# From:

Julia Walter-Herrmann, Corinne Büching (eds.)

**FabLab**

Of Machines, Makers and Inventors

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Ten years after the first FabLab (a so called fabrication laboratory) was opened at MIT, more than 120 FabLabs exist all over the world. Today, it is time to look back at a decade of FabLab activities. This book shows how small production devices, such as laser cutters and 3D printers, and dedicated educationists, researchers and FabLab practitioners transform the fields of learning, work, production, design, maker culture, law and science on a global scale.
In this composition experts from various countries, such as Germany, India or the USA, and distinguished academic institutions, such as MIT or Stanford University, discuss theoretical questions and introduce practical approaches concerning FabLab activities.

**Julia Walter-Herrmann** (MA) and **Corinne Büching** (Dipl.-Soz.) are research assistants in the computer science work group »Digital Media in Education« at the University of Bremen.

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# NOTES ON FABLABS

JULIA WALTER-HERRMANN, CORINNE BÜCHING

Figure 1: Laser-cut and 3D printed objects by Oliver Niewiadomski at fab*digitalgardens in Bremen, Germany (Source: Photography by Justus Holzberger).

*Koothrappali, PhD*: You know, there is a way we can
get action figures to look exactly like us.
*Wolowitz*: Oh yeah? How's that?
*Koothrappali, PhD*: Two words: 3D printer! […] they are an engineer's dream.
Anything you can design a 3D printer can make out of plastic […]
*Wolowitz*: And we can make stuff we need for work with it:
prototypes of my CAD/CAM designs, specialized tools …
*Koothrappali, PhD*: Not to mention 'Malibu Koothrappali'
in his totally bitchin' dream house.[1]
*Big Bang Theory*

"The digital culture's dynamics have led to a general acknowledgment of data production as the most important future option. However, the production of things seems to be outdated: Factories are not sexy!" (Boeing 2010, own translation) At the same time, there are developments and hints suggesting the digital future "lies outside the box, in making the box" (Gershenfeld 2005, p. 17). One will not be limited to making boxes, though. Since new technologies and machines enable people to easily produce chess pieces, jewelry, computers, batteries, teeth, yet action figures that look exactly like oneself (like proclaimed in the TV series Big Bang Theory) and all the other things one can imagine. The concept of turning ideas into things is probably as old as mankind. For a long time, one has been able to read and hear about enchanted lamps, mysterious stones and unknown cases that can make wishes come true and turn words into real objects. This fantasy has persisted over decades. In the 1980s, Star-Trek's spaceship Enterprise had a 'replicator' on board, a machine that could create any inanimate matter on demand.

In the present digital culture, digital data can transform into material objects and the formerly fictional idea of such a 'magic machine' has been turned into reality, namely by the further dissemination of small, digitally controlled production machines in FabLabs, so-called "labs for fabrication" (Gershenfeld 2005, p. 12), that are accessible for a broad public. These machines "are the pint-sized, low-cost descendants of factory-scale, mass manufacturing machines" (Lipson & Kurman 2010), for example 3D printers, laser cutters or CNC machines that produce objects on the basis of rapid prototyping, tooling and manufacturing (Chua et al. 2010, p. 18 et sqq.). Such production machines are able to print, cut or mill objects from data files without any human intervention.

Taking a look at the history and development of both fabrication devices and personal computers, one can imagine that digital fabrication devices will be accessible and used in everyday live in the near future. The first mainframe computers were huge, slow and expensive. To operate them, one needed to be an expert and nearly no one saw a general market for them. Computer pioneer Howard Aiken, a Harvard mathematician and creator of the Mark I calculator, even spoke of a demand of computers in total numbers of only five or six for all of the

1 | Taken from a dialogue between the characters of Rajesh Ramayan 'Raj' Koothrappali, PhD and Howard Joel Wolowitz from the CBS TV series Big Bang Theory, season 6, episode 14, first aired (USA), January 31st 2013.

USA (Ceruzzi 2003, p. 13). The story of digital manufacturing machines can be told likewise: Only twenty years ago, such hardware was huge, slow, expensive. To operate it, one needed to be an expert and nearly no one saw a general market for them. Back then, such machines were already in use in industrial manufacturing, but no one could ever imagine these machines getting established in private households or open accessible workshops. For a long time, people thought digital fabrication devices were only useful for the niche-economy of prototyping. Today such machines (some cost even less than $1000) can be found in every FabLab and even in some private households – and much more than just prototyping is done with them. At present, especially 3D printers, an essential part of every FabLab, increasingly get the media's and hence the public's attention. "A 3D printer is a computer peripheral[2] like any other, but instead of putting ink on paper, or data on a disk, it puts materials together to make objects" (Gershenfeld 1999, p. 65). The popularity of 3D printers can be explained as follows. On the one hand, 3D printers make it remarkably clear how an idea (or at least the virtual, digitally designed representation of an idea) can become a material object. On the other hand – particularly since there are affordable, easy-to-use, ready-made printers available in the market – this 'magic' now seems to be accessible for nearly everyone.

