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Peter Troxler

Beyond Consenting Nerds

Lateral Design Patterns for New Manufacturing

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Hogeschool Rotterdam Uitgeverij

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Beyond Consenting Nerds

Lateral Design Patterns for New Manufacturing

Inaugural Lecture

Peter Troxler

Lector
De revolutie van de maakindustrie

November 17th, 2015

CONTENTS

CHAPTER 1

Industrial Revolution 4.0

Mark Hatch is the CEO and founder of TechShop, a do-it-yourself workshop and fabrication studio with locations across the US. Mark is a former Green Beret and has held several executive positions before founding TechSchop, often bringing businesses successfully into the online marketplace. At Avery Dennison he launched Avery.com, at Kinko's he launched the eCommerce portion of Kinkos.com.

TechShop is supposed to revolutionise industry and radically democratise access to the tools of innovation by making access to these tools cheap and affordable. To that end Mark Hatch works with Autodesk, Ford, GE, and Lowe's, governmental agencies like DARPA, and the Veterans Administration. TechShop must reshape how innovation and manufacturing are done; and according to Mark, it has already had a significant impact on the economic development in the communities in which it is active.

In 'The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers' Mark writes:

> *If you come from a Judeo-Christian religious background, whether Jewish, Protestant, or Catholic, then you know that the first book of the Torah or Old Testament is the book of Genesis. Read Genesis Chapter 1 closely. Whether you believe in the literal interpretation of Creation or not, we can probably agree on two things coming out of this chapter. God is a maker, and he made us in his image. It is a very powerful introduction to God and who we are as humans. What do you know about humanity by the end of the chapter? It says, "God made" (or "let," or "created") some 15 times and ends with making people in his image. At the end of Genesis 1, we may not know much about God or humans, but we do know one thing for sure: we were made to make.*
>
> *There is nothing that can replace making—philosophers, religious scholars, and personal experience make that clear (Hatch, 2013, 12).*

A spectre is haunting Europe—and the Western world: the spectre of a new industrial revolution. Service-based economies of Western, post-industrial countries are hailing the former glory of manufacturing as the silver bullet which will end the current crisis. Reshoring, smart industry and new manufacturing are the magic words at the core of a recipe for new economic prosperity. Makers are the new garage inventor heroes; Fab Labs spell the magic of bringing technology to everybody from young children to old-age pensioners.

3D printing is heralded as the game-changing technology for manufacturing and consumption alike, empowering end users to print, instead of buy, the goods they need and thus invalidating the basic rules of mass production and disrupting the global supply-chains that bring container loads of cheap products from China to the West. In the guise of the maker movement, manufacturing has been reappearing in cities from where it had been banned in the wake of a former industrial revolution, with Fab Labs and maker spaces mushrooming, revitalising emptied industrial buildings and shopping streets, bringing the tools of manufacturing to the masses.

Around the globe, consenting nerds do not get tired of insisting that manufacturing and technology are no longer the domain of specialist engineers and that they are becoming the arena for everybody to express their passion through technology. Like computers some thirty years ago, manufacturing has now reached the desktop—and lost its utilitarian stigma. Manufacturing is no longer a chore, it can also be fun; it is no longer dirty but can even happen in the living room and in the classroom. There is a new industrial revolution taking place, and this time it is for the good of the Earth and for the liberation of humankind.

This new industrial revolution, however, is not the Lernaean Hydra that the word revolution would suggest. It appears rather to be a cuddly pet that brings fun and empowerment to consumers who have been incapacitated by the post-war reality of mass production, mass consumption, and mass compliance with the dictates of mainstream taste—as a romantic vision of a new renaissance reconciling the liberal arts with science and technology. New principles are supposed to change manufacturing: the notion of playfulness, the idea of open source, the concept that ‘quick and dirty’ and ‘just in time’ can prevail over well-planned and ‘just in case’. The creative individualist who stands out from the conformist crowd is the new ‘ideal man’, a Randian hero equipped with welding guns and 3D printers, ready to take over a world where anyone can be excellent by choice alone—if they are only taught to use technology early on and are eager to participate in a sharing economy.

Beyond the sphere of consenting nerds, in the creative industry, artists and artisans who have been practising boutique manufacturing are joined by an increasing number of designers—and engineers—producing their own products and gadgets locally or in a network of small manufacturers, often driven by new ways of reaching customers and financing activities such as crowdfunding. Quite often, these products are made in very small batches or built to order and even offer a degree of personalisation or individualisation.

At the other end of the spectrum, in policymaking and the incumbent industry itself, the various manifestations that together make up that new industrial revolution—increased digitisation, computerisation and robotisation, the collection of increasing amounts of data and the use of digital communication networks—have certainly drawn attention. Many countries are developing industrial policies that address the development of more computerised, more automated, and more data-driven manufacturing that is able to cater for low volumes, high complexity and high variability of products and production. Germany's Industrie 4.0 programme (Dais & Kagermann, 2013), the UK's Industrial Strategy (Department for Business, Industry and Skills [BIS], 2013), and now the Smart Industry Agenda in the Netherlands (Smart Industry, 2014).

Big players in industry are also starting to adapt to the maker movement, Fab Labs and their way of working seriously. Airbus in Toulouse, France, has set up an internal Fab Lab called Protospace to speed up aircraft innovation. GE Appliances in Louisville, Kentucky, has started its microfactory 'FirstBuild', where the crowd is invited to create new household appliances. With the opening of a Fab Lab at the Redondo Beach facility in California of the defence contractor Northrop Grumman, the movement has reached the military-industrial complex. Companies expect more and faster innovation and higher employee involvement from their internal Fab Labs and they are interested to learn how these new ways of working could possibly change the way industry has operated for decades.

While these new forms of industrial production certainly amount to a revolution within manufacturing, the developments also impact on two key resources of manufacturing—people and places. New practices in manufacturing—but also in research and development—require corresponding skills, attitudes and expertise from employees. It seems obvious that with ever increasing presence of technology, the disciplines of science, technology, engineering and mathematics (STEM disciplines) also become increasingly important. Paired with that goes an understanding that so-called '21st century skills' (or capacities) also acquire added importance—creativity, critical thinking, problem solving, communication, collaboration, digital literacy and social and cultural skills are typically mentioned (see Finegold & Notabartolo, 2010). There is broad agreement that teaching these capacities and skills requires radically different approaches to education—approaches that are indeed more in line with some of the practices in the maker movement. These changes in the conceptions of what constitutes effective professional educational practice could truly amount to a revolution in the classroom (see Pellegrino & Hilton, 2013).

New patterns in manufacturing also change the requirements which apply to the places and spaces for manufacturing—particularly when manufacturing takes place in urban environments and when manufacturers desire to interact more directly with their clientele. Equally, the way of (re)developing cities to accommodate new manufacturing entails fundamentally rethinking the administrative, regulatory and policy practices that govern the management, allocation and development of such localities, both with regard to property owners and developers, and with regard to regulatory bodies, particularly local, but also regional and national governments. When big property developers cede to networks of owner-developers or user-developers, the role of government bodies changes to one of a facilitator rather than a regulator, and grand visions give way to continuously evolving but strategically aligned plans. Urban redevelopment does indeed undergo a revolution.

Revolutions tend not to be orderly development processes. All the developments mentioned above are still on-going and new aspects and developments are emerging daily. The mission of the research programme *De revolutie van de maakindustrie* is threefold and corresponds to the further structure of this inaugural lecture:

- to study the impact of the 'Industrial Revolution 4.0' with respect to Making[1] and manufacturing (chapter 2), on people and skills (chapter 3), and on spaces and places (chapter 4) by monitoring current developments, analysing and reviewing them critically, highlighting important elements and separating out hype and exaggeration;
- to actively contribute to these current developments by shaping local manifestations of some of these generic developments, to reflect upon such interventions (chapter 5) and to indicate current gaps in understanding and implementation (chapter 6); and
- to signal future challenges that are likely to impact on the further evolution of the abovementioned revolutions (chapter 7).

1 In this document, 'Making' with a capital letter is used to refer to this emergent industry and to distinguish it from 'making' as the present participle of 'make'.

CHAPTER 2

2 Making and Manufacturing

When Christian Waber and Jiskar Schmitz posted their 'Folding Wood Booklet' on Thingiverse in October 2011, they did not expect that this post would spur a flurry of reactions on blogs ranging from boingboing and Make to Designboom and Inhabitat. This made this technique for creating wooden hinges and bends—also known as 'kerf bending'—hugely popular among makers and designers alike.

Having to answer technical questions was only a minor consequence of publishing the 'Folding Wood Booklet'. The product itself was suddenly under sky-rocketing demand, as were the services Christian and Jiskar provide with their company Snijlab.

Over the years, their business evolved from custom lasercutting to providing bespoke digital design and manufacturing services to local designers, industrial clients and even multinationals.

Making and manufacturing have multiple interactions which are driven mainly by two factors. Firstly, high-tech manufacturing equipment and processes are available and accessible in the more low-end Making context through shared machine shops—the general public can make use of robots, drones and 3D printers in Fab Labs and maker spaces. Secondly, iterative and prototyping-first design methods as practised by artists, designers and makers spill over into industrial design, engineering and manufacturing practice—companies, for instance, shorten new product development processes significantly by applying these tactics.

Computer-controlled manufacturing technology has become extremely easy to operate, to the extent that MIT's Joi Ito proffered 'deploy or die' instead of 'demo or die' as the new motto of the Media Lab. There is no hard boundary anymore, he argues, between a demo and a functional thing (Ito, 2014). Indeed, Neil Gershenfeld's course 'How to make almost anything'—mainly attended by artists and designers, not the engineers and scientists it was initially designed for (Gershenfeld, 2005, p. 6)—was translated into an outreach programme for fabrication laboratories (Fab Labs) in 2001. Over the past decade a global network of over 600 Fab Labs emerged from this programme. In Fab Labs, makers spend their time on the tools of industrial manufacturing and create technology-based weird or useful objects. Fab Labs and other spaces for high-tech DIY (Do-it yourself) form the Maker Movement—a term mainly promoted by Makermedia, its magazine 'Make' and the regular Maker Faires, and TechShop Inc., both funded in 2006. *Making* has become a combination that 'blends Dada, high-tech and DIY' (Heathcote, 2013). Borrowing from Adhocism (Jencks & Silver, 1972/2013) and including contemporary ideas like hacking and mass customisation Making forms a new and potentially explosive mix of leisure activity and entrepreneurship.

When artists, designers and engineers engage in Making activities, they find in Fab Labs not only the equipment to develop and realise their projects, but also like-minded people to help them with design and manufacturing problems. The manufacturing practice that they (re)develop very much resembles earlier small-scale localised alternative production systems, e.g. the arts and crafts movement of the late nineteenth century, the various lines of "appropriate technology" approaches (e.g. Bergmann & Schumacher, 2004; Fuller, 1968; Papanek, 1971; Schumacher, 1973) or the English 'Technology Networks' of the mid-1980s (see Smith, 2014). As 'designpreneurs' (Borja de Mozota, 2011) or self-producing designers, they operate outside of mainstream manufacturing to create their own niche and produce and deliver goods to a market (Margolin, 2003). This emerging industry, situated between artisanal crafts and traditional mass manufacturers, forms a kind of *Boutique Manufacturing* that becomes a new paradigm that builds on the 'deploy or die' imperative.

Manufacturing as mainstream industry in experiencing a sudden revival after three decades of steady decline in Western economies. Germany—which succeeded in maintaining a sound manufacturing base—made about €200 million available for a project called 'Industrie 4.0'. Its aim is to upgrade German industry to use intelligent production systems and processes and to operate in distributed and networked production sites (Dais & Kagermann, 2013). In the UK a new industrial strategy was established in 2013, endowed with several billion pounds of government money. Its focus is on skills, technologies, access to finance, procurement and sector partnerships (BIS, 2013). In the Netherlands, government and industry bodies have proposed a 'Smart Industry Agenda' (Smart Industry, 2014) to render manufacturing more digital, more efficient and more flexible, to produce higher quality and to become better suited to tailored job (or small batch) production. While government programmes mainly focus on advanced manufacturing technologies, robotics and a higher informational integration of manufacturing systems, industry itself also appears interested in reaping the benefits of Making—agility instead of procedures, open innovation instead of R&D silos—to develop some kind of *New Manufacturing*.

2.1 Making

Making in the developed world may be read in at least four ways, depending on the context and one's critical perspective. Firstly, it may be read as a mainly bourgeois pastime that carries the token of rebellion, but in its core are just a new form of entertainment and consumption. Only very few members of the movement develop fundamentally new things, the vast majority simply copy existing projects and add small and mostly cosmetic adaptations. The genealogy of the Rep Rap project—an open source 3D printer for desktop use developed by Adrian Bowyer's team at the University of Bath (Bowyer, 2007)—and its countless clones are a case in point. The success of kits, the popularity of Thingiverse and Instructables for sharing and finding projects, and the steadily growing number of visitors to the Maker Faires are further telling evidence. The readership demography of 'Make Magazine' reveals some more interesting insights into the maker population: eight out of ten readers are male with a median age of 44, report a high median household income of $106,000, and are married home-owners with children under the age of seventeen; 97 % attended college, four out of ten hold postgraduate degrees; and 83% of them are employed (Karlin Associates, 2012).

Secondly, Making may be read as an innovation in technology education. It resonates with the call of industry and its lobbies in many countries, who fear that there will be a decline in the technically skilled workforce. However, critics have accused industry of manipulating the labour market, 'inflating supply and depressing demand for scientists and engineers' (Macilwan, 2013). Furthermore, research has shown that the problem of a diminishing technical workforce is due to location mismatch: talented people are available, but not necessarily where they are needed (Craig, Thomas, Hou & Mathur, 2011). Still, many governments subsidise science, technology, engineering and mathematics (STEM) education. The educational method that corresponds best to a Making environment is 'learning-by-making' (Papert & Harel, 1991, p. 1), constructionist learning, as opposed to traditional instructionist pipeline models of transmitting knowledge. Beyond being an educational method, constructionist learning also has epistemological implications. It is concerned with the nature of knowledge and knowing in answer to questions such as 'What counts as knowledge?' and 'How is this knowledge structured?' It challenges the canonical epistemology of STEM education that knowledge is abstract, impersonal and detached, and counters it with epistemological pluralism (Turkle & Papert, 1991). Increasingly, libraries are starting to play a role in providing Fab Labs as places for out-of-school learning.

Thirdly, Making may be read as a new renaissance that is supposed reuniting the liberal arts with science and engineering in a contemporary and playful way. This notion of play is expressed both in the products and artefacts of the maker movement and in the constructionist approach to learning discussed above. One aspect of play is to try different approaches to a situation or problem and learn from the success or failure of these approaches. Another, complementary aspect of play is that this trial-and-error approach is not impeded by a fear of failure. Failing and learning from failure is important and encouraged, particularly when failure is quick and cheap. In engineering, this means stepping back from rigid, multi-disciplinary, time-consuming systems-engineering approaches and adopting a highly iterative, interdisciplinary and quick mode of working. Airbus has implemented this approach in its internal Protospace, where Airbus employees were able to develop new subsystems for aircraft within weeks rather than the industry standard of several years. Such an approach is much more fundamental than just 'design thinking' as the result of the process is not just a mock-up, but a fully functional, complex product. In the arts, artists have indeed engaged with technology and science for a long time. However, art theory had the tendency to pigeonhole 'art and technology', 'media art', 'computer art', 'Internet art', 'art and science', etc. into separate pockets, which rather unhelpful if one wishes to appreciate the overall contribution of the arts. The umbrella term 'hybrid art' is increasingly used to indicate how artists are doing research and technology development that would be rejected by mainstream science and industry, but is of critical societal relevance.

