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Corporate Makerspaces

Operation Models, Implementation and Contributions to Organizational Learning

Dissertation

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Abstract

Corporations face various challenges in today's complex and dynamic economic world. The pressure on corporations to innovate is increasing and as a result, a corporation's ability to innovate is becoming the decisive success factor for sustainable long-term growth. However, many incumbents have problems to continually develop innovative products. To realize innovations, companies need to develop their organizational learning capabilities. A new promising management tool is a corporate makerspace to support learning and promote creativity and entrepreneurial behavior among the employees.

A makerspace is a physical area in which people can transform ideas into reality with the means of digital fabrication tools. Most important and also most challenging when creating a makerspace is to build an active community of collaboration, exchange and openness, which provides an atmosphere of creativity and innovation. Such a makerspace enhances experimentation, learning by doing and communication, which may stimulate employees' motivation.

This dissertation focuses on operation models of corporate makerspaces, the implementation and the question of how a corporate makerspace supports learning in organizations. The empirical work is based on multiple case study research. Three companies that have already implemented a makerspace are investigated and analyzed. Several data sources are used (semi-structured qualitative interviews, internal documents, publicly available material etc.).

The findings provide detailed insights to the cases and identify different operation models of corporate makerspaces. Additionally, a new taxonomy framework is developed to better compare the various manifestations of makerspaces in general. One part of the results focuses on the aspects of how makerspaces support organizational learning in the areas of knowledge creation, retention and transfer. Managers receive a five-step implementation procedure on how to set up a makerspace in the corporate context.

Zusammenfassung

Unternehmen stehen in der heutigen komplexen und dynamischen Wirtschaftswelt vor vielfältigen Herausforderungen. Der Innovationsdruck auf Unternehmen steigt und die Innovationsfähigkeit eines Unternehmens wird zum entscheidenden Erfolgsfaktor für nachhaltiges langfristiges Wachstum. Viele etablierte Unternehmen haben jedoch Probleme, kontinuierlich innovative Produkte zu entwickeln. Um Innovationen zu realisieren, müssen Unternehmen ihre organisationalen Lernfähigkeiten entwickeln. Ein neues vielversprechendes Management-Tool ist die Implementierung eines Corporate Makerspace um Lernen zu unterstützen und Kreativität und unternehmerisches Verhalten bei den Mitarbeiterinnen zu fördern.

Ein Makerspace ist eine physische Einrichtung, in dem Menschen ihre Ideen mit digitalen Fertigungsmaschinen in die Realität umsetzen können. Am wichtigsten für einen Makerspace ist es, eine aktive Gemeinschaft von Zusammenarbeit, Austausch und Offenheit aufzubauen um eine Umgebung für Kreativität und Innovation zu schaffen. Ein Makerspace fördert das Experimentieren, Learning-by-Doing und stimuliert die Motivation der Nutzerinnen.

Diese Dissertation beschäftigt sich mit Betriebsmodellen, der Implementierung und mit der Frage, wie ein Corporate Makerspace das Lernen in Organisationen unterstützen kann. Die empirische Arbeit basiert auf mehreren Fallstudien. Drei Unternehmen, die bereits einen Makerspace implementiert haben, werden untersucht und analysiert. Mehrere Datenquellen werden verwendet (semi-strukturierte qualitative Interviews, interne Dokumente, öffentlich verfügbares Material etc.).

Die Ergebnisse liefern detaillierte Einblicke in die Fallstudien und identifizieren dabei verschiedene Betriebsmodelle von Corporate Makerspaces. Darüber hinaus wird ein neues Framework entwickelt, um die verschiedenen Ausprägungen von Makerspaces im Allgemeinen besser vergleichen zu können. Ein Teil der Ergebnisse konzentriert sich auf die Aspekte, wie Makerspaces organisationales Lernen in den Bereichen Wissensgenerierung, Wissensspeicherung und Wissenstransfer unterstützen können. Manager erhalten ein fünf-stufiges Implementierungsverfahren für den Aufbau eines Makerspace im Unternehmenskontext.