But FabLabs are neither chambers of magic nor mere accumulations of 3D printers and other fabrication devices. FabLabs are places where digital culture and material production merge and enter a new stage: There, one can find "collection[s] of commercially available machines and parts lined by software and processes [...] developed for making things" (Gershenfeld 2005, p. 12). These machines are based on digital technologies and operated with computers. Usually, a number of 'conventional' tools, like hammers, saws, and screwdrivers, materials, like plywood, glue, and cardboard, and small electronics, like micro controllers, LEDs, and little motors, are added to the collection of machines in these workshops. In these facilities, people can create material objects that can be beautiful or practical, complex or simple, 'intelligent' or not. FabLabs are open for interested individuals, such as artists, hobbyists and students, but also for entrepreneurs who want to "move more quickly from an idea or concept to a physical object or prototype, or [...] want to experiment with and enhance their practical knowledge of electronics, CADCAM[3], design, 21st century DIY" (Eychenne 2012, p. 5). The software used in FabLabs is usually available under Open Source (or comparable) licenses and therefore adaptable and developable (Delio 2004). Furthermore, a credo amongst "Fabbers" (Neef, Burmeister & Krempl 2005) advocates sharing the developed ideas among FabLabs and fabbers (Fab Charter 2012), mainly in the form of CAD files that are the prerequisites for the production of material objects. In doing so, a wide network of FabLabs around the globe, fabbers and files on various Internet platforms has already been established (Center for Bits and Atoms 2012). In this

2 | According to Eisenberg the commonly used expression 'peripheral' is not a well-chosen term for the promotion of such machines. He says, peripheral brings forth the idea of 3D printers and other manufacturing machines as being something unimportant, especially in comparison to 'the center of attraction' the computer itself (Eisenberg 2008, p. 62; explanatory note by the editors).

3 | CAD is an abbreviation for Computer Aided Design, whereas CAM is a common abbreviation for Computer Aided Manufacturing.

sense, FabLabs are globally connected, open workshops, where people can meet, collaborate, interact and exchange ideas, machines, tools, materials and software with the common purpose of making distinctive and digitally designed objects (from scratch) in an easy accessible and cheap way.

Neil Gershenfeld, physicist at the Massachusetts Institute of Technology's (MIT) Center for Bits and Atoms (CBA), USA, invented the concept of assembling modest production machines in small workshops for enabling everyone to make "almost anything" (Gershenfeld 2005, p. ix). The scientist installed the first FabLab in 2002[4] near his home university at the South End Technology Center in Boston, being supported by the National Science Foundation of the USA (Gershenfeld 2005, p. 25; Nunez 2010, p. 23). In 1998, Gershenfeld first offered a university course with the title How to Make (Almost) Anything, based on the use of professional production machines. "The workshops were designed for advanced Physical Sciences students in the throes of their research and promised to provide much needed experience on the kinds of high-tech fabrication tools" (Turner 2010, p. 29). When eventually, more than a hundred students signed up for the class, of which only a few had a background or at least any knowledge in 'cutting-edge' Physics and fabrication technologies, Gershenfeld started to wonder what all the architects and artists were doing in his class that had been planned for only ten students. The course instructor was even more surprised that the students' motivation to take the class was rather personal than scientific. The students wished to create "things they'd always wanted, but that didn't exist" (Gershenfeld 2005, p. 6), like missing or broken pieces of alarm clocks or 'artistic extravaganzas'. Surprisingly, all students managed to complete the course, dealing with the design, the use of computer-controlled machines and even the compulsory circuit building. They accomplished the course by spreading and exchanging knowledge within the huge and heterogeneous group. "The learning process was driven by the demand for, rather than the supply of, knowledge" (Gershenfeld 2005, p. 7), clarifies Gershenfeld. When the same scenario re-appeared year after year in his 'maker class', he realized the potential of a get-together of high-tech production machines with heterogeneous audiences and further developed the idea of establishing a permanent FabLab outside MIT, providing opportunities for tinkering, learning and creating for everyone. That was the moment FabLabs were born (Gershenfeld 2005, pp. 4-12)[5].

