.law.duke.edu/dlj/vol52/iss6/3/ (accessed 20. Sept. 2012).

Bessen, James E. and Nuvolari, Alessandro, Knowledge Sharing Among Inventors: Some Historical Perspectives (2012, forthcoming). In: Dietmar Harhoff and Karim Lakhani eds., Revolutionizing Innovation: Users, Communities and Open Innovation. Cambridge: MIT Press. Pre-Print: Boston Univ. School of Law, Law and Economics Research Paper No. 11-51; LEM Working Paper 2011/21. Available at http://www.bu.edu/law/faculty/scholarship/workingpapers/documents/BessenJ-NuvolariA101411fin.pdf

Bollier, David (2007). The Growth of the Commons Paradigm. In: Ellinor Ostrom and Charlotte Hess (eds.). Understanding Knowledge as a Commons. From Theory to Practice. Cambridge, MA: The MIT Press. pp. 27-40.

Clemens, Elisabeth S. (2005). Two Kinds of Stuff: The current encounter of social movements and organizations. In Gerald. F. Davis, Doug McAdam, W. Richard Scott, and Mayer N. Zald (eds.), Social Movements and Organization Theory, pp. 351-366. New York: Cambridge University Press.

Davis Gerald. F., McAdam, Doug, Scott, W. Richard and Zald, Mayer N. (eds.) (2005), Social Movements and Organization Theory. New York: Cambridge University Press.

Dobusch, Leonard, Quack, Sigric (2010). Managing Boundaries between Organizations and Communities: Comparing Creative Commons and Wikimedia. Paper presented at the 3rd Free Culture Research Conference, October 8-9, 2010, Berlin. Online available: http://wikis.fu-berlin.de/download/attachments/59080767/Dobusch-Quack-Paper.pdf (accessed 20. Sept. 2012).

Egyedi, Tineke M. (2012). Disruptive Inverse Infrastructures: Conclusions and Policy Recommendations. In: Egyedi, Tineke M., Mehos, Donna C. (eds.) (2012). Inverse Infrastructures. Disrupting Networks from Below. Cheltenham: Edgar Elgar; pp. 239-264.

Egyedi, Tineke M., Mehos, Donna C. (eds.) (2012). Inverse Infrastructures. Disrupting Networks from Below. Cheltenham: Edgar Elgar.

Fuster Morell, Mayo (2011). The Wikimedia Foundation and the Governance of Wikipedia's Infrastructure. Historical Trajectories and Its Hybrid Character. In: Lovink, Gert, Tkacz, Nathaniel (eds.). Critical Point of View. A Wikipedia Reader. Amsterdam: Institute of Network Cultures; pp. 325-341. Online at: http://www.networkcultures.org/_uploads/%237reader_Wikipedia.pdf (accessed 20. Sept. 2012).

Gershenfeld, Neil (2005). Fab. The Coming Revolution on Your Desktop. New York: Basic Books.

Gershenfeld, Neil (2006). Digital Revolution in Fabrication. TED talk. Online at: http://www.ted.com/talks/neil_gershenfeld_on_fab_labs.html (accessed 20. Sept. 2012).

Heller, Frank (2004). Action Research and Research Action: A Family of Methods. In: Catherine Cassell and Gillian Symon (eds.) Essential Guide to Qualitative Methods in Organizational Research. London: Sage. pp. 349-360.

Hippel, von, Eric, Jeroen P J de Jong, and Stephen Flowers. Comparing Business and Household Sector Innovation in Consumer Products: Findings From a Representative Study in the UK. Online at: http://ssrn.com/abstract=1683503 (accessed 20. Sept. 2012).

Lanzara, Giovan Francesco, Morner, Michèle (2004). Making and Sharing at Electronic Crossroads: The Evolutionary Ecology of Open Source. Paper presented at the The Fifth European Conference on Organizational Knowledge, Learning, and Capabilities, 2-3 April, 2004, University of Innsbruck, Austria. Online at: http://www2.warwick.ac.uk/fac/soc/wbs/conf/olkc/archive/oklc5/papers/j-3_lanzara.pdf (accessed 20. Sept. 2012).

Newman, Nic (2011). Mainstream media and the distribution of news in the age of social discovery. How social media are changing the production, distribution and discovery of news and further disrupting the business models of mainstream media companies. Oxford: Reuters Institute for the Study of Journalism. Online at: http://reutersinstitute.politics.ox.ac.uk/fileadmin/documents/Publications/Working_Papers/Mainstream_media_and_the_distribution_of_news_.pdf (accessed 20. September 2012).

Nuvolari, Alessandro 2004. Collective Invention during the British Industrial Revolution: The Case of the Cornish Pumping Engine. *Cambridge Journal of Economics, 28,* 3: 347–363.

O'Reilly, Tim (2005-09-30). What Is Web 2.0. Online at: http://oreilly.com/web2/archive/what-is-web-20.html (accessed 20. Sept. 2012).

O'Mahoney, Siobhán, Lakhani, Karim R. (2011). Organizations in the Shadow of Communities. In: Marquis, Chris, Lounsbury, Michael, Greenwood, Royston (eds.). Communities and Organizations. pp. 3-36. Bingley: Emerald Group.