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List of abbreviations

CAD .... Computer Aided Design
CBA .... Center for Bits and Atoms
CBV .... Capability-Based View
CEID .... Center of Engineering Innovation and Design
CNC .... Computerized Numerical Control
DCV .... Dynamic Capability View
DIWO .... Do-It-With-Others
DIY .... Do-It-Yourself
DTU .... Technical University of Denmark
FabLab .... Fabrication Laboratory
FDM .... Fused Deposition Modelling
GBS .... Goal Based Scenario
GUI .... Graphical User Interface
ICT .... Information and Communication Technologies
IoT .... Internet-of-Things
IPR .... Intellectual Property Rights
ISN .... Internal Social Network
IT .... Information Technology
KPI .... Key Performance Indicator, Key performance indicator
MIT .... Massachusetts Institute of Technology
MOOC .... Massive Online Open Courses
NGO .... Non-Governmental Organization
NIH .... Not-Invented-Here
OI .... Open Innovation
PARC .... Palo Alto Research Center
PC .... Personal Computer
PDP .... Product development process
R&D .... Research and Development
RBV .... Resource-Based View

RP .... Rapid Prototyping
RQ .... Research Question
SLA .... Stereolithography
SLS .... Selective Laser Sintering
SME .... Small and Medium-sized Enterprises
SOP .... Specific Operating Procedures
STEM .... Science, Technology, Engineering, Mathematics
U.S. .... United States
VRIN .... Valuable, Rare, Inimitable, Non-substitutable

"Making is fundamental to what it means to be human. We must make, create, and express ourselves to feel whole. There is something unique about making physical things. These things are like little pieces of us and seem to embody portions of our souls."

Mark Hatch, 2014

1 Introduction

The first chapter briefly introduces the topic of the thesis and summarizes the issue in practice and theory. Finally, the structure of the dissertation is presented.

1.1 Initial situation

Competitiveness challenge for organizations. Companies need to survive in an increasingly complex, dynamic, competitive and ever more rapidly changing environment (Schwab 2017). The main factors are globalization (Wiersema and Bowen 2008), cost pressure, continually rising technological change (Sood and Tellis 2005; Christensen et al. 1998; Bower and Christensen 1995; Hamel and Prahalad 1994; Utterback 1994), greater desire for individualization, increased innovation dynamics (Parry et al. 2009; Langerak and Hultink 2005; Kessler and Bierly 2002), diffusion speed (Lee et al. 2003) reduced development times, increased complexity of products, and decreased product life cycles (Eigner and Stelzer 2009; Becker and Steele 1995).

Innovative capability – the ability to steadily produce innovations – is the crucial factor for companies to stay competitive and to grow sustainably in the long term (Damanpour and Aravind 2012; Bullinger 2006), regardless of the industry concerned (Steiber 2014). This also entails an increased need for flexibility and the ability to transform the organization (Spath and Koch 2009; Eigner and Stelzer 2009; Becker and Steele 1995). A company's ability to innovate depends on a range of factors such as the skills and competencies of the people involved, the processes, the structure, the network, the strategy of leadership and the innovation culture (Spath et al. 2006).

Emergence of maker movement and makerspaces. During the last decade, the so-called maker movement has evolved. The number of physical community spaces offering access to high-tech manufacturing equipment to the public – makerspaces – has increased dramatically (Cavalcanti 2013), especially in schools, libraries, museums and community centers (Litts 2014, p. 3).

Nowadays, the maker movement is spreading rapidly around the world (Fab Foundation 2017). In the last decade hundreds of makerspaces, hackerspaces and FabLabs emerged in many places around the globe. Such places open up the opportunity to individuals to manufacture their own product ideas by themselves – simply and inexpensively. Here, the 'makers' can use modern digital fabrication infrastructure to which they had no access in the past. These initiatives share the goal of democratizing the manufacturing process.

They enable individuals to build hardware products, a situation which was almost impossible in the past without traditional organizational backing. Making and makerspaces have gained traction in various contexts, and this has materialized as the maker movement, which is characterized by the mobilization of makers around the world (Anderson 2012). Over the last decade, makerspaces have become hotbeds for technological innovation and entrepreneurship, assisting inventors to bring their idea from the drawing board to the market (Kalish 2014).

Providing access to prototyping facilities with digital production equipment and creating a community of collaboration and open-mindedness in makerspaces inside corporate boundaries promises to be a new way to foster the creativity of employees and support the innovative capability of companies. Meanwhile, some established enterprises (e.g. Ford Motor Company) have recognized the inherent benefits of makerspaces and try to skim this potential by investing in makerspaces.