4 | Different authors name various origins and commencing dates of FabLabs, mostly depending on the discourses and movements they relate themselves to, such as hacker- or Open Hardware movements. All authors of this book refer to the labs that arouse in the outreach of MIT's CBA.

5 | Meanwhile, the course How To Make (almost) Anything is available online at the CBA's website, last viewed 15 January 2013 <http://fab.cba.mit.edu/classes/MIT/863.08/>, so that everybody who is interested can take Gershenfeld's class independent of being an MIT student. The web seminar is also an essential part of many FabLabs around the world, where the lessons are streamed via Internet on a weekly basis. The How To Make (Almost) Anything course offers instructions for students and interested people about digital fabrication and the use of high-tech manufacturing tools. The seminar is part of the Fab Academy, an online outreach program of the CBA that can be visited here, last viewed 15 January 2013 < http://www.fabacademy.org/>.

From the outset, Gershenfeld's fundamental idea was not only "to make (almost) anything" (Gershenfeld 2005, p. ix), but to make fabrication technologies accessible for 'almost anybody' and hence empower people to "start their own technological futures" (Gershenfeld 2005, p. 17). He states that we "had a digital revolution, but we don't need to keep having it. Personal fabrication will bring the programmability of the digital worlds we've intended to the physical world we inhabit" (Gershenfeld 2005, p. 17). The scientist compares the development of FabLabs with the rise of the Web 2.0, when tools and applications for composing, editing and sharing digital content online became increasingly available for everyone, turning users into prosumers. In FabLabs, the possibilities of digital fabrication become further accessible and prosumers can compose, edit and share (designs for) material artifacts (Gershenfeld 2006). These potentials are exponentiated by the idea of a FabLab as an early version of a "Personal Fabricator" (Neef, Burmeister & Krempl 2005, p. 20; Gershenfeld 1999, p. 64 et sqq.), a digital production machine at home. Such an expansion could have an enormous impact on the value of things, communal life, or even whole economies. By all means, Gershenfeld understands FabLabs and related technical progresses rather as a "concept for development" (Boeing 2010; own translation) than simply as high-tech production laboratories. FabLabs shall stand for a concept of reducing the uneven distribution between the few producers and the many consumers or at least herald a future that links itself to a pre-industrialized past: "Such a future really represents a return to our industrial roots, before art was separated from artisans, when production was done for individuals rather than the masses" (Gershenfeld 2005, p. 8). The idea of an individualization and democratization of (the means of) production caused the establishment of further FabLabs in India in 2002 and in Ghana in 2004 (Delio 2004), where people should be supported in producing things of personal need and desire and therefore reduce economic dependencies and develop a 'subsistent freedom'. A 'doing good factor' doubtlessly is an essential part of the approximately 120 FabLabs on five continents (Center for Bits and Atoms 2012).

Right from the start, all FabLabs have been operated based on the same basic principles "to empower, to educate, and to create 'almost anything'" (Nunez 2010, p. 24; his emphasis). This belief was already put on record by the CBA in the Fab Charter, sort of the FabLabs' 'constitution'. The Fab Charter furthermore sheds light on additional FabLab relevant aspects, such as open access to labs and machines for everyone, responsibility for own actions, machines and environment, free knowledge dissemination, the protection of intellectual property rights and the sustainability of FabLab activities (Fab Charter 2012). Since the establishment of the first FabLab, field practitioners and laboratory researchers gather regularly for various meetings. The International Fab Lab Forum and Symposium on Digital Fabrication takes place at different FabLabs around the globe each year (Center for Bits and Atoms 2012). These conferences are strongly supported by the International Fab Lab Association that was officially established in 2011. The Fab Lab Association is an association of around 200 active and dedicated FabLab members that aim at serving the FabLab community by sharing their experience working with digital fabrication and organize the widespread FabLabs and individuals (International Fab Lab Association 2012).