Okoli, Chitu, Mehdi, Mohamad, Mesgari, Mostafa, Nielsen, Finn Årup and Lanamäki, Arto, The People's Encyclopedia Under the Gaze of the Sages: A Systematic Review of Scholarly Research on Wikipedia (March 13, 2012). Online at: http://ssrn.com/abstract=2021326 or http://dx.doi.org/10.2139/ssrn.2021326

Ostrom, Elinor (2008). Polycentric systems as one approach for solving collective- action problems. Working paper number W08-6, Bloomington: The Vincent and Elinor Ostrom Workshop in Political Theory and Policy Analysis. Online at: http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/4417/W08-6_Ostrom_DLC.pdf?sequence=1 (accessed 20. Sept. 2012).

Ostrom, Elinor, Hess, Charlotte (2007). A Framework for Analyzing the Knowledge Commons. In: Ellinor Ostrom and Charlotte Hess (eds.). Understanding Knowledge as a Commons. From Theory to Practice. Cambridge, MA: The MIT Press. pp. 41-81.

Ostrom, Vincent, and Ostrom, Elinor (1977). Public Goods and Public Choices. In: E.S. Savas (ed.), Alternatives for Delivering Public Services: Toward Improved Performance. Boulder, Westview Press.

PEJ (2012). YouTube & the News: A New Kind of Visual Journalism. PEJ report, 16 July 2012. Pew Research Center, Project for Excellence in Journalism. Online at http://www.journalism.org/node/30171 (accessed 20. September 2012)

Raymond, Eric (1999). The Cathedral and the Bazaar. Knowledge, Technology & Policy, 12, nr. 3: 23-49.

Rifkin, Jeremy. 2011. The Third Industrial Revolution. How Lateral Power is Transforming Energy, the Economy, and the World. New York: Palgrave Macmillan.

Rifkin, Jeremy (2012). Beyond Austerity: A Sustainable Third Industrial Revolution Economic Growth Plan For the European Union. An Executive Summary of Jeremy Rifkin's Keynote Speech for the Mission Growth Summit: Europe at the Lead of the New Industrial Revolution, hosted by The European Commission, May 29th 2012. Available online at http://ec.europa.eu/enterprise/policies/innovation/files/mg-speech-rifkin_en.pdf (accessed 20. Sept. 2012).

Senge, Peter M. (1990) The Fifth Discipline: The Art and Practice of the Learning Organization. New York: Doubleday.

Siefkes, Christian (2008). From Exchange to Contributions. Generalizing Peer Production Into the Physical World. Berlin: Siefkes. Online at http://peerconomy.org/text/peer-economy.pdf (accessed 20. Sept. 2012).

Stark, David C. (2001). Ambiguous Assets for Uncertain Environments: Heterarchy in Postsocialist Firms. In Paul DiMaggio (ed.). The Twenty-First-Century Firm: Changing Economic Organization in International Perspective. Princeton: University Press, pp. 69–104.

Thomson, Michael, Koskinen, Taipo (eds.) (2012). Design for Growth and Prosperity. Report and Recommendations of the European Design Leadership Board. Brussels: DG Enterprise and Industry of the European Commission. Online at: http://ec.europa.eu/enterprise/policies/innovation/files/design/design-for-growth-and-prosperity-report_en.pdf (accessed 20. Sept. 2012).

Van de Ven, Andrew H. (2007), Engaged Scholarship: A Guide for Organizational and Social Research. Oxford: Oxford University Press.

Vree, Wim G. (2003). Internet en Rijkswaterstaat: een ICT-infrastructuur langs water en wegen. Inaugurele rede uitgesproken bij de aanvaarding van het ambt van hoogleraar ICT aan de faculteit Techniek, Bestuur en Management van de Technische Universiteit Delft, 29. Jan. 2003. Online at: http://www.tbm.tudelft.nl/en/about-faculty/departments/iss-department/ict-section/staff/wim-vree/publications/inaugural-speech/ (accessed 20. Sept. 2012).

Vree, Wim G. (2012). The Internet and Rijkswaterstaat: An ICT Infrastructure for Roads and Waterways. In: Egyedi, Tineke M., Mehos, Donna C. (eds.) (2012). Inverse Infrastructures. Disrupting Networks from Below. Cheltenham: Edgar Elgar; pp. 267-290.

Young, Neil, Mossberg, Walt, Kafka, Peter (2012). Dive into Media: Neil Young. 31 January 2012. Online at: http://allthingsd.com/video/?video_id=1598C8DC-7B17-4E42-A95A-DE703ACC12A9 (accessed 20. September 2012).

About the Author

Peter Troxler is a Research Professor at Rotterdam University of Applied Sciences on the topic of the Revolution in Manufacturing. His field of research is the impact of readily available direct digital manufacturing technologies and the design and manufacturing practice of “fabbers” and “makers” on the creative and manufacturing industries, and the emergence of networked co-operation paradigms and business models based open source principles.

Peter is an industrial engineer by training (PhD 1999 from ETH Zurich). He worked in factory automation, attaching robots and automatic tool-changers to CNC milling machines before pursuing his career as a business consultant and later as a research manager at the University of Aberdeen in knowledge technologies and knowledge management.

Peter has acquired notable experience and standing in community building—among others working with his own fringe theater company in Lucerne, Switzerland, organizing arts festivals in Switzerland and Scotland, and as the community representative for knowlegeboard the largest community of knowledge management researchers in the mid 2000s.

Since 2007, Peter has been involved in Fab Labs in various ways, initially as a project manager of the Fab Lab Amsterdam, then as co-organizer of the international Fab Lab workshop and symposium in Amsterdam in 2010 and supporting new Fab Labs getting started in Switzerland (Lucerne) and the Netherlands (Rotterdam). In 2012/13 he was the president of the International Fab Lab Association.