1.2 Issue in practice: Industry perspective

To realize innovations, companies need to develop their organizational learning capabilities (Stata and Almond 1989). Organizational learning offers the basis for developing innovations successfully (Alegre and Chiva 2008). Scholars and practitioners argue that organizational learning is the only way for a firm to create a sustainable competitive advantage (Reese and Hunter 2016). Therefore, being a continuous learning organization becomes crucial for a company to maintain its competitiveness and innovative capability (Hansen et al. 2010). But, in the complex and dynamic business world, it is difficult for companies to continuously develop innovative products (Jeschke et al. 2011a, p. 12).

In practice, the traditional standardized innovation processes of corporations do not allow for experimentation and trying out new things (Kohler 2016). Many companies do not offer their designers and employees the opportunity to produce prototypes independently. In some cases, however, a company-internal prototype construction unit may carry out the production of samples for the designers and engineers. Usually, these facilities are equipped with professional machines and operation is restricted to the responsible personnel. In most companies, building prototypes is outsourced and manufactured by external suppliers and is often associated with waiting times. Here, the implementation of a makerspaces within the company and to allowing employees to turn their ideas into reality and to make things by themselves, may be beneficial in various areas (e.g. creativity, time reduction).

1.3 Issue in theory: Research perspective

Organizational learning is the basis for solving problems and producing innovations. It is essential to have appropriate organizational members, organizational context and processes within the organization (Lam 2004, p. 14). The central question of organizational learning is how individual experiences, insights and knowledge can be transferred into collective or organizational knowledge as a preliminary stage to organizational skills (Argote 2013b). That leads on to the question of how can a firm leverage its organizational learning capabilities.

Efficient strategies to master uncertainties are based on subjective learning and implicit knowledge. This results in a demand for learning and knowledge that can be gained only from learning in the process of work. Therefore, being a continuous learning organization becomes a basic step for companies in order to maintain their competitiveness and their innovative capabilities in an unpredictable future (Hansen et al. 2010).

Thus, it is necessary to research new ways to foster the organizational learning capabilities within enterprises such as the implementation of a corporate makerspace.

1.4 Research process and thesis outline

The structure of the thesis is based on the research process of Karlsson (2016): (1) identifying an issue to research; (2) literature review and mapping of existing knowledge; (3) specifying the purpose of the intended research; (4) derivation of specific research questions; (5) choice of research approach and methods; (6) development of conceptual frameworks; (7) data collection; (8) analyzing and interpreting the data; (9) synthesizing and concluding; and (10) evaluating the research and suggesting further research.

Chapter 1 describes the initial situation and the motivation for this thesis (issue in practice and research). The structure of the thesis is also presented (see Figure 1).

Chapter 2 scrutinizes the global trend in the maker movement and its main drivers, focuses on makerspaces and their manifestations, types and categorization. Further sections provide the theoretical anchoring of the makerspace concept to scientific theories and examine the relevant literature. The interim conclusion summarizes the state of knowledge, elaborates the research gap, derives the objectives of the thesis and the research questions.

Chapter 3 presents the applied research design and the empirical approach. This chapter includes the description of the conceptual frameworks, sampling considerations, and methods for data collection and analysis.

Chapter 4 focuses on data analysis and provides detailed information on the case studies conducted followed by the cross-case evaluation.

Chapter 5 offers an interim conclusion, which introduces possible operation models of corporate makerspaces. Based on the findings a new taxonomy framework is developed.

Chapter 6 elaborates the roles played by corporate makerspaces in organizational learning and links the findings to the theoretical foundations.

Chapter 7 proposes a procedural model on how to implement a makerspace within the corporate context and describes considerations and challenges for the process.

Chapter 8 concludes by answering the research questions. The scientific value of the dissertation is elaborated, followed by the management implications. Areas for further research are suggested.