Fourthly, Making may be read as a 'new industrial revolution' (Anderson, 2012). This revolution has a number of ingredients: empowerment through mastery of technology gives people the means to understand and build seemingly very complex things. It also allows people to understand that the way technology works in most cases is not a technological given. On the contrary, it is determined by decisions made by humans—often engineers working for big corporations whose motives might not always be to build socially useful products. It therefore allows people to expose corporate strategies—e.g. design for obsolescence, the notion that you do not own a product if you cannot open it--and stimulates the quest to repair broken goods, or for the gendered design of technology. Another ingredient of the revolution is the move away from globalised mass production to local, small-batch production and lateral and networked forms of organisation (Rifkin, 2011). Indeed the fab charter also states that 'Fab Labs are a global network of local labs' (Center for Bits and Atoms [CBA], 2012). Technical empowerment and local production create the hope that this revolution will create new work and income, in particular for the high number of unemployed youth, in an emerging collaborative and sharing economy. In its contemporary manifestation, however, the sharing economy has slid rapidly 'from neighborliness to the most precarious of casual labor' (Slee, 2014). A final revolutionary aspect of Fab Lab and the maker movement is the impact on scientific endeavour. Technical empowerment allows individuals to participate in and carry out scientific research. Citizen science allows for large scale, distributed and long-term data collection and investigation, greatly expanding the capacities of hybrid art mentioned above. It is bound to complement and contrast the established production systems of scientific knowledge.

2.2 Boutique Manufacturing

New manufacturing principles are at the basis of an emerging new manufacturing industry. Small-batch production is gaining traction as new products are developed quickly and cheaply and shipped to customers within relatively short time frames. The industry also appears to blur the boundaries between what used to be clear divisions of labour and clear-cut roles in the supply chain. Customers, in particular, acquire new roles as co-creators of products and, communities start to build around new products that go substantially beyond traditional brand fandom. End users can choose to improve products and share those improvements with the manufacturer, or they can share ways of using products with other users. These communities become a strong and active parts of the brand ecosystem.

Examples of such companies include 3D printer manufacturers MakerBot and Ultimaker, or Arduino, which manufactures a popular electronics and micro-controller experimentation and development kit. Ultimaker built a community of about 1,600 users, who discuss their experience with and suggest improvements to the machine. In doing so, they provide the internal R&D department with useful empirical information and an input into the innovation process. MakerBot and Arduino have set up platforms where users can share the way they use the products. Thingiverse, MakerBot's platform, has become the number one resource for people wanting to share and find designs for 3D printing.

The Arduino Playground, a wiki where users share their code, circuit diagrams and tutorials, is a resource that adds to the popularity and usefulness of the kit.

These boutique manufacturing projects are often collaborative. Various individuals and organisations join and leave the project at various stages of its development. The available manufacturing infrastructure makes it relatively cheap and easy to switch back and forth between development and design, and prototyping and testing. This collaborative and iterative mode of production is structurally different to traditional in-house research and development. It requires new ways of organising R&D and new tools to handle intellectual assets that facilitate collaboration across the boundaries of organisations and seamless iteration between designing and prototyping.

An organisational model that has been suggested is peer production (Benkler, 2002). It is characterised by '(1) radical decentralisation of the capacity to contribute to effective action and the authority to decide on the contribution and (2) reliance on social information flows, organisational approaches, and motivation structures, rather than on prices or commands, to motivate and direct productive contributions' (Benkler, 2004, p. 331). This does not mean, however, that 'anything goes' in a peer production setting; there are typically coordination mechanisms in place to decide if an individual contribution is accepted into the project. Often the project initiators have the final say—as 'benevolent dictators' balancing the interests of the project and the cohesion in the peer production community. Status within peer production communities is often based on the contributions of individuals to the community and the project. However, at the same time such a meritocracy is intriguing and problematic. It is intriguing in that it promises that people will be judged and rewarded for their contribution, their merit. It is also highly problematic in that it completely ignores the question what factors actually contribute to that merit, such as speaking a language or not, or having a certain education or not.

Networked groups which practise new modes of production and who work on integrated and mixed technologies also need new tools to manage their intellectual assets, such as inventions and designs. Patents, as the traditional answer, have long come to the end of their serviceable life as a 'one-size-fits-all' solution, which is not a surprise given the fact that all Western patent laws are 'but a series of footnotes' to the first modern general patent statute enacted in Venice in 1474 (Nard & Morriss, 2006, p. 234). The patent system was 'designed for an era before such technological innovations such as internet transmission, global e-commerce, open-access research networks, cumulative and complex invention models, and bioinformatics' (Maskus, 2012, p. 315). New tools include open-source inspired 'open-hardware licenses', but also the layering of legal titles (such as licensing, trademarks, design) and the further exploration of the role of the public domain.

Indeed, industry appears to increasingly using open-source approaches, from open-source drug discovery to the recent announcement of Tesla Motors that 'all our patent are belong *[sic]* to you' (Musk, 2014), although the actual significance of this remains uncertain.

Additionally, any legal title granting protection or a monopoly on the commercial exploitation of intellectual assets places the burden of monitoring and pursuing infringement on the shoulders of the holder of that title. A manufacturing system that allows (almost) everybody to make (almost) anything or to have (almost) anything made is an environment in which such a monitoring task is a demanding endeavour. So for very practical reasons entities in new manufacturing might wish to make their projects open source, particularly as open source brings limited risks and low transaction costs compared to the patent system, which involves litigation risk and high transaction costs (Cimoli, Dosi, Maskus, Okediji & Reichman, 2014, p. 30).

Peer production and the idea of open-source products which are freely available (as in beer) often provoke the rather romantic notion of 'sharing is caring'. A sharing economy is expected to be one in which people use things instead of owning them and rent out what they own when they are not using it. This sharing economy would do away with the failures of capitalism—for instance, supposedly rigged prices in cartels of hotel owners and taxi companies—and would create new jobs or at least income for more people. Making in shared Fab Labs perfectly fits that image and could help liberate the world from poor products dumped upon us by the increasingly complex capitalist manufacturing system geared towards mass consumption.

In reality, however, the proponents of this sharing economy—AirBnB, Uber—are met with protests and legal action. They are mainly criticised for obstructing improvements in labour and consumer rights protection as they are impinge on the market of traditional and more regulated service providers—hotels, taxis, etc. The (capitalist) business valuations of the central platforms that 'facilitate' such supply and demand in the sharing economy mainly benefit the owners of these platforms, and these benefits 'are not exactly trickling down' (Cagle, 2014). Furthermore, Brad Burnham suspects that these businesses are merely replacing the fixed costs of inventory by the fixed costs of having venture capital investors (see Bercovici, 2014).

The sharing economy has the appearance of a social Happy Valley. Making is supposed to bring about 'Meaning in a Throwaway World' (Frauenfelder, 2010), to help in the quest for more control over one's life, to bring simplicity and clarity to the absurd chaos of modern life, 'to forge a deeper connection and a more rewarding sense of involvement with the world around us' (*op. cit.*, p. 3). 'The sharing economy is largely heralded as a "return to the village," an ahistoric utopia where we were friends with all of our trusted neighbors, lived in harmony with nature, and wanted not to consume, but to share' (Le Tellier, 2014). Fab Labs are depicted as a possible answer to mass youth unemployment, for instance in Italy where it reached around forty percent in 2013 (Maietta & Aliverti, 2013, p. 31). A depressed labour market is certainly one precondition for the sharing economy as people need to supplement their income. Roose (2014) suggests that 'in many cases, people join the sharing economy because they've recently lost a full-time job and are piecing together income from several part-time gigs to replace it.'

In the 'Open Source Everything Manifesto', Steele (2013) depicts a world of bottom-up, consensual, collective decision-making based on open-source principles and peer production: 'The wealth of networks, the wealth of knowledge, revolutionary wealth—all can create a nonzero win-win Earth that works for one hundred per cent of humanity. This is the "utopia" that Buckminster Fuller foresaw, now within our reach' (p. 55). In his analysis, particularly the US and the UK, but eventually most Western countries, are on the brink of a revolution, as many of the preconditions of a revolution have been fulfilled—'from elite isolation to concentrated wealth to inadequate socialisation and education, to concentrated land holdings to loss of authority to repression of new technologies especially in relation to energy, to the atrophy of the public sector and spread of corruption, to media dishonesty, to mass unemployment of young men and on and on and on' (Ahmed, 2014). A powerful scandal that could not be ignored could ignite the revolution, according to Steele.

Others have also tried to create a peer-produced 'free and libre open knowledge (FLOK) society' (Barandiaran & Vila-Viñas, 2015) as a counterpart to neoliberalism, a project that is vaguely reminiscent of anarchists' ideas—imagining the dissolution of hierarchy and the like. As the first outcomes of an experiment to 'create a FLOK society in Ecuador' started to percolate, this approach appeared to lack any reliable approach to pertinent change. The experiment certainly was not the 'Tunisian fruit seller' (Ahmed, 2014) to trigger Steele's open source revolution.

Both 3D printers and electronics kits are generic products in the sense that they allow for many different applications. They are also complex products that require a substantial amount of specific knowledge and experience for their effective and enjoyable use. By building those communities of users who share such knowledge, MakerBot, Ultimaker and Arduino in essence created a knowledge commons as part of their product-service system. Such a knowledge commons creates a strong brand asset to counter knock-off copying, as Anderson (2012) explicitly shows for the DIY Drones project.

There has been an explosion in the literature on the subject of Start-Up Entrepreneurship, like Lean Start-Up, Disciplined Entrepreneurship and the Business Model Canvas (see e.g. Teece, 2012; Arend, 2013). However, the establishment of a designer/maker business has a number of specific characteristics. One is essentially building a factory, which traditionally requires substantial investment, and it may be difficult to release a minimal viable product until a facility has actually been built. However, as described above, the internet provides a platform to communicate with potential customers, sell them an idea and the values of a new brand (for example, Fairphone) or product, or even localise the production of a product in a local facility (e.g. Opendesk). It is these innovative approaches to bringing products to market and overcoming the obstacles of significant upfront investment that the Business Design Studio will seek to capture and share.

Not all products created in new manufacturing share those same characteristics of being generic and knowledge-intensive in their use. Still the creation of a community around a new manufacturing initiative is an appealing move. Opendesk, a platform to showcase furniture designs and facilitate their local production, uses a community approach to curate their catalogue of designs by voting and showcasing the use of the designs on an interactive map.

Further work will analyse which parts of this approach are usable for other products and services, and under which circumstances and conditions, particularly with regards to the creative industry in Rotterdam and its potential for economic leverage (Rutten, 2014).

2.3 New Manufacturing

The manufacturing technologies used, however, constitute one core difference between those earlier ideas and Fab Labs and the Maker Movement. The computer-controlled machines of Fab Labs require little specialist tooling and setting up. A point in case is 3D printing, which in many cases allows users to manufacture a part directly from the computer drawing. Other examples include computer-controlled sheet material cutting and milling. A significant reduction of tooling and set-up cost diminishes the economic advantage of mass production or even makes it disappear, as Brody & Pureswaran (2013) have shown. Flexibility and suitability for tailored job production are inherent characteristics of Fab Lab-style manufacturing.

Design and manufacturing in Fab Labs normally take place physically in the same place and in an iterative fashion. This closeness in space and time allows for faster feedback between the two activities, which are typically separated in mass manufacturing. One consequence is that design and development lead times can be shortened to a great deal—an idea that has been known in industry for a long time

(Takeuchi & Nonaka, 1986; Schuh & Wiendahl, 1997) and that has been widely researched and implemented as 'concurrent engineering'.

Prototyping has its roots in the early days of mechanical engineering (Ullman 2010, p. 116) and remains an important tool in engineering and designing physical products. Still it appears to be absent from most state-of-the-art theoretical design models (Elverum & Welo, 2014, p. 492). Concurrent engineering, i.e. the interface between product design and engineering, on the one hand, and manufacturing on the other hand, are still in need of further advances. Such advances should enable practitioners to manage this interface based on experience and intuition, rather than well-researched methodologies and methods that bridge the gap between generalisation and instantiation (Dekkers, Chang & Kreutzfeld, 2013, pp. 329-330).

The first examples of how industry adapts to and absorbs the new manufacturing paradigm are emerging. Engineers at Ford have prototyped a vibrating gear-shift knob that uses real-time car data to provide haptic feedback to the drive. The knob was produced on a home-grade MakerBot 3D printer, its electronics used repurposed parts of a Kinect. The project has been shared publicly on Ford's OpenXC platform.

Airbus has established its internal Fab Lab called Protospace in Toulouse, France. At their Protospace, Airbus developed a prototype of what they call 'Immersive Deported View', an instrument to give the pilot a 360° view from underneath a plane when taxiing, consisting of a set of cameras and a virtual reality headset. This development took them only a couple of weeks, which is incredibly short compared to the usual lead times of several years for such a development (Loubière, 2014).

GE Appliances took the concept one step further and set up a microfactory, FirstBuild, in partnership with the University of Louisville, Kentucky, Local Motors (an open-source car builder community), MakerBot (a company producing home-grade 3D printers) and TechShop Inc. (which operates maker spaces in the US). The microfactory is supposed to 'harness the global brain of the maker community to bring innovative, new products to market faster' (GE Appliances, 2014).

These examples show how new manufacturing principles are deployed in a context of open innovation (Chesbrough, 2006; von Hippel, 2005), providing decentralisation of power, and how they provide empowerment of employees in the case of Ford and Airbus, and even customers in the case of GE Appliances. While these examples certainly are just a small beginning of how manufacturing could change, there are other studies that focus mainly on the impact of digital manufacturing technology—particularly 3D printing, use robotics in assembly and open-source electronics. Brody and Pureswaran (2013) find that those new manufacturing technologies might not only lower the average manufacturing costs of products, but may possibly lead to a '90 percent decrease in the minimum economic scale of production required to enter the industry' (p. 10) over the course of the coming twenty years.

CHAPTER 3

People and Skills

Neil *Gershenfeld, the founding father of Fab Labs, recounts how he set up the first Fab Lab outside MIT:*

> *Starting in December of 2003, a CBA team led by Sherry Lassiter, a colleague of mine, set up the first fab lab at the South End Technology Center, in inner-city Boston. SETC is run by Mel King, an activist [and former MIT professor] who has pioneered the introduction of new technologies to urban communities, from video production to Internet access. For him, digital fabrication machines were a natural next step.*
>
> *For all the differences between the MIT campus and the South End, the responses at both places were equally enthusiastic. A group of girls from the area used the tools in the lab to put on a high-tech street-corner craft sale, simultaneously having fun, expressing themselves, learning technical skills and earning income. Some of the home-schooled children in the neighborhood who have used the fab lab for hands-on training have since gone on to careers in technology (Gershenfeld, 2012, 47-48).*

Despite their apparent 'desktop convenience', the digital manufacturing technologies of Making are not that simple and straightforward to use. Turning an idea into a physical object is still not a trivial process and typically involves creating a digital, three-dimensional model, probably preparing that model so it can drive a digital fabricator, and often a considerable amount of post-production (see e.g. Ree, 2011; Hielscher & Smith, 2014). All sorts of skills—technical, creative, and interpersonal—play a role in this process,.

The technical skills relate to science, technology, engineering and maths (STEM) education, which recently received considerable interest from industry, educators and policymakers alike. Including Making in curricula is seen as a promising attempt to make STEM education more broadly accessible, particularly for young women, and more fun. There is broad agreement that beyond disciplinary training, education needs to provide students with 21st century skills—creativity, critical thinking, problem solving, communication, collaboration, digital literacy, and social and cultural skills (see Finegold & Notabartolo, 2010; Pellegrino & Hilton, 2013).

Education is also supposed to prepare students for a career which might regularly force them to revise and update their knowledge and skills as a 21st century form of life-long learning. Teaching to learn requires radically different approaches in education—reducing instruction and increasing construction of knowledge. Corresponding learning formats and teaching methods are indeed more akin to some of the practices in Making.

Making has made its way into education on the primary, secondary and tertiary levels.

3.1 STEM Education

Science, technology, engineering and maths—the STEM disciplines—have received a lot of attention from educators and a strong industry lobby recently. They paint a picture of an increasing demand for a STEM skilled workforce that would not find sufficient supply in the labour market if there were not more science and engineering students. In Western countries it has become commonplace to publicly argue that this shortage of technically skilled personnel is actually imminent.