At present various authors enthusiastically declare the world to be in a phase of transition. "The New Industrial Revolution" (Anderson 2012) and the end of mass production are proclaimed likewise. Such predictions mainly draw on the increasing availability of new ways and machines for production, similar to those in FabLabs. MIT's Technology Review even set up a blog section about the topic, where the "Next Wave of Manufacturing" (Technology Review 2013) and a "manufacturing renaissance" (Technology Review 2013) were announced, thus the blog critically advices companies to "invent the manufacturing technology of tomorrow" (Technology Review 2013). However, the impacts of FabLabs spread into many different social fields, not only into the techno-economic sphere. In times of a digital culture and increasing individualization within changing societies, FabLabs are important places for corporate learning, working and playing with advanced technologies. Being a global movement and part of a rising maker culture, FabLabs are central for an understanding of the present (and future) world. The democratization of production comes along with a 'democratization of innovation' by various potential actors. That means that, in FabLabs, everybody can invent, create and modify things and everybody can become an artist. With relatively low constraints, people can design objects that are not only unique, but meet high design standards, too. Such an approach transforms the fields of arts and crafts, as FabLabs further promote an understanding of modern crafting, making, or DIY as a response to mass culture. Despite the potential of democratization of innovation through FabLabs, a frequently referenced concern focuses on the diversity of potential actors[6]. It should be taken into account that not only academic urban males in their late twenties participate in the FabLab culture. FabLabs may create initiatives to invite economically and socially disadvantaged people to FabLabs, e.g., by organizing special workshops for marginalized people. Another relevant aspect of FabLabs stresses their potential for learning that was already put down in the Fab Charter. In order to establish a creative culture of making instead of copying, FabLab-based activities may also be included in school curricula for problem-based learning, creative hands-on activities and developing skills for documenting and communicating ideas and problems efficiently.

But even if the praises and promises for FabLabs are high at the moment, new techniques and technologies never appear without contempt, criticism and fear. Aspects such as copyright – which have mainly affected music and filmmakers until now – will affect the manufacturing sector, too. In a world where one can remotely print the same objects virtually everywhere, this will not only develop international collaboration, but also challenge limitations of national legislation. The advantage that one can print his/her own spare parts to replace the broken original parts will bring about issues such as security, liability and warranty. The cases of printable weapons and digitally manufactured food incite discussions about the power of technology and user ethics. Meanwhile, many FabLab practitioners and activists are concerned with establishing business models for their FabLabs and improving the organizational structures supporting a global community.

6 | Various speakers at the conference FabLearn – Transformative Learning Technologies Lab, 2012, in Palo Alto, Cal., USA, raised these concerns. For more information see the website, last viewed 25 December 2012 <http://tltl.stanford.edu/fablearn2012>.

Ten years after the first FabLab opened, it is time to look back on a decade of FabLab activities and enrich the number of written academic research about it. The sustaining of academic standards and scientific perspectives on the phenomenon of FabLabs is an essential feature of the several articles of the following book; the pictures and illustrations pay tribute to the design approach of FabLabs. Far beyond any revolutionary rhetoric, this collection seeks to scientifically analyze FabLabs and its entailed cultural and social changes with its foundations and impacts. It is not meant to explain any potential new world order(s) but to precisely analyze existing FabLab-related phenomena and to conclude their significance for present and future societies. Not only does it work as a compendium about various aspects FabLabs deal with – the delectable ones as well as the critical ones – but it also tries to show how a range of topics can be negotiated in/with FabLabs and what their theoretical foundations are. In doing so, 'FabLab – Of Machines, Makers and Inventors' is no technological report, but rather an analysis of the present times, discussing various approaches to and social and cultural impacts of FabLabs. In this composition, fabbers, scientists and designers reflect their perspective, experience and knowledge, discuss relevant theoretical and empirical questions and problems and introduce practical methods and outcomes of digital fabrication. In this volume, divers FabLab experts, either practitioners or field researchers, give insides to FabLab related issues, knowledge and organizational structures. Since FabLabs are continuously developing and the range of relevant and related aspects seems to be endless, the list of authors and topics must remain incomplete.

This volume is divided into five sections (and an epilogue) according to the varying foci in order to systemize the various FabLab-relevant issues. They are called 'The Movement', 'Materiality and Virtuality', 'Maker Culture', 'Technology and Infrastructure', 'Community and Environment'. Each section begins with a 'Notes on ...' chapter, in which experts of a specific issue report their very personal experiences and subjective view on a certain topic. The further chapters in each case discuss one aspect of an issue under a specific perspective, either on a theoretical or empirical base, or based on experiences in the field.

The first section is called 'The Movement' and deals with aspects that concern all FabLabs or that are mostly related to the global association or sum of FabLabs. It describes how different FabLabs work together, how they are linked, which aspects are relevant for the establishment of a FabLab or how a FabLab can focus on a certain aspect, like gender or empowerment for children.