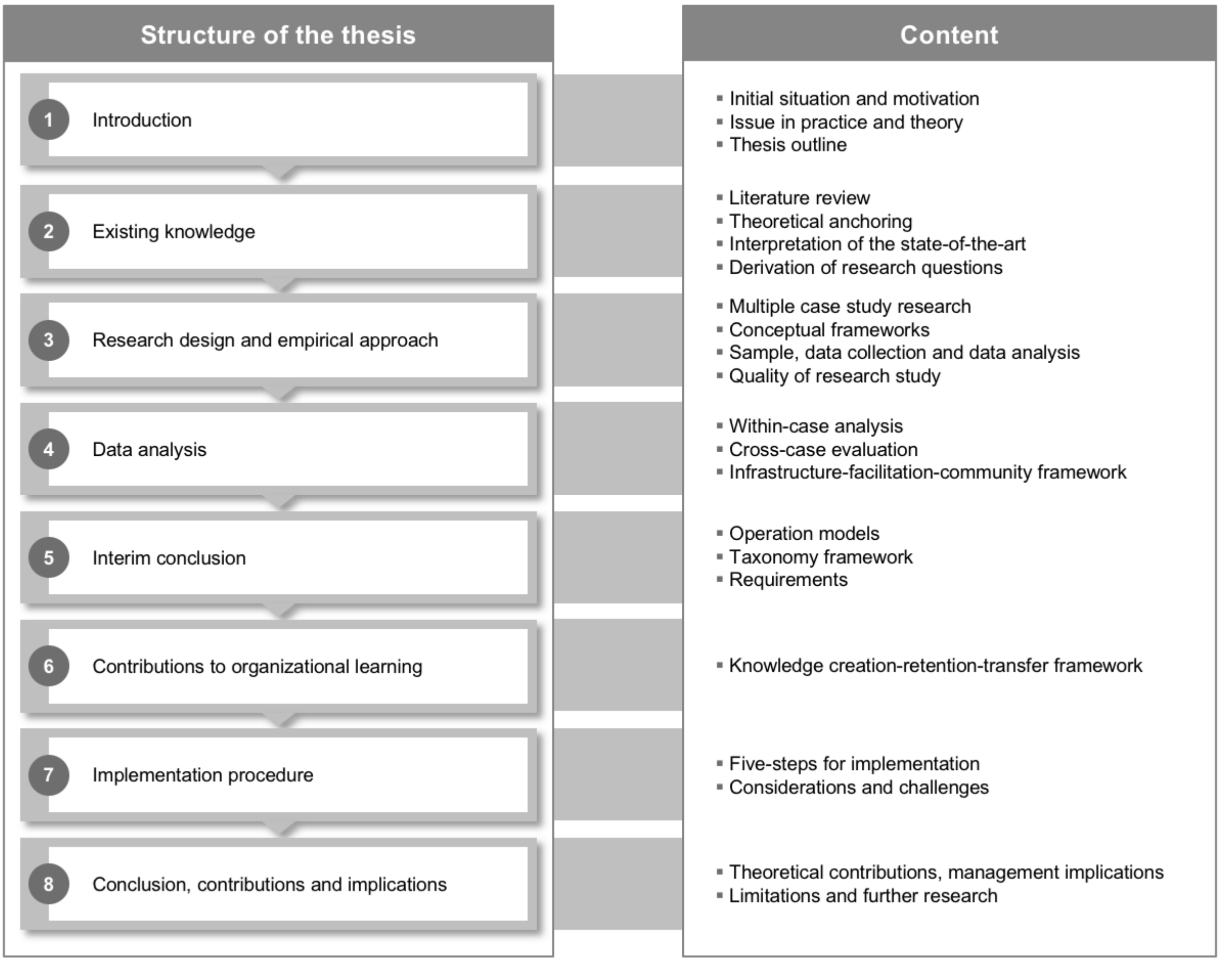

Figure 1: Structure of the thesis[1]

[1] Author's illustration

2 Existing knowledge

The main purpose of this chapter is the mapping of existing knowledge. This chapter starts with an exploration of the most important aspects of the maker movement and the description of the maker movement element system. The subsequent sections examine the broad topic of makerspaces in general, the most relevant manifestations of makerspaces, and elaborates on their similarities and differences. This is followed by a description of types and categorization frameworks. Afterwards, the basics in terms of organizations, organizational capabilities, organizational learning and innovation are introduced. The section on related work focuses in more detail on relevant studies and current position on scientific research on makerspaces. Here, diverse approaches and models for established enterprises on how to react to the maker movement and makerspace trend are explained. Additionally, the concept of a third place is introduced. The interim conclusion summarizes the state of knowledge, identifies the research gap, introduces the objectives for the thesis and derives the research questions.