Whether this projection is correct does not remain undisputed. Critics argue that already 'we may be training too many scientists' (Watson, 2010), that the increase in STEM salaries—or rather the striking lack of it—in the past decade does not support the idea of a workforce shortage (Brooks, 2013), that flooding the market with STEM graduates even 'reduces competition for their services and cuts their wages' (Macilwain, 2013).

I agree with Brooks, who warns that ‘pushing more students towards such courses without ensuring they learn more than just fact-farting and number-juggling may fill entry-level jobs’ but would fail to ‘bring through those who will solve the problems of climate change and energy, food and water scarcity’ (Brooks, 2013). Indeed, the abstract mastery of STEM subjects is not sufficient. What is required is their practical application in invention and manufacturing.

Many new projects require the combination and integration of various STEM disciplines—computing, electronics, mechanical engineering and materials science—often in relatively small teams. Those disciplines not only differ in their scope, they also differ in their methodological approach. These differences become strikingly apparent in the on-going digitalisation of products and services (Deken, 2015), be it in Making, new manufacturing or traditional industries. They make interdisciplinary collaboration particularly challenging and impose high demands on the social skills of people and the ability to reflect on their disciplinary background.

3.2 21st Century Skills

There is broad debate—and agreement—that students today need different skills to those taught to previous generations. So-called 21st century skills include e.g. critical thinking and problem solving, collaboration and leadership, agility and adaptability, initiative and entrepreneurialism, effective oral and written communication, accessing and analysing information, curiosity and imagination (Wagner, 2008).

However, these skills do not *replace* the requirement for profound understanding of the basics of their disciplines. On the contrary, to be able to face 21st century challenges—the problems of climate change and energy, food and water scarcity, the problems of an ageing society, and of a society that needs to re-engage with its own responsibility and that exists in a more densely technicised world—students need to develop an understanding of the basics of their disciplines that is ‘more than just fact-farting and number-juggling’ (Brooks, 2013).

At the same time, education itself is undergoing fundamental changes. Factual knowledge and its interpretations have become publicly accessible to a degree unknown only a few decades ago. Drivers behind this development are both technical and social. The Internet has become a major repository of knowledge and its contextualisation. Open access in academic publishing is beginning to break down the walls of the universities’ ivory towers. Courses, lectures, presentations and tutorials that are available online in the most diverse formats—massive open online courses (MOOCs), open courseware, video lectures, etc.—decouple teaching and the lecture theatre.

In this context, education, the University and the lecture have to be reinvented. The goal of education is to provide students with basic disciplinary knowledge, with 21st century skills, with the ability to revise and update their knowledge and skills. It must also provide students with the awareness that this might be required regularly throughout their careers to a far greater extent than the concept of 'life-long learning' traditionally suggested.

3.3 From Instruction to the Construction of Knowledge

Education itself needs to move away from pure 'instruction' to the 'construction' of knowledge. The idea that humans learn by constructing mental models from experiencing previous knowledge and an interaction with other ideas and the material world was developed by Jean Piaget (1973) and further advanced as 'constructionism' by Seymour Papert (Papert & Harel, 1991).

This type of education is based on Jean Piaget's theory of cognitive development and his work on the future of education: 'To Understand is to Invent' (Piaget, 1973) and Seymour Papert's Constructionism (Papert & Harel, 1991). Also important is Lev Vygotsky's concept of the 'zone of proximal development' denoting those mental capabilities in the development of a child that are not yet fully developed, but are in the process of maturation and can be developed 'under adult guidance or in collaboration with more capable peers' (Vygotsky, 1930-1934/1978, p. 86).

In the construction part, exploration and experimentation of the disciplinary domain—and its neighbouring domains—play a crucial role. Students need to experience that any disciplinary knowledge is complex and, in principle, inexhaustible. They need to experience that there are very few barriers to accessing almost any information. Students need to experience that establishing and understanding the contextualisation of knowledge is an intrinsic part of their own learning process, which is a life-long endeavour. In doing so, they develop and practise their research, learning and design skills.

The instruction part of education, however, does not become less important. On the contrary, given the time constraints and the abundance of content education is faced with, instruction needs to be more focused on laying the foundations of a discipline and giving basic guidance for the construction part of education.

The instruments educators have at hand to design education are manifold and span multiple media and types of interactions. 'Canned' and interactive content, mediated and face-to-face interaction, and a variety of activity formats have always been the ingredients of what made education worthwhile, both for teachers and learners. The addition of new skills to basic disciplinary knowledge, the shift towards a larger constructionist share in education and the availability of new media require and facilitate a revision of that mix of ingredients.

3.4 Making in Education

With regard to Making-based educational initiatives, the landscape appears fragmented and disconnected. Makermedia, partly with the support of DARPA (the U.S. Defense Advanced Research Projects Agency), has been actively promoting the maker approach to schools and educators since 2012 with books, kits and a whole maker education initiative (makered.org), including a network of young makers clubs across the U.S.A. (youngmakers.org). Paulo Blikstein's work at Stanford's Transforming Learning Technology Lab is less propaganda and more academically rooted, which is underlined by his scholarly work and the annual FabLearn conferences he organises. Blikstein started his educational programme Fab@School in 2009 (fablabatschool.org), claiming it was the first programme designed from the ground up specifically to serve grades 6-12, and reaching out from Stanford to Palo Alto, Moscow and Bangkok.

The Lab approach is not only valid in (primary and) secondary education, but also in higher education, where the focus is not only on teaching technical capabilities, but also on developing appropriate methods to employ these capabilities. These methods are fundamentally rooted in the human-centred approach of design thinking, as popularised by Tim Brown (2008). Hauan & Johannessen (1993, p. 175) call it the capability of 'interacting in ambidextrous ways (logico-rational and emotional-intuitive)'.

Prominent examples include Neil Gershenfeld's course MAS.863 at MIT, 'How to make (almost) anything' that formed the very beginning of the development of Fab Labs, and Matt Ratto's course number INF2241H, 'Critical Making: Information Studies, Social Values, and Physical Computing'. Again, these approaches build—probably more implicitly in the case of Gershenfeld, certainly explicitly in the case of Ratto—on the work of Vygotsky, Piaget and Papert.

Within the Fab Lab network, the role of Fab Labs in education started to become part of the discussion of Fab Lab operations at the annual gatherings around the same time and grew into the international network FabEd, supported by the Fab Foundation and the US-based Teaching Institute for Excellence in STEM (TIES). This initiative has a strong focus on curriculum integration and development and on student assessment. There are more initiatives such as Gary Stager's and Sylvia Martinez's 'Invent to Learn' (Stager & Martinez, 2012), Emily Pilloton's 'Project H' (projecthdesign.com), Per-Ivar Kloen's and Arjan van der Meij's 'FABklas' in The Hague (fabklas.nl), or the Hakidemia network with its outreach activities to Eastern Europe and Africa (hackidemia.com).

As governments around the world bought into the STEM shortage argument, there emerged a market of public funding and corporate sponsorship available to sustain activities in STEM education. The availability of public money is probably one reason why almost every individual Fab Lab and maker space tries to develop its own involvement in primary, secondary or higher education, whether housed within a school or university or beyond.

The reporting of glamorous success stories—by giving one or two examples—risks glossing over some more problematic aspects of Making in education. Firstly, it is relatively easy to create aesthetically attractive objects that are simple and generate a lot of admiration. This 'generates an incentive system in which there is a disproportionate payoff [for students] in staying a "local minimum"' instead of venturing outside of what they already know' (Blikstein, 2013, p. 212). This temptation to trivialise is what Blikstein calls the 'keychain syndrome'. Secondly, the success stories mask the fact that the experience is normally not shared nor reflected upon by peers and educationalists. It is questionable whether such fragmentation allows labs to provide the best service to students and education.

3.5 Lab-centric Approaches

In education—and particularly in design education—problem or project-based education and lab-centric activities are promising approaches to practising constructionist learning and to achieving the goals of teaching 21st century skills. Problem-based and lab-centric activities are concerned with physical artefacts. Physical prototyping has long played an important role in designing and in communicating design, its deliberations and its intermediary and 'final' results. Adenauer & Petruschat (2012) even posit that prototypes have become increasingly important throughout the entire design process from its very start, not only as a result of it. Prototypes are not only an instrument of and for designers themselves, but a 'matrix and medium' for communication and exchange. They form the basis of a 'new design culture' (p. 5) that uses the instrument of physical prototyping to advance the design process, and to think about and reflect on the design.

Utilising physical prototyping for reflection on a design, the underlying explicit and implicit decisions that lead to it, and the intended and unintended consequences it might have has been suggested as a core technique of Critical Making (Ratto, 2011; Somerson & Hermano, 2013). Physical artefacts constitute an extension and a counterpoint to the abstract, cognitive reasoning in terms of 'textual doppelgangers' of standard scholarly dialogue. They are 'forms of technical work that allow materiality to exceed and resist the ways in which we characterise it through language' (Ratto, 2014, p. 229). Physical artefacts carry the potential to open the cognitive 'discussion' of the abstract scholarly dialogue to audiences with other than cognitive learning styles, hence creating more diverse access to education.

Experience not only shows that these methods are able to meet expectations, both in relation to learning and experience. They are equally suitable for addressing diversity and equality in education (see also Blikstein, 2008). However, they require different preparation for and a different attitude to teaching than traditional lectures and exercises. There are also a few pitfalls to be observed and avoided, particularly the risk of benefitting only those students who are already higher achievers, the requirement to strike a good balance between process and product/solution, and the need to mitigate the influence of commercial parties e.g. in the form of commercial content and service providers.

Yet Biesta (2015) warns against overdoing an 'egolocial' approach to education that puts learners in the centre of the world and tempts them to try 'in a rather infantile way, to control the world' (p. 16). He rather advocates an approach that fosters an interaction of the learner with the world 'in a grown up way that is, in a subject-subject relationship, rather than a subject-object relationship' *(ibid.)*. In the latter setting, 'the world can only appear as an object of my signification, of my needs. It is a way of being in the world where I have not become immune for what seeks to address me—a way of being in the world, in short, where I can be taught' *(ibid.)*.

Lastly, educators are required to use appropriate assessment methods. Assessment practices need to be authentic because they are an important driver of students' study habits. If education is to move students beyond reproducing facts, namely to find, contextualise, develop and apply knowledge and to teach them 21st century skills, the approach to assessment has to reflect and strengthen these goals. As formative assessment it provides a means of learning through feedback, but this is the easy part. As summative assessment, it is supposed to measure the outcome of the learning programme and as such it constitutes the ultimate reward mechanism in education. Adequate and appropriate assessment methods are paramount in ensuring that assessment becomes or remains 'the silent killer of learning' (Mazur, 2013). A possible route could be to give students themselves more control over the focus and procedure of the assessment—the process vs. the product of learning—and the panel of assessors or experts, which need not necessarily only consist of teachers.

CHAPTER 4

Places and Spaces

Barcelona was the first city in Europe to open a Fab Lab—at the Institute of Advanced Architecture of Catalonia (IAAC). In 2011 a delegation from Barcelona, including former city officials, Xavier Trias and Antonnio Vives, and IAAC director and then city architect, Vicente Guallart, visited Neil Gershenfeld at MIT to discuss a regeneration model for the city of Barcelona with neighbourhoods that would become self-sufficient zones benefitting from the high-speed hyperconnectedness of the Internet and generating zero emissions into the environment. Neil challenged the representatives of Barcelona to develop a city model that would be built on the import and export of data rather than products: 'Whereas we now have a "Products In-Trash Out" model, we should be moving toward a "Data In-Data Out" model, from "Pito" to "Dido"' (Guallart, 2014, p. 247).

FabLab Barcelona's response to this challenge was the proposal of a FabCity: 'a new model for the city, which relies on the power of giving back to the cities the ability to produce through micro factories inserted in the urban fabric and connected to the citizens' (Diez, 2012, p. 465). FabCity consists of a network of production centres in the inner city of Barcelona, one per city district, connected between themselves and serving as a knowledge, entrepreneurship and production platform for the citizens of Barcelona.

The vision of a FabCity aims to translate the concepts of Making from a local community to the neighbourhood and city levels. This vision is different from the model where a local city council sponsors one maker space or Fab Lab to give citizens a place for private innovation. It is also different to establishing Fab Labs to create a structured and meaningful environment for a certain target audience—as, for example, in the case of the Peace Fab Labs in Belfast and Londonderry. The latter received 1.3 million British pounds in funding from the European Union Peace Programme (quite an exceptional sum in the Fab Lab world) to contribute to direct peace building activities and also as an educational tool.

Making meets city and urban development at a time when traditional real-estate business is becoming economically unviable as the basis for urban development. It also comes at a time when 'smart city' approaches, formerly driven centrally by ICT or governments, start to feel out-dated and must give way to ways of co-creating in which lab-centric approaches are becoming an important ingredient. Cities have various options for responding to these developments. Working towards an urban open innovation environment that opens city development to multiple co-creators appears to be a promising strategy.

4.1 Urban Development in Transition

Urban development is currently undergoing substantial structural changes. The pre-crisis real-estate business case has become increasingly unviable and urban development has had to evolve from a sort of property development XL into a process of urban management. Its perspective has had to switch from a development approach—focused on risk reduction and profit from a temporary albeit lengthy commitment—to a users' perspective that focuses on long-term value creation combined with a continued utilitarian valuation of the property. This means managing and valuing the flows of energy (electricity, gas, heat and cold), water, waste, people, goods and information over the whole life span of a certain development (Peek, 2015).

Urban area development also has to include the future management phase. That means dealing with questions of supply chain integration (Peek & Van Remmen, 2012). Some initiatives lead to vertical integration, as end-users took the lead in the development process or current owners and users used their own transformational powers in grassroots approaches. Others mainly focused on an area-based approach to utilities such as energy and water, resulting in a horizontal integration of real estate with these adjacent sectors. Others again revolve around the material flows in a city and aim to replace the 'Product-In-Trash-Out' mentality with a more sustainable and more locally based production system of sustainable production and reuse (Guallart, 2012, p. 247).

The concurrent involvement of incubators, real-estate developers and urban planners in urban area development in work on developments leading to new manufacturing moves Making out of the narrow field of focus of the proselytisers of the maker movement. It has the potential to render Making relevant beyond the scope of individual inventors. A possible consequence is more sustainable solutions because the urban development process is related to the development and management of all sorts of urban infrastructures. New solutions could form a sharp contrast to what traditional parties in urban development offer. The latter are mainly interested in selling technology and services to governments and other public entities and accordingly have adapted to their top-down and silo structure.

4.2 Smart Urban Development

Technology certainly remains an important driver of innovation. In the field of urban development we find an entire movement based on new technologies under the umbrella of the 'Smart City'. The Smart City approach has gained considerable momentum from the belief that the availability of intellectual capital (or knowledge) and social capital are urban production-factors that determine the competitiveness of cities (Caragliu, Del Bo & Nijkamp, 2009). 'Smart City' refers to sustainable urban development (smart environment), to the incorporation of information and communication technologies in the management of services (smart economy) and to the generation of participatory spaces for collaboration and innovation (smart governance). As such, the concept may serve many different purposes, leaving aside interrelationships and contributions to overarching goals, and remains vague. This is probably why it has become a frequently used term when proposing or justifying urban reforms (Tironi, 2013).

The Smart City concept, Cohen (2015) argues, has developed over time from the purely technology-driven 'Smart City 1.0', mainly promoted by multinationals like IBM, Cisco, Siemens, General Electric and Philips, to a technology-enabled, but city-led approach (Smart City 2.0), spearheaded by Rio de Janeiro and Barcelona, eventually to a citizen co-creation model, as practised in Kansas City, Vienna or Medellin. City governments 'are providing the enabling conditions to allow local sharing activities to emerge. (…) Projects such as Repair Cafes, tool lending libraries for performing repairs to your home, and bike-sharing services have the potential to not only optimize underutilized resources but also raise the quality of life for all residents' (Cohen, 2015). In this context of a 'Smart City 3.0'—a system of systems (Harrison & Abbott Donnelly, 2011) that comprises a whole 'ecosystem of products, services, companies, people and society that are working together creatively to foster innovation within the city' (Cosgrave, Arbuthnot & Tryfonas, 2013, p. 669) Making acquires a powerful enabling role as one of the instruments for 'smart citizens' (Hemment and Townsend, 2014) to 'collectively tune [the city], such that it is efficient, interactive, engaging, adaptive and flexible' (ARUP, 2010).