The section begins with 'Notes on The Movement' by Karsten Joost. Karsten Joost from Bremen, Germany, was born into a family of craftsmen, he is a toolmaker by profession, and defines himself as an artist and networker, too. In his notes he describes his fascination with FabLabs and its origin, while he also expresses an authentic concern about the difficulties he sees in building a FabLab from scratch.

Julia Walter-Herrmann, a researcher in the working group Digital Media in Education (dimeb) at the University of Bremen, Germany, talks about 'FabLabs – A Global Social Movement?' She states that hardly any debate about FabLabs understands FabLabs only as a collection of machines that is resembled in small-scale workshops; most of the texts and lectures about FabLabs also grasp the global alliance of FabLabs under the keyword 'FabLab'. Her text raises the question whether FabLabs can be called a global social movement. Therefore, Walter-Herrmann's text briefly introduces the characteristics of a movement and then follows up with a theoretical and empirical analysis of the worldwide network of FabLabs.

Lambert Grosskopf, who is a legal academic at the University of Bremen, Germany and an Attorney at Law, a Certified Lawyer for Information Technology Law (IT-Law) and a Certified Lawyer for Copyright and Media Law, writes about copyright issues concerning 3D printing, using the example of Germany. In his article 'Homo Fabber and the Law', he claims that the use of 3D printers is engendering an emergent conflict that makes current conflicts of interest among Internet users, copyright holders and exploiters of intellectual property over the issue of file sharing seem like a playground tussle. Soon it will not be the object itself that is swapped over the Internet, but the CAD data file for its production. Grosskopf elucidates the problem set that evolves when a consumer transforms into a prosumer who produces products that are originally protected by copyright, patents, utility models and registered designs autonomously in his or her basement hobby room.

Tanja Carstensen from Hamburg University of Technology, Germany, has been researching gender and various digital technologies for several years. In her contribution 'Gendered FabLabs?' she argues that traditionally, technology has been linked with power and masculinity. In her work she examines which roles gender and the strong connection between technology and masculinity play in FabLabs as high-tech spaces. Following the idea that every new technology opens new possibilities to negotiate gender roles and new gender relations, she analyzes the gendering of FabLabs according to the following categories: access, users, technology, products, education, community and empowerment. In conclusion, she discusses the opportunities for shifts in gender and technological relations.

Irene Posch works for the HappyLab in Vienna, Austria, and previously worked on building the FabLab at the Ars Electronica Center Linz. In her chapter 'Fabricating Environments for Children' she writes about the specific requirements for FabLabs when working with children. She declares that, when it comes to children, an open lab and self-directed access based on peer-to-peer learning are often not enough, as most children do not have the possibility to learn about and with these technologies at any other place. Her article gives an insight into the practical work with children at the local FabLab in Vienna, Austria. The people from the Vienna HappyLab set up introduction workshops as well as an afternoon program allowing children to come to the lab and independently work on their individual projects, while getting professional help where wanted and needed. Their goal is to provide an understanding of the lab's possibilities and allow for personal creation in order to relay ideas that facilitate active and informed use. Posch then reports on her experiences, focusing on the interest and understanding children developed towards the introduced digital fabrication technologies.

The subsequent section is about 'Materiality and Virtuality'. The section's focus lies on the relationship between ideas and their virtual representations and real, materialized, and graspable objects. It presents mathematics and coding, thus the foundation of software and computers, as forms of complex or syntactical arrangements of such immaterial ideas. It asks whether the relationship between materiality and virtuality has changed, now that one can print, mill or cut any (three-dimensional) idea. It furthermore asks whether such an alteration could be crucial for learning. The section ends with an analysis of material objects that are produced in FabLabs.

'Notes on Materiality and Virtuality' by science fiction author Bruce Sterling open this section. Sterling is a visionary of the digital sphere, having published various well-acknowledged novels and texts about a techno-culture and helped to define the cyberpunk genre. Furthermore, he writes a blog hosted by Wired magazine. For his contribution, he referenced the neologism 'spime', which he invented in his book Shaping Things. Spimes are objects that can track their history and interact with the world. In his notes, Sterling explains what this has got to do with FabLabs, while also speaking of sustainability and aspects of a 'healthy ecology'.