2.1 Maker movement

The maker movement is based on the principle that everyone can design, prototype, manufacture, distribute, market and sell their own products (Owyang 2014). Techopedia (2016) relates the maker movement to the *"[...] increasing number of employing do-it-yourself (DIY) and do-it-with-others (DIWO) techniques and processes to develop unique technology products."* Bhatia (2014) defines the maker movement as *"[...] a trend in which, rather than purchasing items from businesses, people are making those items themselves. As a result, instead of buying mass-produced goods, consumers are choosing to purchase items from individual do-it-yourselfers at events known as Maker Fairs and on websites like Etsy."* The term maker movement covers a wide range of different areas, from traditional crafts to high-tech electronics (Anderson 2012, p. 25).

2.1.1 Roots

The roots of the maker movement date to the mid-19th century. Beginning in Scotland, a number of mechanics' institutes emerged globally. These institutions combined libraries, lecture halls, and laboratories in an era before artificial lighting and illuminated reading rooms were available. This effort gained momentum over the following decades due to increasing emphasis on new technologies for manufacturing and construction work. The labs of famous inventors like Thomas Edison and Alexander Graham Bell can be designated as forerunners of today's makerspaces. Both inventors recognized the value of experimentation and collaboration in the product creation process. The role of technology as an invaluable component of the maker movement became more and more evident in the mid-20th century. (Holman 2015)

Basically, the term *digital fabrication* goes back to the development of the first numerically controlled milling machine at the Massachusetts Institute of Technology (MIT), Cambridge in 1952. In the 1980s, the first computer-controlled fabrication machines which could add material (additive manufacturing) rather than remove material came on the market. Today, digital fabrication has developed to a megatrend in all fields of industry. It enables makers to build hardware products themselves, a situation which was almost impossible in the past without traditional organizational backing. The makers of today have easy access to capabilities for designing, manufacturing and distributing their own products. These technologies can modernize traditional fields in education, science and economy. (Gershenfeld 2012)

Gershenfeld and the researchers at the Center for Bits and Atoms (CBA) at MIT play a major role in exploring new possibilities for digital fabrication and pushing boundaries between the digital (bits) and the physical (atoms) world. According to Gershenfeld (2012), the killer app for digital fabrication is *personalization*, which enables the possibility of producing customized products for just one person. The next step is *from consumer to maker* and *from maker to active consumer*, which leads to *mass customization* (Gershenfeld 2012). Mass customization with its goal to provide customized products at mass production prices will increase the competitiveness of companies via on-demand production; flexible manufacturing processes are the key driver to realizing such profitable small-batch production (Gandhi et al. 2014).

The first examples of physical spaces for open production can be found in the occurrence of the neighborhood based machine shops in the 1960s and 70s (Seravalli 2014, p. 109). In the same decade, the *hacker culture* emerged, which describes communities where its members are committed to peer production, to knowledge sharing and to designing open technologies that can be modified by users (Lévy 2010).

Another important cornerstone was the foundation of Xerox Palo Alto Research Center (PARC) in 1970. This institution, designed as a collaborative work space, is responsible for the development of new digital technologies such as the Ethernet and the first laser printer. In the 1980s, 3D printing technologies appeared, a technology that remains central to the maker movement today (Holman 2015).

During the last decade, a new movement emerged that draws from this history but departs from it in significant ways. The maker movement is based on the growing network of makerspaces that expand the ideas of the web generation into hardware (Lindtner et al. 2014). One major cornerstone was the establishment of the first fabrication laboratory (FabLab) developed by Gershenfeld and his team from the CBA at the MIT in 2003 (see chapter 2.2.1.2). The impressive success of the FabLab initiative can be seen in a rapid rise of more than 1000 registered labs worldwide until 2017 (Fab Foundation 2017).

Another important aspect related to the maker movement are Maker Fairs, which were started by the publisher of MAKE Magazine in 2005. Maker Fairs are events where innovation and interdisciplinary meet, where individuals present their work and skills gained out of their maker projects. The rapid growth of the maker movement is demonstrated by the rising measure of Maker Fairs in the USA (see Figure 2).