4.3 Lab-centric Approach: Third Places

Relocating research, innovation and production functions to the centres of neighbourhoods—both in terms of locality and in terms of governance, ownership and use—has the potential to add to the liveability of cities and to the local economy. Such an urban development strategy could have the lab at its centre as a key instrument for citizen empowerment.
However, there are at least two pitfalls to watch out for: firstly, the lab must not become just a clever instrument for benefitting corporate strategy through free crowdsourcing, particularly in the Living Lab concept (Salmelin, 2009); and secondly, activities at the lab must not feed primarily the venture capital-driven, (neo-)liberal phantasies of white Western middle-class males of labs, as the source of renewed entrepreneurship and gonzo innovation that deliver a quick and profitable exit.

Societal empowerment requires more than just enabling individuals to realise their technological phantasies in a technology-affirmative environment that is disconnected from the bigger societal questions that drive transition: questions of equity, fairness and diversity, questions of power and economic relations, questions of responsible use of resources and of sustainability. With Bookchin (1982), I argue that it does not make sense to embark on empowerment through access to technology without examining and shaping the political and social structures in which they are embedded.

Lab-centric initiatives in cities need to develop into new institutions of a radically different type of economy, an economy that fundamentally contrasts the conventional top-down organisation of society that characterised much of the economic, social, and political life of the fossil-fuel based industrial era. Its new paradigms are ‘distributed’ and ‘collaborative’, paradigms that appeal to a new generation of people who grew up with the Internet and who have for all their lives been engaged in distributed and collaborative social spaces, in parallel to the traditional, hierarchical environments of family, school and job. In this way, the new lab-centric institutions can become a further evolution of the well-known concept of third places (Oldenburg, 1989; Oldenburg 2000), as public, civic spaces in the built environment.

4.4 What Can Cities Do: A Typology

Looking at examples of cities and Fab Labs, a typology of four routes emerges regarding the way in which urban area development and Making can possibly interact (Troxler, 2014). Firstly, here are many places where there is little or no interaction between urban development and Making. City governments adopt a *laisser-faire* approach and labs are not concerned with city-wide topics. Secondly, in other cities, such as the examples of Barcelona and Belfast mentioned above, there is top-down government interest in setting-up a lab infrastructure. This situation is very much akin to Cohen's Smart City 2.0. Thirdly, the opposite model also exists—cities where there are labs that are actually concerned with creating a wider impact through Making. Well-known examples are De War in Amersfoort, the Netherlands, or various initiatives in Berlin, such as Betahaus, or the Fab Lab in St. Pauli, Hamburg's St. Pauli quarter.

Fourthly, building on Cohen's typology and reasoning, we expect to see a '3.0' model for the interaction of urban area development and Making in which city governments provide the enabling conditions—in terms of technology, economy, society, and governance—in which city-wide, layered and multi-stakeholder processes of co-creation and collective or collaborative use are the dominant patterns of urban area development. In Barcelona, where the city government still pursues as '2.0' strategy, the Fab Labs themselves are opposing the attempts to bureaucratise Fab Labs: 'It isn't about incorporating fablabs into governmental structures, but rather about hacking them' (Diez & Claude, 2015). The notion clearly is that a combination of the many initiatives in the public and private sectors, in companies and in education could lead to 'something unique (...) cooking in Barcelona' *(ibid.)*.

4.5 Towards an Urban Open Innovation Environment

If urban area development ultimately is to achieve equity, fairness and diversity—while promoting economic prosperity and sustainable and liveable cities—power and economic relations need to be taken into consideration. In this context, attention must be drawn to the role of government that traditionally has been top-down and hierarchical with an illusion of manageability. It is confronted with its own fear of letting loose when confronted with adopting a hands-off approach. This reality of government needs to interface with and connect to the quite different reality of spaces and initiatives that are more networked, laterally connected and governed bottom-up. Only if cities manage to bring the two together will they be able to advance their societies and economies. This requires some core values that have to be shared on both sides:

- the value of openness, which in this context is not restricted to open source in the sense of intellectual assets, but openness and transparency as a governance principle; the right to produce and participate;
- the value of ownership and what it means to make a city, in which responsibility is a key value (also because it is at the core of the fab lab charters); this is the right to occupy and make the city a place where 'you and others' like to live; and

- the value of prototyping, of taking the maker approach, which is associated with trial and failure, with experimenting quickly and cheaply with no fear of failure, and adapting this approach to a city development context; this is the right to implement the unfinished and refine it just in time rather than just in case.

A new type of an Urban Open Innovation Environment (Peek & Troxler, 2014) is a potentially strong change agent for radical innovation in the field of urban area development, as it combines supply chain integration, empowering ICT and grass-roots initiatives, as co-creators of the city. The success of new, lab-centric initiatives largely depends on their open character, not being part of the dominant regime of large companies and (governmental) institutions, even while they will most certainly come under pressure from shopping malls and corporate enterprises trying to transform public space into an extension of the market. That does not necessarily mean resigning third spaces to a niche of activities driven by counter culture which are not willing or able to leverage their efforts. True openness in this respect refers to the ability not only involve to niche players, but also to make crossovers to change minded actors within the dominant regime so that (Rifkin, 2011) new regimes may emerge though lateral development and the change may become irreversible.

Governments have an important role to play here. For Urban Open Innovation Environments to be truly open, certain room to experiment and to innovate is required. Yet, only focussing on the operational level of concrete projects is not enough. For a new regime to emerge, efforts on the tactical level have to be made, involving the support of emerging new, lateral 'institutions' that are able to generate business from radical innovations. These environments should enable new types of entrepreneurship, such as micro-multinationals, and social enterprises operating beyond traditional business models. In this way, Urban Open Innovation Environments are able to become a constant force in the field of urban area development, making cities in transition more sustainable and resilient, and through inclusion and equity adding to the quality of life.

CHAPTER 5

Design Patterns for New Manufacturing

The so-called Gang of Four (GoF) are the authors of the landmark book Design Patterns: Elements of Reusable Object-Oriented Software. This sprawling and desultory screed first made its appearance at OOPSLA '94, amidst much fanfare and high expectations. At OOPSLA '99 the nefarious cabal, John Vlissides, Ralph Johnson, Richard Helm, and Erich Gamma, were placed on trial for Crimes against Computer Science. The Show Trial of the Gang of Four sought to illuminate the triumphs, excesses, foibles, and future of the patterns movement via a somewhat unorthodox format.

The Gang of Four were accused, among other crimes against Computer Science, of having engaged in the usurpation of perfectly good English words and well-known technical terms for the purpose of establishing an arcane argot known only to a narrow circle of GoF initiates; of elevating design from the realm of technical artifacts to a conceptual level; promoting a cult of personality, and the establishment of a cottage industry of consultants, trainers, and sundry acolytes to interpret their abstruse musings; of encouraging novices to act like experts by distilling hard-won design expertise into patterns; of cataloguing mere experience, rather than conducting novel research, and thus displaying an utter disregard for traditional standards of academic originality.

The court provided the accused with an opportunity to confess their crimes, or to engage in such futile defiant outbursts as they might see fit. The audience served as the jury, and was also invited to provide testimony. Denunciations as well as support from GoF apologists were in order.

In their seminal publication that makes 'design patterns' a commonality in programming, Erich Gamma and colleagues compare the use of these patterns to how novelists and playwrights work: instead of designing their plots from scratch, 'they follow patterns like "Tragically Flawed Hero" (Macbeth, Hamlet, etc.) or "The Romantic Novel" (countless romance novels)' (Gamma, Vlissides, Johnson & Helm, 1995, p. 1). The actual concept of design patterns is typically attributed to the architect Christopher Alexander. Design patterns are supposed to describe the core of a solution to a certain problem that occurs over and over again. The description is such 'that you can use this solution a million times over, without ever doing it the same way twice' (Alexander *et. al.*, 1977, x).

Despite the criticism of the design pattern approach—even in the eyes of its inventor that it basically does not work (Grabow, 1983), that it is merely a fix for underlying flaws in programming languages (Hannemann & Kiczales, 2002; Norvig, 1998), that it unnecessarily adds complexity (McConnell, 2004, p. 105)—and despite the verdict in the Show Trial of the Gang of Four of 'Guilty by a simple minority' (approx. 2/3 for conviction 1/3 against)—I prefer the term over 'blueprint' or 'best practice' for a number of reasons. First and foremost, the term 'best practice', in particular, implies to describe an optimal solution the existence of which I strongly contest in the complex, evolving socio-technical environment of new manufacturing. Secondly, the term 'blueprint' implies the notion that one simply would have to adhere to it to the letter in order to be successful (actually something Gamma et al. (1995) also suggested to be true of design patterns).

The term 'design pattern', on the other hand, suggests the notion that one might wish to copy the approach 'to design a satisfying and ecologically appropriate environment' (Alexander, Silverstein, Angel, Ishikawa & Abrams, 1975, p. 3, emphasis added) for oneself and one's activities. What all three expressions have in common is that they are abstract descriptions of local solutions that have been tried and tested before, improved over time, evaluated against other solutions and found to be at least worthwhile sharing so others could re-use them when encountering a similar problem.

A design pattern—the way I am using the term here—is a proven local solution to a design problem which is assumed to be a recurring problem. The description of the design pattern pays special attention to the context in which the local solution has been developed and applied, in particular to the competing 'forces' it needs to balance, and it references pertinent theoretical foundations. A design pattern draws attention to the possible and experienced positive and negative consequences of its application. It may also reference higher-level patterns describing the context in which it can be applied, and lower-level patterns that could be used within the setting of the current pattern to further refine the solution.

5.1 Making

A Fab Lab: Stadslab Rotterdam

The Stadslab at the Rotterdam University of Applied Sciences is a co-production of the Department of Communication, Media Technology and Informatics (CMI) and the research centre Creating 010. It serves as the prototyping and experimentation facility for a variety of programmes in computing science, media technology and communication and multimedia design, and it is the research lab for the programme *De revolutie van de maakindustrie*.

Setting up the Stadslab required interpreting and adopting the relatively vague blueprint of what a Fab Lab is in the educational context of Rotterdam University of Applied Sciences, and particularly the Department of Communication, Media Technology and Informatics (CMI).

The Stadslab was positioned around the themes of 'meten, weten doen'—to measure, to master, to make. The measuring part is concerned with a wide variety of sensors and their application in 'smart objects', interactive clothing, and all sorts of applications for the Internet of Things. The mastering part deals with the data generated by sensors and from other sources (big data) and supports projects with open government data and the Rotterdam data store. The making part is the Fab Lab proper with digital manufacturing equipment and electronics workbenches.

The Stadslab in actual fact acts as a contact point where research and education meet and where new learning communities of students and teachers develop that build on the methodologies, technologies and equipment in the lab. These communities develop educational initiatives in the lab, in the wider context of Rotterdam University of Applied Sciences and beyond. The lab facilitates and supports the translation of practical questions posed by users into research that will eventually contribute to education.

Many educational programmes and courses make use of the facilities of the Stadslab—such as the minors 'Smart Things' and 'Urban Interaction Design', and an honours minor and a couple of electives have been developed around the capabilities of the Stadslab. The minor 'Making for Professionals' links Making to social innovation projects in the city. The two electives provide an introduction to the capabilities of the lab—one more oriented towards digital manufacturing, the other more towards electronics.

As the lab is available to students from all faculties, it not only acts as a prototyping facility for students of architecture, urban planning, arts, industrial design and, of course, from the host department CMI, but the lab also creates a melting pot where these students can meet and interact on an informal basis. From this interaction, award winning student projects emerged, such as the 'Fashion on Brainwaves' project by Jasna Rokegem (Rokegem, 2015)—a set of interactive silhouettes that change colour and shape based on the rudimentary electroencephalographic signals—'brainwaves'—a cheap 'MindWave Mobile' headset can pick up, used mainly as a rough indicator of attention (Kravitz, 2014).

The lab also acts as a gateway to the city. As mentioned above, several minor programmes specifically address interaction and innovation in an urban context. Beyond those programmes that actively address urban issues, the lab is structurally open to the general public, which brings in citizens with a wide-ranging set of projects and issues—from printing replacement parts to engraving branding labels for designer clothing, from using the lab infrastructure in primary and secondary education to printing MRI scan data of complicated hip fractures for preparing surgery.

As is the case for most if not all Fab Labs and maker spaces, the Stadslab has no proper methodology for SME engagement and innovation, and business development support. The University recently launched its own 'Incubator Academy' (Ploegman, 2015), which indicates that there is apparently a need for such programmes. A corresponding development at the Stadslab—probably best developed in close collaboration with the Incubator Academy—could blend open innovation at the Stadslab with commercialisation at the Incubator Academy, two concepts that often are seen as incompatible and viewed in isolation from each other. Central to such an approach would be connecting business and education to develop and test jointly new approaches to R&D, innovation and commercialisation.

Knowledge Sharing in Fab Labs

Maker communities democratise manufacturing through hands-on learning, transdisciplinary work and open-source knowledge sharing. The Fab Lab community, in particular, is committed to participating in global knowledge sharing. For sharing back into the global commons, however, new knowledge needs to be documented in a way that allows the sharing it by the means of information and communication technologies. However, insight into whether and how knowledge is in fact shared globally in the Fab Lab community is scarce.

An empirical study was carried out, based on qualitative interviews with sixteen Fab Lab users (Wolf, Troxler, Kocher, Harboe & Gaudenz, 2013). In these interviews, the respondents talked about seventeen projects, some of them collective projects that were analysed as case studies. These case studies revealed that knowledge sharing is not impeded by the barriers discussed elsewhere in literature, such as motivational or technological impediments (Rangachari, 2009). Nevertheless, the cases showed that global open knowledge sharing was far from being the norm, and sharing remains mainly local, personal or project specific.
To understand better how sharing actually happens when it happens, another

study (Wolf & Troxler, 2015a) applied actor-network theory as the underlying theoretical framework to a co-design project in a digital maker community—the Teletransportation project (Neves, 2013). At the core of this project was a basic digital design for a cup that can be 3D-printed. The study showed that the different network types reassemble around nodes that result from translations (and therefore transformations) of the initial project idea and the code that allowed the participants to a 3D-print cup. It was able to show translations and the circular movement in the network as well as translation costs, time effects, intermediaries and mediators.

The challenge, however, remains that global knowledge sharing appears to be difficult and inefficient, hampered by a complex bundle of issues. Documenting what one has made is seen as difficult, time consuming and extra work that is not fun (Wolf *et al.*, 2013). Fab Lab users often do not find or do not take the time to document what they do in a way that they feel is good enough to be shared online and globally. Moreover, making physical things involves a lot of tacit knowledge which is difficult to share through mediated channels (Polanyi, 1967; Sennet, 2012). Possible routes for future investigation could be the gamification of documentation—making documenting fun, as in the case of the Teleportation project—or its more tight integration with the (digital) manufacturing processes in a "smart industry" approach. Developing and maintaining a Fab Lab knowledge commons—as expressed in the notion of 'shared capabilities' (CBA, 2012)—probably requires interventions regarding technology, participation and governance that establish the network as a polycentric network of small and local or regional subnetworks. On a global level, the network would need to address interoperability of (sub)communities and try to establish common Fab Lab protocol layers—not only covering technical issues, but also key social, organisational and governance aspects.

5.2 Boutique Manufacturing—Business Design

Community-based Business Models: Insights from Open Design

The Open Design movement can be understood as one of the recent approaches that strive to democratise access to knowledge and production devices. Similar to open-source communities, maker-project details, like design blueprints, are made freely available online to everybody. Activities in collaborative user communities, like those of the digital maker movement, promise value co-creation strategies in relation to the entire value ecosystem, in particular to all contributors. Such claims potentially promise new business models that contain peer-production patterns, i.e. patterns that are based upon the community's co-creation principles of open knowledge sharing, altruism, collaboration, and common ownership of resources and the results of production.