Frieder Nake is a professor emeritus from the University of the Arts Bremen and the University of Bremen, Germany. Nake is one of the founding fathers of (digital) computer art. He is a mathematician and a computer scientist, and his dedication and unique approach to scientific problems gave him the sobriquet 'poet of sciences'. He won several awards – not only for his artistic work, but also for his extraordinary teaching. In his text 'Considering Algorithmics and Aesthetics', he explains that algorithms are statements of generality. In contrast, works of art are statements of particularity. The two kinds of statements differ in some more respects, but in the digital domain they must come closer and, in fact, unite. Here, algorithmics and aesthetics should support each other. Nake's essay recalls the historic moment in 1965 when the generative art movement started. It characterizes the ontological status of art and technology and furthermore hints at the dialectical unity of virtuality and actuality. Examples – amongst it an example by famous computer artist Casey Reas – demonstrate how the algorithmic and the aesthetic tendencies of today's world have begun to meet.

The subsequent contribution comes from Heidi Schelhowe, who is a university professor for Digital Media in Education (dimeb) and the head of a working group of the same name. Schelhowe is an internationally renowned researcher and the Vice Rector for Teaching at the University of Bremen. Her research focuses on educational applications in Computer Science and Media Informatics, as well as on digital media and media education within the context of pedagogical didactics. In her contribution 'Digital Realities, Physical Action and Deep Learning – FabLabs as Educational Environments?', she discusses the educational potential that arises from the special alliance of virtuality and materiality in FabLabs. She presents a brief history of learning materials and arrangements and its role for society. Referring to this history, she explores the very specific and original benefit that FabLabs can offer in comparison to other educational environments from a general and theoretical point of view.

The section 'Materiality and Virtuality' ends with an article by Corinne Büching about 'A Universe of Objects'. Büching is a sociologist in the field of science and technology. She is a research assistant in the computer science's working group dimeb at the University of Bremen, Germany. In her text, she first introduces a concept about the essence of (digitally produced) objects, furthermore demonstrating how these objects can be empirically analyzed. She concludes her text with the analysis of objects that evolved from a workshop she gave at the FabLab St. Pauli.

The third section titled 'Maker Culture' centers on the production of things in workshops and in an artisan and hand-made way in contrast to the common mass production in factories. It further explores how the formerly separated spheres of professional design and amateurish craft are currently negotiated with the introduction of digital production machines into both spheres. Catchwords that are relevant for this section are, for example, empowerment, DIY, crafting, tinkering and design. The section discusses aspects of professionalism and design in (digital) manufacturing, but also the history of making and producing things with the support of computers.

The section starts with 'Notes on Maker Culture' by Eva-Sophie Katterfeldt, Anja Zeising and Michael Lund. They are all researchers from the working group dimeb and have various backgrounds in Digital Media, Computer Science, Art and Cultural Studies. From these various standpoints, they regard the topic of maker culture, briefly explain the origin of the term and relate it to other aspects of maker culture such as interaction design and everyday crafting.

The second text was also contributed by a dimeb-member, Bernard Robben, a senior researcher at the University of Bremen. He has published various articles on media theory, the computer as a medium, tangible embedded and embodied interaction and the design of 'be-greifbar' (tangible and graspable) media. In his article, he presents 'The History of Production with Computers' in order to carve out their potential for digital fabrication. The paper brings into focus the close relationship between the evolution of production machinery and of plans, models, drawings, and diagrams. It describes the interweavement of physical machinery and the corresponding virtual one within the context of processes of technological and social change.

The chapter 'Maker Culture, Digital Tools and Exploration Support for FabLabs' by dimeb-researcher Eva-Sophie Katterfeldt introduces the so-called 'maker culture' in which FabLabs are situated. She explains what this maker movement distinguishes from previous DIY cultures is the involvement of digital media in the creation process – as web platforms for information retrieval, communication and sharing, as tools for digital crafting, as well as target artifacts of creation processes. Open sharing, creativity, learning and participation are values of the maker culture. FabLabs offer this whole range of involvement with digital media, inviting everyone to participate independent of skill. Katterfeldt argues that in order to make these opportunities better examinable for every maker the design of digital crafting tools should be rethought.

Jens Dyvik, a cabinetmaker and designer from Norway, who is currently on a FabLab world tour, wrote the article 'Thoughts from the Road of a FabLab Nomad' when he was visiting the FabLab in Indonesia. Dyvik's goal is to research personal manufacturing and Open Source design around the world. The findings of his research will be communicated through a documentary called 'Making Living Sharing'. In his text, based on his experiences, he asks how designers can support people in creating their own products. Moreover, he discusses whether designers can still make a living if they shared their designs with the world. Dyvik is working towards answers to his research goals by visiting FabLabs around the world and by learning how they facilitate knowledge-sharing and personal production.