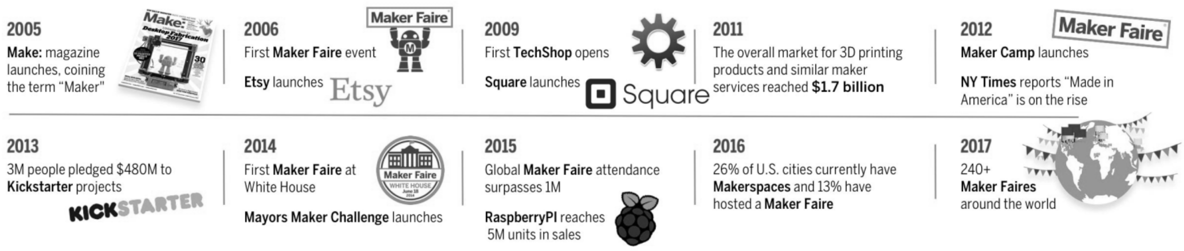

Figure 2: Maker movement milestones[2]

Maker Fairs are events that offer the opportunity for everyone to show their inventions and ingenuity. These events take place in many cities and serve the sharing and collaboration between makers. In 2006, 22,000 people were attending Maker Fairs, in 2014 the number increased to 760,000 visitors. (215,000 people visited the two major Maker Fairs in the Bay Area and New York City). The number of annual Maker Fairs increased from 61 in 2012 to more than 240 around the world in 2017 (Maker Media 2017a).

Mark Hatch (2014, p. 2), the founder of TechShop, describes the basic structure of the maker movement using the following nine elements in his *Maker Movement Manifesto:* make, share, give, learn, tool up, play, participate, support, and change. According to Anderson (2012, p. 25), three features are characteristic for the maker movement: (1) *people create new prototypes and products using digital desktop-tools;* (2) a *culture of sharing and collaborating* on projects in online communities based on a cultural norm exists; and (3) *unified file standards* are used in projects.

Two important aspects of the maker movement are its openness and collaboration. These have their roots in the do-it-yourself and do-it-with-others and open source software and

[2] Maker Media. 2017b. *The Rise of the Movement* [Online].

hardware movements. Due to the development of the Internet, the already existing *off-line* DIY communities exploded. The ability to communicate over long distances enabled people in different locations to share information and exchange ideas. That was the point, when DIY moved on to DIWO, which puts collaboration in the foreground.

2.1.2 Enabler

Making is not new, but modern technologies, globalization, and cultural shifts have positively influenced the maker movement. According to Piller and Ramsauer (2014) three drivers are responsible for the current upturn of the maker movement in the last decade:

1. *Tools to innovate:* Important technologies and resources such as laboratory capacity, Internet access, processing power, Computer Aided Design (CAD) programs, 3D printers for prototyping and simulation software are much more affordable today.
2. *Access to digital production facilities:* Individuals have access to a production infrastructure of industrial quality in the contemporary world (FabLabs, TechShops, hackerspaces, makerspaces or similar DIY labs, Shapeways, Ponoko etc.). All these initiatives share the goal of democratizing the manufacturing process.
3. *Open databases:* Publicly accessible repositories such as Thingiverse allow the use of various designs under Creative Commons licenses and thus a much more efficient development process.

Reviewing the available literature, the emergence of the maker movement in the beginning of the 21st century is summarized into the following eight enablers (Ramsauer 2017):

1. *Demand for personalization:* Consumers want increased customization, and to give an individual touch to the product they are purchasing such as fitness trackers or smart thermostats (Maker Media 2013; Dougherty et al. 2014). The widespread access to new technologies can allow individuals to design and produce tangible objects on demand (Gershenfeld 2012, pp. 2-6).
2. *Open hardware and open software:* Hardware and Software tools are available for everyone, which lowers the entry barriers for entrepreneurs (Piller and Ramsauer 2014; Yuvaraj and Maurya 2016).
3. *Common design file standards:* Standardization (e.g. stl-files) allows for easy cross-platform data exchange (Anderson 2012). Open access databases allow the use of designs from others under Common Creative licenses (Piller and Ramsauer 2014).

4. *Sharing economy with online repositories:* Inspiration from, e.g. MAKE Magazine (online) or Instructables help to spread an understanding of making as a form of creativity and innovation (Lindtner et al. 2014).
5. *Seed capital from crowdfunding sites:* Proliferation of crowd-funding websites such as Kickstarter provide an easy way to get seed capital (Lindtner et al. 2014).
6. *Inexpensive manufacturing hubs:* Availability of digital production infrastructure at a physical space where people get together enables them to turn their ideas into reality (Lindtner et al. 2014). Tools of today are typically easy to use, relatively inexpensive, and more accessible on a global scale to wide audiences than in the past (Hatch 2014; Piller and Ramsauer 2014). Especially important for the maker movement is Additive Manufacturing (3D print) technology.
7. *International shipping:* Globalization offers cheaper international shipping and easier access to international vendors for small-batch manufacturing, e.g. Shenzhen in China (Hagel et al. 2014).
8. *E-commerce distribution:* The boundary between product makers and product sellers is becoming more and more blurred with e-commerce like Etsy, where people build and sell products themselves with quick turnaround times (Chen 2013; Dougherty et al. 2014).