Community-based business models so far have not been in the focus of management studies. To identify, analyse and understand them, however, would be potentially beneficial in broadening and deepening the conceptual basis of this still relatively young research area of business models. To address this issue, we described community-based business models from the open design community Thingiverse in a multi-case study (Wolf & Troxler, 2015b). We found that most of the entrepreneurs in actual fact operated a portfolio of different business-model patterns. Not all of these patterns were geared towards generating monetary profits. On the contrary, patterns regularly also included altruistic and hedonistic elements. Our findings are aimed at enabling both researchers and managers to think and act on the basis of a broader and more complete understanding of the strategic issues and options of business model design and innovation.

The key challenges appeared to be governing a business according to open-source and applying peer-production principles, while generating societal and individual value in addition to economic value. Indeed, both challenges are still poorly understood and have received little attention in management research (see Arend, 2013; Zott & Amit, 2013). Open source, i.e. giving away for free what traditionally was considered 'intellectual property' that had to be protected seemingly at all cost still remains an enigma for Western companies—while copying and recopying is reportedly at the core of China's innovation system. For a long time researchers have argued that a shift is required in governments' innovation policies, for example with respect to intellectual property (von Hippel & Jin, 2009). Translating open source into viable business models that do not require cross-subsidisation by conventional economic engines is the subject of theoretical research and practical experimentation.

EU Business Design Studio

The EU Business Design Studio was a two-part workshop carried out in partnership with the Cultural Enterprise Office Scotland and held in Glasgow and Rotterdam respectively. The objectives of the EU Business Design Studio was to understand the opportunities for design, maker and manufacturing businesses in Europe today, as well as the obstacles they had to overcome, and to investigate how technology—and, in particular, a maker approach to technology—could help businesses establish themselves, develop their products and connect with their customers. To this end, nine young entrepreneurs from Scotland and six from the Netherlands met to tell each other the stories of how they developed their businesses.

The key insights these participants gained from these workshops were, first, that as entrepreneurs they regarded clients not just as paying customers, but as their best ambassadors, product developers, usability experts, marketeers and business developers. They apparently created social value by making their clients an integral part of their overall value proposition. Secondly, by establishing paths to reusing, repurposing or recycling their products they were creating ecological value. This required them to think through their whole supply chain, raw materials, production processes and distribution logistics. Thirdly, they created economic value by telling their customers those stories that made them connect to the business and the products and made them value the product in the price range they aimed to achieve.

Prototyping was a recurring theme in all the stories of how these fifteen entrepreneurs developed their businesses—and not so much prototyping the products and services they offered, but actually prototyping their own business models. This is an emergent feature in business model research. The literature acknowledges that entrepreneurs start from a rather vague picture of their business and gradually develop and extend their companies' activities (e.g. Cavalcante, Kesting & Ulhøi, 2011), yet there are few accounts of how that development actually takes place—the case study on chef Ferran Adrià of elBulli (Svejenova, Planellas & Vives, 2010) being a notable exception. Prototyping of business models goes far beyond just simulating them as 'best' practice recommendations (see Osterwalder & Pigneur, 2009). It deserves much deeper study and understanding, both theoretically, as George and Bock (2011) note when they call for 'empirical studies [that] identify business model characteristics that impel of hinder routinization or routine development' (p. 106), and practically in business incubator and accelerator contexts—an area which existing business accelerators and maker spaces could explore together.

5.3 Making and Education

Elective Courses at the Stadslab

As was mentioned above, we developed a couple of electives and a minor around this Fab Lab. The name of the first elective course was 'What do you need to make (almost) anything?'—an introduction to Fab Lab machinery and electronics modelled on Neil Gershenfeld's MIT course 'How to make (almost) anything' and adapted to the constraints of the education provided by Dutch universities of applied sciences. The duration of the course was ten weeks, equalling two EC credits. The course was designed around a radical application of iterative prototyping—over the ten weeks students built six intermediary and one final prototype of an interactive device that needed to include mechanical and electronic parts (Mostert-van der Sar, Mulder, Remijn & Troxler, 2013). After a short introductory overview, they spent most of their time in class exploring the topic at hand—e.g. micro-controller programming, sensors, actuators—typically in small teams that foster peer-learning.

Over the years, the course has been delivered by near ‘generations’ of teachers, handed down the line as it were. This has led to a refinement of the course. It was split into two separate courses, one with a focus on 3D printing and laser cutting, the other towards electronics and microcontroller programming. Yet handing over teaching from the authors of the course to other teachers—even if they were required to attend the course themselves before being entrusted to teach it themselves—led to a feeling of degradation of the course on the part of its authors. This is an issue that needs to be investigated and addressed in due course as it raises the question to what extent effective maker education is actually dependent on the individual traits of educators rather than on transferrable teaching methods.

Within the faculty of Communication, Media and Informatics, the elective and its use of the Stadslab have truly gained design pattern status. In the on-going review of the curricula, particularly in the case of the programme in creative media and game technology (formerly media technology), the focus has been on more hands-on activities, more problem-based education and more student ownership of the learning process. Such redesign contributes to turning the curriculum into one which is geared towards developing the personalities of students and training them in 21st century skills, rather than just disciplinary proficiencies.

Continuous Professional Development for Teachers

The Stadslab—by being available and through active outreach—also attracted the interest of primary and secondary school teachers who wanted to make use of that kind of infrastructure for their STEM education. To serve this interest, a continuous professional development programme for secondary school teachers was developed and tested (Troxler, Mostert-van der Sar & de Wit, 2014). The programme consisted of visits to research and design labs at a variety of institutions in order to avoid institutional bias. Participants’ own questions formed the backdrop to study the labs and to transform findings from the visits into valuable insights and actionable interventions for their own educational practice. The participants collected those insights in a publication, identified the main ideas and related them to didactic principles (Troxler *et al.* 2014).

While this intervention was successful, certainly on the surface, there are a number of issues that such programmes need to be aware of (see Vossoughi & Bevan, 2014)—a (too?) narrow focus on STEM, fetishising an allegedly ‘revolutionary toolset’ (Martin, 2014, p. 37), polarising high-tech digital making in contrast to low-tech handicrafts, a focus on middle and high school students, and the usually short duration of interventions that makes sustainable implementation questionable (Dorph & Cannady, 2014). Accordingly, a number of additional activities have been started to address some of these issues. A similar programme that aims to translate the experiences from secondary education to primary education is currently being undertaken and another programme to combine maker education with arts and cultural history is under development.

The Dutch Petition on Maker Education

In late 2014 the Dutch community of maker education professionals got together to submit the petition *'Leren door te maken: het nieuwe maken in het onderwijs'* (learning by making: new making in education) to the Lower House of the Dutch Parliament (Petitie leren door te maken, 2014). The petition argued that one needed not only to be able to 'read' technology, but also to be able to 'write' it (which between the lines maker education is supposed to enable). Furthermore the petition stated that maker education had no explicit position in education and requested Parliament's Standing Committee on Education, Culture and Science explicitly to provide some scope for initiatives aimed at developing and promoting maker education in order to give students the opportunity to apply and develop their talents irrespective of their level of education.

When the petition was drawn up, there was substantial discussion on who would best be suited to spearhead such maker education initiatives. Many were firmly of the view that practising educators with a maker ethos should be driving the development, rather than the think-tanks and research centres. However, this was not really explicitly spelled out in the petition, except that it was authored by 'teachers, head teachers, Fab Labs, companies, public libraries and other cultural agents' *('leraren, schoolleiders, FabLabs, bedrijven, openbare bibliotheken en andere cultuurmakers', loc. cit.)*.

Putting teachers and head teachers in the lead role was a major achievement of the petition. The real aim was to prevent the notorious intermediaries from occupying the emerging space and to preserve it for the practitioners. Yet there was literally no discussion about the educational reasons why the signatories would join the petition. The relatively vague term of 'maker education' was deemed sufficient to join forces. The self-selected community of signatories will be challenged, sooner or later, to clarify what their shared values are to start and sustain such an initiative.
Indeed, Vossoughi and Bevan (2014) state a number of tensions and gaps in the literature, of which 'making towards what ends' (the why of making rather than the how and what) is just one. Others include the academic-vocational divide (particularly interesting also in the context of how the Dutch university of applied sciences sector positions itself), the representation of making and makers (as male, white and middle-class), the often missing engagement with questions of gendered, socio-economic and ethnic equity and the lack of 'more explicit and detailed analyses of pedagogy in making/tinkering environments' (p. 37).

5.4 Urban Development: Rotterdam Maakstad

During the past five years, Rotterdam has seen a growth in Maker initiatives. The Stadslab at Rotterdam University of Applied Sciences opened in 2011 as the first Fab Lab in Rotterdam (and the tenth in the Netherlands). In 2013, RDM Makerspace and Het Lab were opened, and a fourth maker space in Delfshaven will open in 2016. Creative makers such as Daan Roosegarde, Joep van Lieshout and the Keilewerf have settled in Merwe-Vierhavens, turning the former port area into a 'vast, optimistic laboratory for artistry and cultural experiment' (Koorenhof, Ketting & Liem, 2015, p. 13). The start-up accelerator, SuGu Club, the Design Dock business centre and Fair Design Plein, a social enterprise and boutique manufacturer producing for local designers, are located in the same area.

Rotterdam publicly started to call itself a *'maakstad'* (city of Making) of the 21st century. Boutique manufacturing is explicitly part of the city's vision, 'manufacturing rises in importance, particularly on a small scale, at the level of the district or neighbourhood, and it will grow more closely into the habitat of Rotterdammers. This requires different forms of entrepreneurship and suitable spaces' (Agendastad, 2015, p. 10). The Merwe-Vierhavens area has been designated as the place where Rotterdam will develop the maakstad (Stadshavens Rotterdam, 2014). Rotterdam aims to follow an approach of organic city redevelopment, a small-scale, gradual and open-ended process, in which the municipality acts as the facilitator and small contractors, developers and individuals develop and manage the area according to a consistent and collective strategy (Buitelaar et al., 2012).

An important element in this approach is to connect current and new parties in the area in order to create social, economic and physical value. Herein lies an interesting parallel to the new business models found in boutique manufacturing, which also include the creation of different types of value beyond the purely economic. Another striking parallel is the notion that plans and visions might play a role in organic city redevelopment, but that they do not have to contain the final picture, but should remain open to spatial and social initiatives that spring up as opportunities arise along the way. This appears quite similar to the idea of business-model prototyping found in boutique manufacturing.

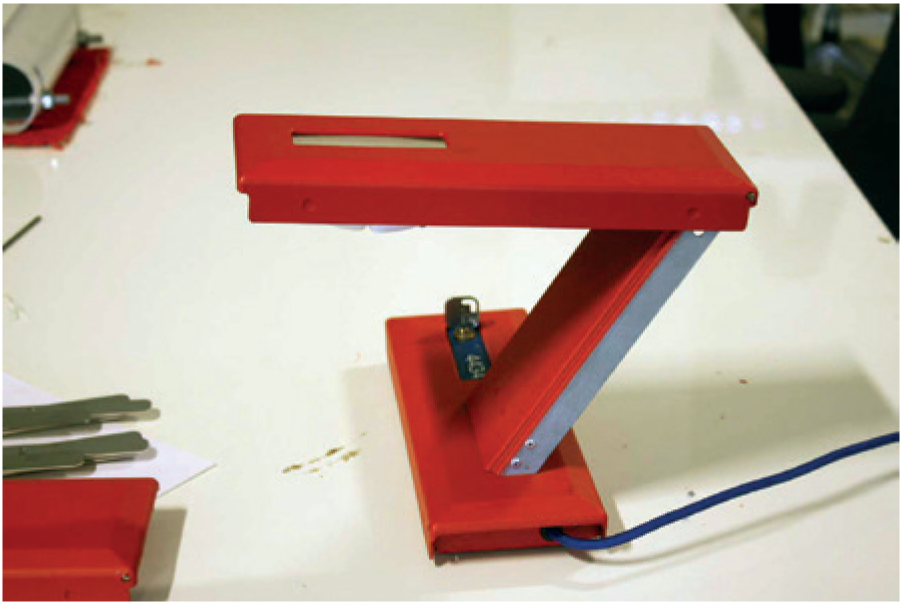
CHAPTER 6

Current Issues

When Tessa Vaendel and Thomas Hesseling created the 'LichtPost Lamp', a desk lamp made from retired P.O. Boxes, they did not know how much this product could become a signatory tale of Making. Their submission was a response to a challenge posed to TU Delft design students by the Dutch design agency VerdraaidGoed ('looped goods' in their own translation) that specialises in repurposing and upcycling waste materials.

To manufacture the lamp, VerdraaidGoed partnered with Made In 4 Havens. Assembly engineer Henk-Jan Willems fixed the original design so it could actually be produced. The initial production run of the 'LichtPost Lamp' was financed through a crowdfunding campaign.

Made In 4 Havens is a social enterprise dreamed up by Ebami Tom that offers manufacturing services to designers and provides employment and re-skilling opportunities to the unemployed from a Rotterdam neighbourhood. The company itself is based in a former port area earmarked for urban redevelopment.



This signatory tale of the *'LichtPost Lamp'* includes all the issues Making is struggling with today. First and foremost, it is the drive to innovate in new ways—in this case in a sustainable, circular way. The story shows how this drive, however, requires new business models and supply chains, new approaches to business development, and being 'smart' about manufacturing in a way mainstream industry could never imagine. The story is also a reminder that today's students (even from such a prestigious institution as TU Delft) are not exactly well prepared to design products for manufacturing, let alone for small-batch, boutique manufacturing. Finally, the story is exemplary of how intricately interwoven small-scale social-entrepreneurship initiatives are with Making ventures, on the one hand, (the 'humble plan', so to speak) and, on the other hand, the urban development plans (as it were the 'big visions').

The tale of the *'LichtPost Lamp'* might just be one example as there are many other projects that are of interest to the argument of Making as a new industry: Carola Zee, 'reshoring' her artisanal ceramics production from China to Rotterdam; RotterZwam, cultivating mushrooms on a circular, re-use model; and Better Future Factory, developing recycled raw material for 3D printing. Yet 'LichtPost Lamp' is the most instructive in terms of how relevant it is to make use of the network, to connect laterally with friendly players and to grow horizontally rather than vertically to achieve business success. This idea eventually resides at the core of what the revolution in manufacturing *(De revolutie van de maakindustrie)* is about.

6.1 Making and Manufacturing

Making and manufacturing continue to interact. The two main drivers behind these interactions—the accessibility of high-tech manufacturing equipment and prototyping-first design methods—create new and interesting challenges beyond the purely technological and tactical issues. Firstly, they create new opportunities in relation to the way entrepreneurs and companies design, execute and govern their activities, i.e. what their *business models* are. Secondly, they offer new routes for entrepreneurs to approach *business development* from grasping an opportunity to expanding their business. Thirdly, they offer a different perspective on contemporary industrial development strategies, such as *Industrie 4.0* and Smart Industry, by offering alternative epistemologies of governance.

Business Models

A business model describes what a firm does (producing products and services in addressable market spaces), how a firm carries out what it does (linking factors of production and upstream and downstream markets) and how a firm steers its activities and those of external parties (controlling flows of information, resources and goods through legal instruments and incentives). The business model depicts 'the content, structure, and governance of transactions designed so as to create value through the exploitation of business opportunities' (Amit and Zott, 2001, p. 511). As the role of external parties becomes more important to business models, value creation and capture is seen as a network of actors that extend the resources of a firm into 'a system of interdependent activities that transcends the focal firm and spans its boundaries' (Zott and Amit, 2010, p. 216).

In such a networked view, the issue of governance becomes particularly interesting. In the context of Making, there are several developments that are linked to the question of governance. Firstly, there is the rather irreversible trend of mass-customisation and the provision of 'consumer-customised' goods. In these models, the end-users are given significant influence on the configuration and appearance of the products they purchase. Secondly, there is a tendency to establish "networked manufacturing" chains that are much more extensively coupled in terms of logistics and information exchange. Corresponding manufacturing practices need to be developed. Thirdly, 'open source' practices are evolving into viable governance strategies for developing and exchanging intellectual property (IP). However, the implications of open source on business models are still poorly understood. Established companies and start-ups are experimenting with creating unique selling propositions that are independent of IP protection.