The fourth section of this book, 'Technology and Infrastructure', is dedicated to the technology-relevant aspects of FabLabs. On the one hand, it explains individual machines, such as 3D printers, laser cutters and CNC mills; on the other hand, it also describes how the produced artifacts can again be enriched with several technologies like microcontrollers. Furthermore, it relates technological characteristics to qualities of a technological infrastructure. Aspects of digitization already find their expression in the philosophy of Open Source for the production and development of software and even hardware, but the section also raises critical concerns when it comes to turns of organizing or financing these technological infrastructures.

The section starts with 'Notes on Technology and Infrastructure' from Bre Pettis, co-founder and CEO of MakerBot®, a Brooklyn-based company for 3D printers, and of Thingiverse, an internet platform where people can share their 3D printing files. MakerBot's new, low-cost desktop 3D printer, the Replicator 2, made it into media coverage all over the world, and Pettis was even represented on the cover of Wired magazine. In his text, he introduces his company and the machines it sells, he furthermore envisions a future of 3D printing.

The next article, 'Machines for Personal Fabrication', comes from René Bohne. Bohne is a research assistant at the Media Computing Group at the Rheinisch Technische Hochschule Aachen, Germany. He is also the local FabLab manager at his university. Bohne is highly interested in personal fabrication and personal design as well as wearable computing and smart fashion. For this book, he introduces tools for digital fabrication used in FabLabs today. In addition, his paper describes tools for personal fabrication at home. Explaining, for example, the technical differences between additional and subtractive fabrication, this contribution works at the same time as an introductory text for FabLab novices and technically interested people.

The following chapter, 'Digital Fabrication in Educational Contexts – Ideas For a Constructionist Workshop Setting' by Nadine Dittert and Dennis Krannich, presents practical efforts combining FabLabs with tangible technology. Dittert and Krannich are both research assistants in the working group dimeb at the University of Bremen. They are computer scientists who are not only interested in setting up a FabLab at their local university, but also in developing learning and teaching scenarios for FabLabs. In their article, they discuss their experiences with 'teaching FabLabs'. As an example, they show the 'Fab-tast-O-matic' – a chain reaction machine (inspired by Rube Goldberg's machines) – that was built in a student's Bachelor project. The machine consists of four different layers that are equipped with Arduino micro controllers and electronic components, 3D printed and laser-cut parts, and other tinkering materials. Their assumption is that digital fabrication enables people to explore how to represent a functional description of a system by physical shapes, and ask in return to which extent a functional description of a physical system can be abstracted.

Peter Troxler contributed the last text in the section 'Technology and Infrastructure'. Troxler is often referred to be the mastermind of the European FabLab movement; he furthermore is a Research Professor at Rotterdam University of Applied Sciences and a freelance researcher at the joint of business administration, society and technology. In his article 'Making the Third Industrial Revolution – The Struggle for Polycentric Structures and a New Peer-Production Commons in the FabLab Community' Troxler addresses how economic models and cycles of innovation change, based on new ways of producing things, such as peer production or Open Design, and organizational structures and models, such as the Open Source movement, or FabLabs. But the chapter also aims to provide more than just a definition of the problem of the struggle for more polycentric structures. It also addresses how to build effective forms of collective action and self-organization for the FabLab community and how to break free from traditional systems and creatively design new systems that tap into the capabilities of that community.

Section five is called 'Community and Environment'. This part deals with examples of FabLabs that are embedded in a (local) community, aiming at improving the status quo. It shows how individuals and groups can benefit from FabLabs. The section illustrates several best practices of FabLabs around the world and how they empower, educate, and create 'almost anything'. It displays the impact of FabLabs for the field of learning, neighborhood development, health, and cooperation.

Bart Bakker from the Netherlands opens the section with 'Notes on Community and Environment'. Bakker is deeply involved with Protospace, the main FabLab in Utrecht, Netherlands, and with the Dutch FabLab Society. In addition, Bart Bakker set up a mini FabLab in his garage in Utrecht. He constantly invites artists, engineers, and the interested public to visit his 18 $m^2$ space, where his FabLab for cutting and printing objects is set up between his model railroad and his car. In his notes, he talks about his experiences with FabLab machines and describes his experiences with engaging in a project for Open Source laser cutters.