2.1.3 Maker

Maker is used as a term for individuals or groups producing objects based on their own ideas. But doing things by oneself is not something new. Dougherty (2012a) notes that making is part of our daily life. Consequently, every human being is a maker, the individual building a drone, someone cooking a meal for the family as well as a programmer creating a new website.

Peppler et. al (2016, p. 2) explain a maker as anyone who builds or adapts objects by hand, often with the simple pleasure of figuring out how things work. Similarly, Hagel et. al (2014) describe makers as people who love to do things by themselves. The maker community has identified making as an alternative to the consumer culture and seeks to hack, mod, tinker, create, and reuse tools and materials (Peppler et al. 2016, p. 2). A study of Intel and Make Magazine (2014, p. 10) revealed that makers would define themselves mainly as ‘hobbyist’ or ‘tinkerer’. According to a study of Sleigh et al. (2015) on 97 labs in the UK, the most important reason for people to use the labs is socializing with others (41 percent) and not the manufacturing tools as one may suppose. Learning new things is mentioned by 35 percent of the makers and only 33 percent referred to making as their main priority.

Following the categorization of Hagel et al. (2014), maker are classified according to three groups within the maker movement ecosystem: The first group is called *zero to maker.* An individual gets inspired and starts to make something. It is required that the people have the knowledge on how to design something as well as access to production infrastructure. The second group is called m*aker to maker.* Makers start to engage in the maker ecosystem by sharing and collaborating (often within online platforms). The third group is called m*aker to market.* At this stage, makers start to commercialize their ideas.

In this perspective, some makers can be perceived as *lead users.* Empirical research in several fields shows that users frequently develop and use prototype versions of what later become commercially significant new products and processes (Shaw 1985; Lionetta 1977; von Hippel 1976; Knight 1963). It has also been argued that innovation by users will tend to be concentrated among lead users. Lead users are defined as those who combine two characteristics: (1) they expect attractive innovation-related profits which flow from designing a solution which meets their own needs and so are likely to innovate; and (2) they experience needs ahead of the majority of a target market (von Hippel 1986, p. 796). Von Hippel (2001, p. 1) states, that user innovation also takes place in communities and across various fields, e.g. software codes or physical products. All makers have access to the open and collaborative network of the worldwide maker community.

2.1.4 Elements

Hagel et. al (2014) structure available platforms and resources of the maker movement ecosystem along the three types of makers, as described in chapter 2.1.3 (see Figure 3).