Changes in the governance of the business model often also have direct implications for the content and the structure of the business model. The 'what' could be extended by ideas such as cyber-physical systems, goods as services or creating other kinds of values than only monetary value. The 'how' might include platform models in which the platforms add value beyond simply matching supply and demand and models that involve a community of users or consumers in business activities beyond branding and customer loyalty.

Business Development

The term 'business development' designates the activities and capabilities of an entrepreneur or a company when they see and grasp an opportunity and expand their business. It comprises 'routines and skills that serve to enable growth by identifying opportunities and guiding the deployment of resources' (Davis & Sun, 2006, p. 146) and 'the tasks and processes concerning analytical preparation of potential growth opportunities, and the support and monitoring of the implementation of growth opportunities' (Sørensen, 2012, p. 26). In the context of Making, business development appears in two archetypical instances—the development of an individual maker-entrepreneur into a Making-based business and the integration of Making into the operations of existing businesses.

The first instance is concerned with the transition from individual Making into boutique manufacturing, which requires a certain degree of industrialisation of Making processes—e.g. design for manufacturing and assembly, standardisation of processes to maintain quality levels or the scaling of operations to serve a larger customer base. This transition regularly appears to create problems in Kickstarter projects (and many other crowdfunded ventures) and it has been articulated clearly in the business design studio case studies. Yet solutions typically emerge on an ad-hoc basis and there is little systematic knowledge of how to deal with this challenge, nor is there structural support for makers to make this transition, e.g. in Fab Labs and maker spaces.

The second instance is concerned with the combination of iterative and intuitive ways of working, as practised by artists and designers, and the more linear, procedural approach in industry. This is, in fact, an inverse challenge to the one makers face, as it entails loosening up some of the rigidity of industrial procedures. The application of more 'agile' ways of working is evident in innovation and new product development. It remains to be seen if 'agile manufacturing'—albeit introduced as a concept decades ago (e.g. Booth, 1996; De Vor, Graves & Mills, 1997; Kidd, 1994; Kidd, 1995)—will find wider adoption in industry in the context of new business opportunities emerging, e.g. from 'the software-defined supply chain' (Brody & Pureshwaran, 2013).

The business design studio cases indicate that business development itself—as an activity rather than a function—is not necessarily the linear sequence of analytical preparation and implementation that Sørensen (2012) suggests. Rather, entrepreneurs appear to be adopting a prototyping approach to business development—exploring and responding to opportunities as they emerge. Other studies indicate that entrepreneurs have an evolving portfolio of business patterns rather than a single business model (Sabatier, Mangematin & Rousselle, 2010; Svejenova *et al*. 2010; Wolf & Troxler, 2015b).

Smart Industry

National smart industry agendas (e.g. Dais & Kagermann, 2013; BIS, 2013; Smart Industry, 2014) appear to focus mainly on reaping the benefits of advanced manufacturing technologies, such as robotics or 3D printing, and a higher informational integration of manufacturing systems—very much akin to earlier initiatives in relation to computer-integrated manufacturing (CIM, see, for instance, Scheer 1989; Jäger 1990; Krallmann 1990).

The images these strategies evoke are those of a high-tech manufacturing industry that is highly predictable, algorithmic and analytical. Smart industry appears essentially as (yet another) human-out-of-the-loop technology—literally through maximising automation that eliminates the intervention of humans in the manufacturing process and figuratively through the ‘purified parlance of algorithms’ (Sadowski & Selinger, 2014, p. 164) that eliminates the discussion of the ‘whys’ and the biases, values and politics embedded in these algorithms.

Making itself is not free from technocracy. On the contrary, some of the maker-movement rhetoric is outright technocratic. Yet there is another end of the spectrum, with ‘punk manufacturing’ (Bone & Johnson, 2009, p. 96) and critical making (Ratto, 2011; Ratto & Boler, 2014) and the notion of ‘making is connecting’ (Gauntlett, 2011)—materially, socially and environmentally. Analogous to the critique of smart cities (Smart City 1.0 according to Cohen (2015)), engaged, critical and political Making may contrast and amend the vision of smart industry as a technocratic project so that it becomes, like ‘Smart Industry 3.0’, efficient, interactive, engaging, adaptive, flexible and based on human values.

6.2 Making and Education

Making and Education continue to be an interesting—and challenging—match as education itself is in transformation. In *higher education* Making brings new, non-linguistic modes of learning research and design skills. In *primary and secondary* education, where Making is strongly tied to STEM education, its true potential lies in fostering critical and constructionist learning. *Internationally*, more reflection and exchange is needed on the successes and failures of Making in education.

Research and Design Skills in Higher Education

Creative professionals base their position on research and design skills, ranging from the technical to the conceptual. There is growing awareness that educating future professionals in these skills requires rethinking of the curriculum and of the methods of teaching and learning (see e.g. Chabot, Cramer, Rutten & Troxler, 2013; Hoojer, 2015). An inspiring learning environment and a constructionist approach are promising starting points. Research through design may prove to be an important method for the training of creative professionals, through which they learn to design solutions in interaction with a practical application and in a setting that allows for mistakes and in which errors, as failures, open the way for new and different approaches. Innovation ultimately does not come from truthful reproduction—whether facts or behaviour—but from applying what one learnt earlier in new contexts. A possible implementation of such a strategy can be found in (critical) Making.

Making itself also has great potential to attract students to ‘get their hands dirty’ with digital manufacturing. It demonstrates how the gap between disciplines, e.g. product design and electronics, can be bridged in an easy and attractive way. This effect has been found elsewhere as well (Gershenfeld, 2005; Ratto, 2011) and can easily be replicated. As more universities and Fab Labs begin to develop this route—the Fab Lab at the University of Cergy-Pontoise near Paris has had three diploma courses accredited, the Fab Lab in Zurich is providing a digital fabrication course for design classes at the University of Applied Sciences and Arts, ZHdK, Zurich, to name a few—it will become important to share experience and efforts. There is also room to integrate and further develop distributed design studio approaches (Lauche *et al.*, 2007).

Finally, a problem has been signalled in the Dutch universities of applies sciences sector. While access to universities of applied sciences has steadily opened to students from a broad range of socio-economic strata, the system appears to favour autochthonous female students and disenfranchise non-Western males in terms of completing their degree programme within five years of starting their studies (Bormans, Bajwa, Braam & Dekker, 2015). The authors come to the conclusion that teachers can make the difference by providing professional mastery and creating ties with the discipline. With Biesta (2014) they argue that education encompasses qualification, personal development and socialisation. Through its antithetical stance to the heavily cognitively biased and linguistic forms of education, Making is supposed to assist this process, as it adds ways of interacting with professional practice that exceed the possibilities language alone offers (see Ratto, 2014).

Making in Primary and Secondary Education

Teaching research and design skills—and the related professional attitude creative professionals require—is a serious challenge if students have been primed in primary and secondary education only to reproduce facts and exhibit standardised behaviour. There are, of course, many ways to eschew this fallacy and to educate children to become critical citizens, but most of them, such as philosophy or cultural history, are strongly tied to a (cognitive, linguistic) discourse. Making offers an approach that is not purely linguistic.

Yet Making in primary and secondary education is most strongly tied to teaching science, technology, engineering and mathematics (STEM) with the purely utilitarian aim of ‘getting students passionate about technology by stimulating their curiosity and showing them the importance of technology in an appealing way’ (Techniekpact, 2013, p.3). This motivation is a far cry from the goal of liberating students from the duty of reproduction, if only temporally. STEM education could even be read as a move to ‘train’ children to accept technocratic reasoning more easily.

Moreover, Making has an almost subversive potential to counteract a purely technocratic agenda and initiate critical discourse on technology. Examples include Paulo Blikstein's work at Stanford's Transforming Learning Technology Lab, Emily Pilloton's 'Project H', or Per-Ivar Kloen's and Arjan van der Meij's *'FABklas'* in The Hague. Yet rather than deploying Making as a Trojan Horse to introduce critical discourse through the back door, it should be used as a gateway to open the discussion on some of the wider issues regarding STEM education and to foster critical and constructionist learning in general.

International exchange and comparison

As indicated above, making and education is a combination that is also being developed and implemented elsewhere. There is a whole community of educators and makers forming in the Netherlands. There are also similar efforts abroad, for instance in the United States of America. Still these efforts are relatively disconnected. When the communities meet, the focus is on sharing success stories rather than talking about blunders, which seems at least a little strange given their mantra of 'failure as a means to success' (Hlubinka *et al*. 2013, p. 25). More exchange and more reflection is needed.

The majority of these initiatives are still rather pragmatic and focus on the immediate effects of Making in the classroom. Even in academic journals and at conferences, the majority of contributions on making and education are case studies. While this is not surprising in an emerging field, it is time to evaluate properly the many initiatives and to validate the claims that are used to promote Making in education.

Finally, some wider issues of Making in education have been signalled. The major concerns are the 'white male middle-class' image of Making (Buechley, 2013), the 'key chain syndrome or the temptations of trivialization' of Fab Labs in schools (Blikstein, 2013, p. 8), i.e. settling for simple projects that are very admired by external observers, and Biesta's 'non-egological approach to education' (Biesta, 2015), i.e. to overcome the infantile stance of occupying the centre of the world yet living in the world. These concerns are worthy of deeper investigation, and the responses need to be transformed into educational practice.

6.3 Places and Spaces

In the area of urban (re)development, there are at least three aspects that need to be developed further. The *new places* where Making takes place could benefit from more detailed study and exchange. A next *economy* is emerging that is based on principles of circularity, locality and lateral structures. Lateral, sideways connections generate a new form of *governance* that is closely related to co-creation and engenders new forms of urban (re)development.

New Places

When studying Making and boutique manufacturing initiatives in the Business Design Studio programme, it became clear that the requirements of space and community were an essential element of this new movement. Across Europe, there are places emerging that appear to offer a fertile environment for boutique manufacturing, often shaped after the known models of incubators and accelerators.

There is probably no one single recipe for how such a boutique manufacturing incubator or accelerator should be shaped. The mix of occupants of such a place has to be taken into account, as well as the local environment and its geographical, economic and social characteristics. Joining up the boutique manufacturing accelerators across Europe and connecting them by exchanging practices and case studies would certainly lead to a better understanding of the phenomenon.

Ultimately, principles could be derived to guide the establishment of such boutique manufacturing accelerators. These should not only concern the inner workings of such a place, but also its integration into the wider local context and the anticipation of its development against a backdrop of economically, ecologically and socially sustainable urban renewal.

New Economy: Circular, Local, Lateral

There are relatively strong signals that point towards a transition to a new global economy. In Rotterdam, in particular, these are the rising pressure on the petrochemical cluster, shifts in the labour market and a decrease in new building activity, to name a few. This new economy will be more fundamentally based on circular material flows, it will depend more strongly on local business transactions and it will be characterised by lateral governance of these transactions.

These emergent characteristics of the new economy—circularity, locality, laterality—are compatible with Making, its expression in boutique and new manufacturing, and its requirements for spaces and places, although they are not necessarily and inseparably inherent to Making. This means that developments in Making will converge, as if by some magical occurrence, to form this new economy, but that Making, too, has to be directed, steered or ‘nudged’ towards circular, local and lateral structures.

New Governance: Urban Co-creation

Parallel to how business models evolve from formerly monolithic or linear structures into networks of value creation (see above), urban development that creates the places and spaces for Making is developing a ‘new style’ characterised by networks of interacting, autonomous entities (Peek 2015). It is no surprise that in this context urban development, or rather urban co-creation, is also referred to as ‘making city’ (*‘stadmaken’*, Franke, Niemans & Soeterbroek, 2015).

Urban co-creation is introducing lateral governance into urban development. This appears to be a possible next step in the developments that were signalled earlier, particularly the concept of polycentric cities (for a discussion of this, see e.g. Davoudi, 2003), the emergence of ‘inverse infrastructures’ (Egyedi, Vrancken & Ubacht, 2007; Egyedy & Mehos, 2012), and the concept of organic city redevelopment (Buitelaar *et al.*, 2012) sketched above.

CHAPTER 7

Conclusions and Outlook

If there is one lesson we can learn from globalisation and the ever-increasing reach of the market, it is that the logic of the market exerts enormous pressure on existing social structures. If we are indeed seeing the emergence of a substantial component of non-market production at the very core of our economic engine—the production and exchange of information and through it of information-based goods, tools, services and capabilities—then this change suggests a genuine limit on the extent of the market. Such a limit, growing from within the very market that it limits, in its most advanced loci, would represent a genuine shift in direction for what appeared to be the ever-increasing global reach of the market economy and society in the past half-century.

What we are seeing now is the emergence of more effective collective action practices that are decentralised, but do not rely on either the price system or a managerial structure for coordination. This kind of information production by agents operating on a decentralised, non-proprietary model is not completely new. Science is built by many people contributing incrementally—not operating on market signals, not being handed their research marching orders by a boss—independently deciding what to research, bringing their collaboration together and creating science. What we see in the networked information economy is a dramatic increase in the importance and the centrality of information produced in this way. (Benkler et al., 2008, xiii)

7.1 Conclusions

Making

After cautiously appearing with the new millennium and making its official start ten years ago, Making has become a phenomenon and a term that will persist for a while. Its various incarnations—maker movement, Fab Labs, maker spaces—have become the subject of political agendas and academic inquiry. Making is a pastime, an educational innovation, a new renaissance, reuniting the liberal arts with science and engineering and constituting a new industrial revolution which is empowering people through technology. For the non-initiated, Making still has a geeky flavour to it which is partly an ingredient of the branding of some maker initiatives. Yet Making has certainly become more than just the occupation of some consenting nerds.

Making is starting to have an economic impact as boutique manufacturers integrate principles of Making—such as prototyping, digital tools, open source and communities—in their business models. There is potential for self-employed and micro-enterprises to build a network and grow laterally instead of only gaining more mass individually or being swallowed by some large multinational. In that context it is interesting that businesses are also starting to prototype their business models as they grow.

Even incumbent industry is starting to develop an interest in these principles and is looking into new ways of innovating and manufacturing. Whether the reason for this is open innovation, more effective use of internal talent or simply employee retention that motivates companies, Making is becoming a 'tool' in the hands of business. Yet incumbent industry could also benefit from the networked, lateral approach that is often at the core of collaboration between Making initiatives.

Education

Making has a significant link to education. There is a strong call for more STEM education, which is not undisputed but resonates with the skills demanded by a high-tech world. There is an equally strong drive to equip students with 21st century skills which, some argue, could be achieved by including Making in the curriculum—as a very concrete, hands-on implementation of constructionist learning.

However, adding, for instance, a Fab Lab to a school or university also requires a profound revision of educational practice, including planning activities and assessing performance and outcomes. Simply offering something different for a change is not good enough, and revising education also needs to address the question in whose name education is offered, why to provide maker education and not only how and what.

Urban (re)development

Making and urban (re)development are connected in two ways. On the one hand, there is a new and changing manufacturing industry, from boutique to established, that is looking to accommodate its activities, ideally in places that reflect the spirit of Making. On the other hand, there are many places in which post-industrial urban (re)development is desired or already happening, for which Making is an attractive ingredient—much akin to the argument of the creative class.

However, there is also a deeper link between Making and contemporary urban (re) development which relates to the issue of prototyping. Prototyping is one salient ingredient of Making—both with respect to the products of services and with respect to the way a Making business is established. Prototyping—or rather an incremental development path—is becoming a key characteristic of urban (re) development. The latter is evolving into a much more co-created practice that leaves room for experiments and creates multi-dimensional value—social, economic and physical.

7.2 The Future is Lateral

There is a common thread which connects the three areas discussed, namely Making, education, and urban (re)development—a different way or organising, grouping, aligning and governing activities in these fields. This way of organising is resounding a theme that has been discussed in economics, social science and to a certain extent in organisation theory for a while: the theme of the network (Barnes, 1954), of self-organisation (Trist & Bamforth, 1951), of peer-production (Benkler, 2006), of the Commons (Ostrom, 1990) and of lateral governance (Rifkin, 2011).