The first chapter of the section is entitled 'Digital Fabrication and 'Making' in Education: The Democratization of Invention'. It is a contribution from Paulo Blikstein, who is an Assistant Professor at Stanford University, USA. He is affiliated to the Stanford University's Graduate School of Education and (by courtesy) Computer Science Department. He designs and researches expressive technologies for learning, especially for underprivileged people. In his text he classifies learning experiences with FabLabs in the tradition of 'unconventional pedagogy' as so evolved by John Dewey, Seymour Papert, and Paulo Freire. He argues that digital fabrication and making could be a new and major chapter in the process of bringing powerful ideas, literacies, and expressive tools to children. Using examples of implemented FabLab learning scenarios Blikstein highlights five important design principles.

Axel Sylvester and Tanja Döring contribute the next chapter to the section 'Community and Environment'. Sylvester and Döring are involved in the FabLab in their hometown Hamburg, specifically a borough called St. Pauli, in Germany. Sylvester is an IT consultant and independent researcher, he is also engaged in the global Fab Lab Association. Döring is a computer scientist, who works as a research assistant at the University of Bremen at the Center for Computing and Communication Technologies. Their article 'Urban Development with FabLabs' describes the potential they see for the role of FabLabs in a larger network of innovation, and applies urban development patterns to FabLabs on the basis of experiences from the FabLab Fabulous St. Pauli in Hamburg.

In the third chapter, the manager of the FabLab at Vigyan Ashram in Pabal, India, Yogesh Ramesh Kulkarni, explains the particular challenges and specific opportunities a FabLab in rural India has (to face). In his text 'Small Ideas, Big Opportunities – FabLab at Vigyan Ashram Pabal, India', he introduces the history of this FabLab, its educational approaches, how the FabLab blends with 'traditional' manufacturing tools, as well as some successful stories, which were 'shaped' through the FabLab at Vigyan Ashram. He furthermore argues that one distinctive feature of FabLabs in rural India is that it can help to solve 'grass-root problems' of local villagers. In doing so, students cannot only help to find unique solutions to specific local problems, but they can also learn something important for their lives and get empowered through a practical hands-on learning experience.

Alex Schaub wrote the subsequent contribution about 'Affordable Medical Prostheses Created in FabLabs'. Schaub is the FabLab manager of Waag Society's FabLab in Amsterdam in the Netherlands. Furthermore, he is the head of the $50 Leg Prosthesis Project in Yogyakarta in Indonesia. In his chapter, Schaub describes that developing a $50 below-knee prosthesis is a challenge. Moreover, he questions whether it is even possible, considering that a below-knee prosthesis costs $4,000 in the Western world. The chapter explains how Waag Society's FabLab Amsterdam and the FabLab Yogyakarta in Indonesia, run by the media and art laboratory House of Natural Fiber, are trying to turn such a challenge into reality.

The epilogue 'FabLabs: Thoughts and Remembrances' is written by Sherry Lassiter. She is the Director of the international Fab Foundation and Program Manager for the Center of Bits and Atoms at the MIT. Lassiter supports and coordinates the worldwide FabLab network. Her text leads us back to the place where FabLabs were 'born' – the MIT. Ten years after the first FabLab opened, Lassiter reviews the last ten years of FabLab activities and introduces various projects in the outreach of CBA from around the world.

The idea for this compilation arose during a research project called Subject Formations and Digital Culture that was funded by the VW-Foundation in Hannover, Germany. At one stage of the project, we empirically researched learning in interaction with digital artifacts and therefore conducted workshops with young adults in FabLabs. Besides conducting our empirical research, we also developed a growing fascination for FabLabs that was shared by our working group Digital Media in Education (dimeb) at the Center for Computing and Communication Technologies at the University of Bremen, Germany. While those co-workers who were more interested in technology started to build 3D printers and tinkered with them, we, as social scientists, were more interested in FabLabs as a social phenomenon, asking ourselves: What possibilities for economy, learning, and crafting do FabLabs offer? Has the relationship between virtual and material objects changed through FabLabs, and what is the motivation for fabbers to engage in the labs? How will the future of FabLabs look like? These were all questions that kept us up all night. While discussing these questions with the head of dimeb, Heidi Schelhowe, we recognized that there was no person, book or article that could answer all our inquiries. In addition, we realized that there were hardly any scientific texts addressing our questions – except of course the fundamental books of Neil Gershenfeld, which had been published years before. For this reason, without further ado, we decided to gather the existing FabLab knowledge and edit it for this collected edition. However, as is usual with any project, no one can master it alone, which is why we would like to thank all those helpful hands and clever minds that supported us.

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We now hope that the articles in this collection offer valuable information and enrich the debate about FabLabs in a constructive way.

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