If considered to be more than just an assembly of individual maker heroes, **Making** is fundamentally cooperative when it eschews the lure of venture-capital fuelled individualism with its grim exit perspectives. The future of Making lies in cooperation: the key to Fab Labs and the maker movement is not personal fabrication, but social fabrication. The grassroots proponents of the maker movement basically carry the power of lateral governance.

There is maybe a threat of corporate takeover in Making if multinationals start to sponsor Making activities and begin to incorporate pockets of Making into their own structures and operations. There is a threat to groups within Making to become overly self-contained through aggressive branding, wanting to become world-leaders in Making, establishing standards that exclude rather than include the out-group. The answer to these threats is to return to lateral governance and to nourish the network, even if there is no easy ready solution and even if one has to abandon the craving to achieve the position of 'the first', 'the biggest' or 'the leading' enterprise and adopt a lateral *attitude*.

Such an attitude must come from **people** who have learnt to think, learn and act in laterally governed settings. The most prominent setting to learn such an attitude is certainly education. Being able to interact laterally is learnt similarly to 21st century capacities. Both essentially require personality development gained through being exposed to situations that require these capacities, rather than memorising facts and behavioural action scripts.

Creating situations of lateral governance in education means fundamentally discarding instructors and educators as hierarchically superior. In a constructionist educational setting, teachers must act rather as facilitators, curators, navigators of a field or discipline, approaching teaching from a lateral attitude themselves.

The **places** where Making will happen also need to be developed, maintained and governed in a lateral way. Many development initiatives —however naïve, idiosyncratic and non-cooperative they sometimes might be— already aim to co-create urban spaces and places. City councils and regional and national governments are increasingly waking up to the call and are eager to include grassroots initiatives and to create an environment for lateral development—albeit coming from a traditionally hierarchical position.

There is still a lot of room to create and animate cooperation, to provide education about the commons, and to develop lateral business and governance models in urban development. The right criteria to evaluate initiatives need to be found, inclusiveness has to be addressed and a possible bias towards corporate solutions has to be investigated. Grassroots initiatives often also have to stop themselves being competitive and develop a relationship of 'coopetition'.

7.3 Beyond Consenting Nerds

For Making to move beyond the circles of consenting nerds it needs to contribute to the bigger challenges of society—becoming economically, socially and ecologically sustainability, developing the network, achieving equality, defying technocracy, and elaborating on the notion of lateral governance.

Sustainability

Notwithstanding its limitations, Making can have a substantial impact on sustainability—economically, socially and ecologically. For Making to contribute to economic sustainability there needs to be a development away from depending on public subsidies and towards developing value propositions that allow makers to become economically self-sufficient. Experience shows that this requires new approaches to creating value that are based on network approaches and involve multiple, interdependent parties. Such business models are not taught at business schools and do not emerge from the practices of general business consultants. Rather they require conscious co-creation by the parties involved and, as examples have shown, 'uniting profitability with a 2.0 and open rationale, thus solving the "puzzle" of the open business model' (Delbosc, 2014, p. 59).

For Making to contribute to social sustainability it needs to pursue its path of individual empowerment. However, it is important not to leave social innovation and empowerment to chance: social innovation must be pursued actively and in conjunction with attaining economic sustainability. Many enterprises in the 'sharing economy' have promoted individual empowerment as social innovation, but eventually only recreated an old-style 'renting economy' in which those entities which profit economically from a 'sharing' business do so by exploiting resources they do not even own and augmenting inequality. By creating networks of value creation, Making will be able to contribute to positive social transitions that broadly contribute to diversity, equality and inclusion.

Ecological sustainability is an equally challenging call for Making. Energy and material consumption and waste generation are serious issues at present. Taking 3D printing as an example, the materials used are either ABS (acrylonitrile butadiene styrene, a common plastic polymer) made from oil or PLA (polylactic acid, a bio-based polymer) which is often made from genetically modified corn. While oil is not a sustainable source of raw materials, the issue with corn is the competition between food, material and biofuel manufacturing for farm land. Both materials, ABS and PLA, do not degrade naturally in landfills. There are currently no easy recycling routes for these materials that would guarantee the material safety that is required in their application. Research on sustainability in Fab Labs has only just started (see, for example, Kohtala, 2013; Kohtala, 2016). So far the conclusion is that it remains to be seen if Fab Labs are able to transform themselves into a platform for participatory ecological innovation.

Network

Despite its prominent place the term network has, for instance, in the fab charter—it stars with the sentence 'Fab Labs are a global network of local labs' (CBA, 2012)—and the important functions the network is supposed to provide—'operational, educational, technical, financial, and logistical assistance'—the Fab Lab network has still to develop. Other initiatives in Making are even more disconnected and thrive, for example, mainly on the marketing efforts of Makermedia.

There are a few services the network offers to the Fab Labs, mainly a couple of yellow pages listing the Fab Labs globally. There are also a number of websites offering guidance for setting up Fab Labs and a plethora of other sites aiming to promote exchange, to create business opportunities and to attract funding. It has been acknowledged early on in the Fab Lab network that it requires multiple forms of alignment—lateral, bottom-up and layered instead of top-down—and that the network needs distributed leadership that is based on influence, not authority (Cutcher-Gershenfeld, 2007). Yet many of the initiatives to strengthen the network are in actual fact authoritative approaches as they are try to become the single central resource for a certain purpose or to define what a Fab Lab is once and for all.

Equality

The annual ritual in which the Fab Lab network gathers for an international fab forum and symposium (or 'conference and festival' as it was called in Barcelona in 2014) is one established structure for promoting connections within the Fab Lab network. Local and regional Maker Faires have a similar function. The growing attendance to these events, however, conceals that they risk losing out on broad, inclusive participation from the whole network. The cost of attending is high if it involves international travel to far away countries—and for a large section of the Making population any destination is by definition far away. Spending several days away is a substantial demand on the time budget of many a maker. Remote participation is virtually impossible, and while selected content might be available as a video stream, bandwidth at the receiving end might not be sufficient. It is a huge challenge for the whole maker movement to become and remain inclusive and not to create a divide between the ordinary members of the maker movement and a Making elite. However, developing the sharing capabilities of the network is a burden borne mainly by the wealthy participants in the network. There is a potential issue of colonisation, of the Western white male ideology (or role model) dominating the discourse. A telling example is the promotional video 'A Fab-ulous Future: What Is a Fab Lab?' by the Manufacturing Institute (2012) where a plane is seen circling the earth and parachuting replicas of the Manchester Fab Lab onto remote parts of the planet.

Technocracy

Another challenge which Making faces is its position in relation to social and political questions, as was mentioned above. The louder voices in the maker movement appear to side with the ideals of liberal individualism, projecting makers as a new breed of Randian heroes. Is this image of the creative individualist, who perseveres against all odds in the pursuit of his goals—even when his ability and independence lead to conflicts with others—really the ideal Making aspires to? As Making empowers people through technology, they have to acknowledge that technology is a site of power. Consequently, the question needs to be asked 'In whose name is this done?' If the maker movement is indeed the final phase of winning the digital revolution (Gershenfeld, 2006), the earlier developments in this digital revolution should be a warning: the first decade of the Internet revolution (approx. 1995 to 2005) brought horizontality, cooperation and decentralisation, and a vaguely anarchistic outlook. The second decade of Web 2.0 with its focus on data placed central control in the hands of unregulated corporations, 'politically speaking … a counter revolution' (Stalder, 2013).

What is required is developing a critical discourse around a few implicit assumptions—technology is not neutral but 'society made durable' (Latour, 1990), technology and people are 'entities that do things' (Latour, 1994), and technology comes with built-in societal, cultural and political assumptions. Participation will not just work, out-of-the-box as it were, but is influenced by local cultural and social variables, such as heterogeneity and the role of elites. Downward accountability and upward commitment are key to making participation work

(Mansuri & Rao, 2004). As Making is at the forefront of technical innovation in and for society, in moral controversies it is expected to provide leadership and not to adopt a ‘neutral’ hands-off attitude. Overall, in Morozov’s analysis, ‘there’s more politicking—and politics—to be done here than enthusiasts … are willing to acknowledge’ (Morozov, 2014). A particularly difficult case in point is the issue of funding of Fab Labs and their activities by large business corporations.

Lateral

While still growing at an exponential pace, the maker movement, Fab Labs, maker spaces and makers in general have to develop their practices of interaction and exchange. They have to keep abandoning top-down, centre-out as the one single possible imaginable approach for organising and experimenting with polycentric, bottom-up and lateral schemes. This in fact means that actors need to engage in constructing their practice and becoming institutions in ‘a dialectic synthesis of what is going on in a society and what people are doing’ (Sztompka, 1991, p. 96). They will need to avoid the potential enticement of the corporate privatisation of Making and the cajolement of fab-washing. While being earnest—as an infrastructure for learning skills, developing inventions, creating businesses and producing personalised products, and as a movement that is building its identity in a complex socio-technical and politico-economic environment—Fab Labs should not forget that play is a crucial ingredient, as is their non-utilitarian social role as third places, distinct from the first and second places of home and work (Oldenburg, 1989), providing for civil society, democracy and civic engagement.

In the long term, Making has to prepare for a time when the concept has lost its novelty, when fabbing is not fabulous anymore. Depending on the decisions players like Fab Labs make about their purposes now and the routes they take in the near future, this could mean retiring to the position of consumer-oriented, commodity-producing facilities for consenting nerds, or being part of a much broader development of the cultural, scientific and political (re)configuration of society.

Glossary

The Maker Movement

What today is known as the 'maker movement' has emerged over the past decade. In 2005 Neil Gershenfeld's book Fab: The Coming Revolution on your Desktop - From Personal Computing to Personal Fabrication appeared (Gershenfeld, 2005). For a long time, this book was the only substantial publication on Fab Labs, reflecting on the first five years of their global development and installation.

In the same year as Fab appeared, publisher O'Reilly launched Make Magazine, which in its first issue prominently featured Boston's first Fab Lab. According to their website, Make Magazine promotes 'DIY-projects, how-tos and inspiration from geeks, makers and hackers'. The clientele of Make Magazine in the U.S. are mainly white, Western, middle-class men in full employment and with an above average household income (Karlin Associates, 2012, pp. 24-25). Leah Buechley (2013) analysed 39 copies of Make Magazine—85 % of whom sported white men on the cover.

As with other terms coined by O'Reilly, such as 'BarCamp' and 'Web 2.0', 'Make' was bound to set a trend. This trend turned into 'the maker movement', when in 2006 the first Maker Faire was held at the San Mateo Event Center, a mixture of a county fair and trade show. Maker Faires quickly started to grow and spread across the United States and spilled over to the UK in 2009 and into Europe and Japan in 2013. These events and smaller 'Mini Maker Faires' are run under strict franchising agreements with Maker Media. Maker Media Inc. under Dale Dougherty was a spin-off of O'Reilly publishers in 2013 and has become the self-promoted leading collection of brands relating to the maker movement. Besides Make Magazine and Maker Faire, MakerShed is the official online store of Make Magazine, and Maker Media are also active in education.

Next to Maker Media there is another US 'brand' trying to dominate the maker movement—Techshop. Techshop is a chain of member-based workshops that let people of all skill levels come in and use industrial tools and equipment to build their own projects. Its first workshops were opened in the Bay area in 2006. The company is currently looking into expanding to other continents. Techshop founder, Mark Hatch, published The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers (Hatch, 2013). There have been rumours about Techshop opening subsidiaries in Europe—Munich, Paris, Rotterdam—with little follow-up however.

Besides those three strongly branded household names—FabLab, Make and Techshop—there are maker spaces and hacker spaces that form part of the maker movement. Hacker spaces are workshops for people with an interest in technology to socialise, collaborate and share knowledge. Their focus is more on technology in general, but 3D printing and making often plays an important role. Makerspaces are similar to Fab Labs, often equipped with the same machines, but lacking the global network. Sometimes, a public workshop calls itself a 'maker space' to differentiate itself from the Fab Lab network. One reason given is that the Fab Charter (CBA, 2012) requires 'open access for individuals', which is then read as 'gratis access'. Many spaces feel this is a restriction on their business model. This appears to be the case, in particular, when traditional incubators and corporates join forces to establish a joint venture, for example in the case of the Maker Space Munich of the Centre for Innovation and Business Creation at the Technical University of Munich and BMW. The term 'maker space' obviously also refers back to the Make Media brands without being associated with them.

3rd Industrial Revolution

The term 'new', 'next' or often 'third' (but also fourth or fifth) 'industrial revolution' has had many uses in the recent past.

Firstly, it has been tied to specific technologies, such as the Internet and digital technologies (Dosi & Galambos, 2013; Greenwood, 1997), nanotechnology (Burke, 2012), or 3D printing (Lipson & Kurman, 2013).

Secondly, it has been related to an ecologically oriented service economy and other sustainable business practices (Clark & Cooke, 2013; Hawken, Lovins & Lovins 1999). Thirdly, it has been used to describe a combination of distributed business practices in manufacturing, energy production, etc. (Gershenfeld 2005; Rifkin 2011; Rifkin 2014), localised networked production lines producing networked and personalised products (Dais & Kagermann, 2013; Smart Industry, 2014), prosumerism and an end to mass production (Brody & Pureswaran, 2013; Marsh, 2012), and the maker movement and its use of digital manufacturing technology (Anderson, 2012; Gershenfeld, 2005; Hatch, 2013).

Industrial revolution usually brings to mind images of red brick factory buildings, factory owners' villas and cramped workers' housing, characteristic of the developments of the late 18th and early 19th centuries—as well as images of the machines of the era, the coal-powered steam engines and locomotives which were the workhorses of that period. The first industrial revolution, however, was more than just a collection of architectural features: it brought mechanisation, centralised factories and industrial capitalists; its social effect was the division between labour and capital and the rise of the working class.

The industrial revolution also triggered what James R. Beniger (1986) has called the 'control revolution': the development of information processing and communication technologies—including rationalisation and bureaucracy—for controlling the energy and flows of materials within industry. Often referred to as the second industrial revolution, it brought automation and later computerisation of manufacturing, the conveyor belt as a tool for rationalising and controlling assembly, scientific management and management consultants to implement it. Its social effect was the division between white-collar and blue-collar work, and the struggle by managers to gain control over workers, based on a 'military thrust toward total control [that] indulged technical enthusiasms while it ratified managerial propensities' (Noble, 1984, p. 192).

Digital Revolution

The term digital revolution is commonly used to describe the effects the application of computers and the Internet had on industries, in particular on the media and content industries. The digital revolution is a narrative of the disruption of business practices and business models, and the emergence of new products triggered by social developments.

The music industry, for example, may be taken to illustrate this. In the late 20th century the industry established its distribution and business model: major labels secured the rights of artists and sold music stored first on analogue and later on digital media (LPs, cassette tapes, digital compact discs). At that time, it was common practice for consumers to create compilation cassette tapes and share them with friends. However, this did not seem to have any major impact on media sales. As the Internet appeared and with it publicly available compression formats to store and share music of reasonable quality, people moved from sharing cassette tape compilations to sharing music over the Internet. Roughly at the same time, media sales started to crumble and the industry quickly jumped to the conclusion that music sharing over the Internet was the root cause—a claim that was never properly proven (see Zentner, 2009). Dubbed 'piracy', online music sharing became the target of heavy policing by the industry—to no avail, as sales kept tumbling. New business models—Apple's iTunes ecosystem, streaming services such as Spotify and LastFM—are the current answers to a changed reality where the industry has to accept, as singer-songwriter Neil Young put it in an interview, that "piracy is the new radio" (Young, Mossenberg & Kafka, 2012).

Other industries faced similar disruptions—the print industry with the advent of desktop publishing (DTP) and electronic publishing, the news industry when faced with blogs, 'social media' and user-generated YouTube videos of current events (Alterman, 2008; Newman, Dutton & Blank, 2011; Pew Research Center, 2012), or the field of encyclopaedia where crowd-sourced and laterally governed Wikipedia has outgrown *printed encyclopedia in volume, depth, recency and use (Okoli et al., 2012). Disruptive change in these industries would not arise from technology itself, but with social practices developed around technology that embrace the absence of central control and allow for individual and even (to a certain extent) idiosyncratic contribution. The social developments in music, print, news and encyclopaedia give an idea of what is to be expected from digital technology in manufacturing in the decades to come. As Zuboff (1988) aptly remarks, the technical means of automation and information technology create new options for the design of industrial and working conditions, but they do not determine which options are chosen and to what end; technology is always just an option. Moreover, technology creates intrinsically new qualities of experience, but also contingent possibilities as to how the often conflicting demands of social, political and economic interests engage with technology to produce a 'choice'.*

A Short History of Making

Making is often seen as a hedonistic pastime: individuals using low-tech and high-tech manufacturing equipment to produce anything from everyday goods to artworks and weird and useful machines. Fab Labs (fabrication laboratories) and Makerspaces are publicly accessible workshops. Fab Labs, in particular, are a global network of local labs, enabling invention by providing public access to digital fabrication. They share an inventory of core capabilities and can be considered a community resource (CBA, 2012). The initial concept was developed at MIT.

When Neil Gershenfeld started the Center of Bits and Atoms (CBA) at the Massachusetts Institute of Technology (MIT) in 2001 to explore the merging of physical and computer science, he was required to establish a community and outreach programme. To this end, it was decided to select a subset of the digital fabrication equipment, tools and processes—CNC milling, laser cutting, micro-processor programming and electronics—that the centre used for their research and make it available to communities. The first labs were established in the United States (INTEL Computer Clubhouse in Boston, Science Museum of Minnesota), in Costa Rica, in the village of Vigyan Ashram (India), and in Ghana. The scientific interest, beyond outreach, was to understand and review 'the implications and applications, and to enable research into access in the field to prototyping tools for personal fabrication' (CBA, 2005).

Makerspaces are similar, often equipped with the same machines, but lacking the global network. Often, a public workshop calls itself a 'makerspace' to differentiate itself from the Fab Lab network. One reason often given is that the Fab Charter (CBA, 2012) requires 'open access for individuals' which is often read as 'gratis access', which many feel is a restriction on their business model. The name 'makerspace' also refers to the regular Maker Faires, Make Magazine and Maker

Shed, all brands owned and promoted by Makermedia (http://makermedia.com). Makermedia itself, founded in 2005, is an offspring of O'Reilly publishers (independent since 2013) and the self-promoted leader of the maker movement. Maker Faires are events that bring together the proponents of the maker movement, Make Magazine promotes 'DIY-projects, how-tos and inspiration from geeks, makers and hackers', MakerShed is the official online store of Make Magazine.

Techshop is a US-based chain of member-based workshops that lets people of all skill levels come in and use industrial tools and equipment to build their own projects. Its first workshops were opened in the Bay area in 2006. The company is currently looking into expanding into other continents. A first European Techshop announced will be opened in Munich (Zheng, 2013), and Rotterdam is trying to attract a Techshop (Louwes, 2013). Techshops' founder has published the The Maker Movement Manifesto: Rules for Innovation in the New World of Crafters, Hackers, and Tinkerers (Hatch, 2013).

Big industry has started to develop an interest in the maker movement. Ford in the US and BMW in Germany are partnering with Techshop to provide their employees with access to digital manufacturing technology for tinkering outside working hours. Globally, big players have started to fund Fab Lab on a substantial scale. Schlumberger is supporting the development of Fab Labs in Russia, Aramco sponsored the first Fab Lab in Dhahran (Saudi Arabia) and Chevron promised support for the setting up of Fab Labs in US communities where it is active. More interesting, however, are the small-scale, but high-tech developments, certainly from the perspective of emerging socio-technical production paradigms. For instance, Barcelona is pronouncing itself as 'Fab City' and aims to develop neighbourhood Fab Labs in every city district. The Dutch Order of Inventors was a key partner in setting up the Fab Lab in Utrecht. In Amersfoort, the Netherlands, an artists' collective is effectively transforming a former dye factory into a testbed for the transition town movement, centred on a Fab Lab. The Swiss clean tech accelerator, Blue Lion, in Zurich is setting up a Fab Lab for its companies.

Fab Labs

The MIT Fab Lab, Norway, is the oldest Fab Lab in Europe, founded in 2002. It started operations in 2003 and was formally opened in 2005. It emerged from a cooperation project involving Telenor and the MIT in relation to the development of an electronic mesh network to assist shepherding in the Lyngen Alps in northern Norway (Thorstensen, Syversen, Bjørnvold & Walseth 2004).

Prof. Gershenfeld asked what kind of technological problems Telenor had with which the Media Lab could help out. Telenor suggested assisting farmer Haakon Karlsen, who keeps sheep and reindeer on his farm. The farm is in a very alpine

area containing glaciers and valleys with elevations ranging from sea level to 1800 meters above sea level. Karlsen needs to protect his herds from wolverines and lynx, and to keep them out of treacherous areas during the winter.
Karlsen and Telenor also were interested in keeping track of the animals' health and documenting the life (production) cycle within each herd. (Thorstensen, 2002).

In 2005 Neil Gershenfeld's book FAB: The Coming Revolution on Your Desktop—from Personal Computers to Personal Fabrication was published and with it came growing public awareness of the phenomenon. South Africa was the first country to implement a national FabLab programme through the Advanced Manufacturing Technology Strategy of the country's national Department of Science and Technology (Borde & Coetzee, 2005). This included setting up six labs within the time span of two years. The CBA was clearly on a route of 'establishing a growing network of field Fab Labs to explore the prospective users and applications of these technologies' (Mawson, 2005).

Fab Labs in the Netherlands

In 2006, a Dutch website for Fab Labs was set up with the aim of promoting Fab Labs in the Netherlands. A year later, a private Fab Lab foundation was set up in the Netherlands. There were two temporary Dutch FabLabs operating (that later merged into one). In 2008, three more labs started as private initiatives. Clearly something different was going on: this was not a state-run programme, but groups of individuals and private organisations who were keen to have their Fab Labs.

The Netherlands was the first country in Europe in which Fab Labs were not set up in close cooperation with Neil Gershenfeld and the CBA. Neither was there a state-run programme to roll-out labs (as in 2005 in South Africa), nor an initial lab that planned to spin-out more labs over time (as in 2010 in the UK). There was no entity that could have been a paying client for CBA to facilitate outreach in a franchise-like manner. Yet there was a group of enthusiasts, loosely organised in the Dutch Fab Lab foundation, gathering around the idea of Fab Labs and the slogan 'Where the future is being made today!'

This did not impede the spread of the virus. On the contrary, the Dutch press quoted Neil Gershenfeld (Dalm, 2007): 'It is going fast in your country; that doesn't surprise me. The Dutch are good at collaborating and working in networks. That is crucial. You can spearhead this innovation.' Consequently, the Netherlands saw an exponential growth in the number of labs with numbers doubling every twelve to eighteen months. With forty-four labs, of which five are under development today, the Netherlands has the highest density of Fab Labs in Europe and viewed globally ten times as many labs per inhabitants as the Unites States of America, where the concept was created, and twice the density of Switzerland and France.

A couple of additional developments took place in the Netherlands which spread to other European countries and elsewhere. They could most aptly be described as innovation on the initial outreach model devised by CBA.

The first was the development of Fab Labs which differ in size and equipment from the initial model. The initial model required an investment of roughly 100k euros (or dollars). Experience in the Netherlands showed that many capabilities of a Fab Lab could be achieved with an investment of 10k euros. This idea was later incorporated into the outreach strategy of CBA as the notion of 'powers of ten'. The second was the concept of a 'grassroots Fab Lab', demonstrated by Fab Lab Amersfoort—instructions on how to start up a Fab Lab without government subsidies or a host institution covering initial and running costs (Zijp, 2011). The proposal of this Fab Lab Instructable—'how to set up a FabLab in 7 days with 4 people and about €5000'—has inspired many labs in Europe and world-wide.

The Dutch added three elements to the outreach strategy of MIT's CBA: the emergence of independent labs without a formal relationship with MIT, the reinterpretation of the basic machine set to match smaller budgets and the can-do attitude of the grassroots approach. The CBA relatively swiftly scrutinised, accepted and eventually integrated those innovations into their outreach narrative. This was the start of a grand, self-inflicted experiment of socio-technical innovation.

3D Printing

One of the digital manufacturing technologies offered in Fab Labs is 3D printing—or additive manufacturing—whereby objects are built up by adding material layer by layer rather than cutting off excess material from solid blocks of matter. Ideas for the production of three-dimensional objects using such methods date back to the late 19th century—particularly for the creation of topographic models and busts (Bourell, Beaman, Leu & Rosen, 2009). Under the name of 'solid photography' such an approach was patented in the late 1970s by Dynell Electronics Corp. The technology was marketed under 'Sculpture by Solid Photography' and 'Robotic Vision' (Wohlers, 2011). 'Laminated Object Manufacturing' is an additive manufacturing method that appeared on the market in 1991. Laminated Object Manufacturing machines bond layers of plastic sheet material and cut them with a digitally controlled laser cutter.

In the second half of the 20th century a new method of additive manufacturing appeared that made use of a characteristic of some specific materials, mainly resins, called photo polymerisation: these materials harden when exposed to lasers, or ultra-violet or even regular light. This method is called 'stereolithography'. First experiments took place in the 1960s at Battelle Memorial Institute. Various methods were developed in Japan, France, Germany and the U.S. with many

patents granted in the 1980s. Probably the most influential one was Charles Hull's patent (U.S. Patent 4,575,330, 1986), granted in May 1986, which led to the formation of Hull's company 3D Systems. Other additive manufacturing technologies were invented and commercialised in the 1990s.
Only in 2006 or 2007 '3D printing' became the vernacular umbrella term for all additive manufacturing technologies. It was in those years that the technology became popular outside specialist industries. Two developments contributed to this popularity: the appearance of consumer-directed 3D printing services, such as Shapeways, i.Materialize and Ponoko, and the arrival of open-source 3D printers.
A research team around Adrian Bowyer at Bath University (UK) developed the 'Replicating Rapid Protoyper'—or RepRap for short—a table-top sized 3D printer extruding thermoplastic filaments (Bowyer, 2007; Jones et al., 2011) that would be able to produce its own parts—except some standard hardware and electronics parts like rods, nuts and bolts, stepper motors, cables and microchips—and, by doing so, 'replicating' itself. To that end, the team made engineering and electronic designs, a list of materials, the control software and the building and operating instructions publicly available as 'open source', free to use, modify, fork and redistribute. This development sparked the commercialisation of consumer 3D printers, such as the RapMan and the Makerbot in 2009, the Ultimaker in 2010, and the vast number of projects that mushroomed in the years that followed.

The business consultancy company, Gartner, started to include 3D printing in their reports on emerging technologies from 2008 onwards and quickly classified it as being at the 'peak of inflated expectations', where it stayed until today—except that now Gartner has decided to split 3D printing into 'consumer 3D printing' and 'enterprise 3D printing' (Gartner, 2013). The latter is supposed to reach its plateau of productivity within the next few years, while the former remains at the peak of inflated expectations awaiting its 'trough of disillusionment' (Gartner, 2013) before (possibly) moving towards productivity, while the latter is supposed to reach its plateau of productivity within the next few years.

This distinction between consumer 3D printing and enterprise 3D printing is useful in two ways. Firstly, 3D printing as a consumer technology is lagging behind enterprise applications, but could be follow in the wake of their development fairly soon. Such a development is not uncommon and many industries have experienced the consequences of the 'tools of the trade' becoming available to consumers—just think of all the software to create and manipulate media (photos, sound, video and games) that has become ubiquitously available on networked personal computers. Secondly, many developments of 3D printing are relatively close to commercial utilisation in a business environment, which is essentially what Gartner argues.
A study carried out by IBM showed that within 20 years from now, 3D printing of regular goods, such as washing machines, industrial displays, mobile phones, and hearing aids, could be possible and commercially viable (Brody & Pureswaran,

2013). The study shows that this development can have a disruptive impact on supply chains, transforming them from big, complex and global to small, simple, and local.

Urban Development

In the Netherlands, for example, the traditional market-driven form of urban development, involving large real-estate developers and municipalities acting actively on the property market, has failed as a result of the financial and economic crisis. Private and public actors are exploring new ways of working together and new actors, such as private individuals and local collectives, have entered the marketplace. As such, the field of urban development is in the take-off phase of transition and radical innovation is the key to the further development of the change process (Peek & Troxler, 2014).

Before the financial and economic crisis started in 2007, large scale urban development typically involved a municipality actively purchasing land and developing it in partnership with large private property companies. The basis for such a development was a long-term financial model and a 'blueprint' master plan containing certain landmarks or iconic buildings. The phase of management after the works were complete was not part of the area development process. Profits were made at the moment that plots of land and buildings were sold to new owners. Public space was transferred to the municipal department of urban management.

After 2007, the lack of available debt finance and the sudden shift from a sellers' market to a buyers' market brought most large-scale area development to a hold. The capacity to (re)develop no longer lies with municipalities and the large property developers. Their 'marriage' dissolved or is in a state of divorce as both actors have to write down many of the land assets they hold.

This situation left room for other actors to get directly involved in real-estate development, such as local contractors, present land-owners and users and future users of an area. The involvement of these types of actors results in a more bottom-up approach and a decreased in project size. Most striking is the emergence of appreciation for the present state of the area. Where previously a 'tabula rasa'-situation was preferred and sought as the start of the (re)development, a present actors see potential in the existing land use and aim to build on this, limiting upfront investments and benefiting from temporary uses.
Rotmans (2012) confirms that urban area development in the Netherlands is in the take-off phase of a transition process. Changes in the external landscape of area development, like a decrease in population in certain regions of the country, changing working patterns (flexible hours and working from home) and space for

water resilience, have resulted in a deadlock in the pre-crisis development model. The crisis itself was merely a trigger to reveal the faults of the system. In the meantime, at the local level many bottom-up experiments are in the pipeline. People are starting to produce their own renewable energy, individually or in collectives. Others seize this opportunity to design and build their own homes. Some are experimenting with the development of floating homes to live on water or are making use of vacant plots of land for urban farming.

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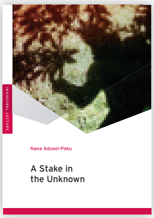

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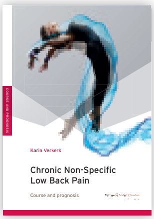

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Peter Troxler

Beyond Consenting Nerds

Lateral Design Patterns for New Manufacturing

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Radical changes are happening in manufacturing. New digital technologies render manufacturing more versatile, more flexible and more accessible. 'Making' has become the term to describe how ordinary individuals use these technologies as a hobby and as a route to generating business.

Some digital manufacturing technologies, including 3D printing, have already become a desktop convenience that allow ordinary people to design and produce their own technical products. Entrepreneurs develop boutique manufacturing as an emerging industry situated between artisanal crafts and traditional mass manufacturers. Incumbent industry is adopting Making as an innovation strategy to achieve what concurrent engineering, rapid prototyping and open innovation so far have failed to deliver. Making is changing how schools teach engineering and technology, and cities are redeveloping former industrial areas for the new entrepreneurs of Making and boutique manufacturing. The impact of Making goes far beyond being a pastime for hobbyists and consenting nerds. It implies a general socio-technical and economic paradigm shift.

Peter Troxler studied Industrial Engineering at ETH Zurich, Switzerland, where he earned his doctorate in 1999 while leading several large factory automation projects for Alstom in Switzerland. After years in management consultancy, he joined the University of Aberdeen, Scotland, as a research manager in advanced knowledge technologies. Back on the Continent he worked at Waag Society, Amsterdam, where he was responsible for the Fab Lab—the place where Making started in the Netherlands. In a unexpected way he returned to his roots in manufacturing and started exploring Making in more detail. He helped to grow the Fab Lab network in Europe substantially and became one of the first researchers to study Fab Labs. Since 2012 he has been affiliated to the research centres Creating 010 and Duurzame HavenStad of Rotterdam University of Applied Sciences.

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