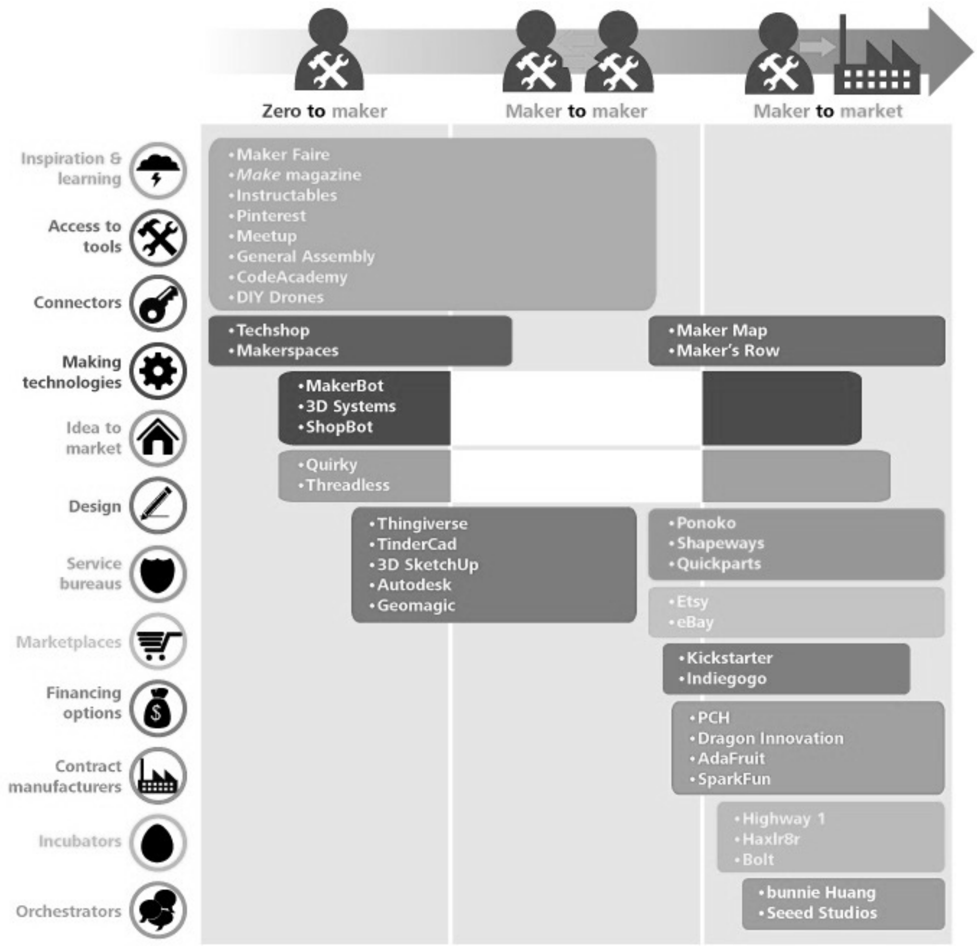

Figure 3: Maker movement ecosystem[3]

Based on the maker movement ecosystem from Hagel et. al (2014), Friessnig et. al (2017) propose the introduction of maker movement elements to classify the thriving fundamentals for the emergence of makerspaces. A maker movement element is a collective term for comparable players such as companies, non-profit organizations or platforms, which fulfill similar roles within the maker movement ecosystem (Friessnig et al. 2017). The maker movement elements are categorized in nine subsystems (Friessnig et al. 2017):

1. *Connect with others – physical:* One element within this subsystem is *fairs and events* such as maker fairs or hackathons. These are especially important to meet potential customers as well as to gather inspiration for new ideas. Other elements are the *maker related facility* itself and *experts' tables* on a specific topic. Networking leads to

[3] Hagel, J., Brown, J.S. & Kulasooriya, D. 2014. A movement in the making. Deloitte Center for the Edge. p. 10.

knowledge acquisition which, especially knowledge from outside, can be an important stimulus for change and organizational improvement (Inkpen and Tsang 2005).

2. *Connect with others – virtual:* The Internet offers makers the opportunity to connect worldwide (permanent access to open and collaborative networks). Websites such as Instructables or Hackster allow new skills to be learned and information exchanged - this element is termed *crowd based instructions*. *Open file repositories* such as GrabCAD or Thingiverse allow makers to share designs with others mostly for free. Another element is *community order platforms* such as OSH Park, where batch orders lead to cost reductions for every community member.
3. *Gather (hardware) knowledge and skills:* Knowledge gathering can be done in *online blogs* that teach skills and help to solve problems (e.g. Hackaday). Articles on specific projects, e.g. from MAKE magazine, provide an *online collection of resources*. Other elements are *books or printed magazines* and *webinars and workshops* such as video tutorials for specific equipment.
4. *Use of open source:* The element *open-source software framework* comprises organizations, which publish code snippets or software frameworks for free. *Open-source hardware* are pre-packed kits and products such as Arduino or RaspberryPi.
5. *Access to prototyping/ fabrication/ manufacturing facilities:* Access to tools for making are crucial for makers. The elements within this category are structured along the equipment on offer such as *digital prototyping machines, wood shop equipment, metal shop equipment, electronic workshop, craft machines,* and *testing equipment*. Additionally, *cloud computing platforms* are becoming more important as is the possibility of *renting a micro factory* for small batch size production (e.g. FirstBuild).
6. *Use of maker (CAx) software:* Elements such as free *3D design software* (e.g. SketchUp*)*, *2D design software* (e.g. Inkscape), *simulation software* (e.g. Simscale) and *developer tools for electronics* (e.g. Upverter, KiCAD) allow designing and simulating free of charge.
7. *Access to international vendors and shipping:* The element *contract manufacturer for low volume* covers companies with specialized offers for low volume projects at an affordable price (e.g. Seeed Studio). *Platforms for distributed manufacturing* such as Fictiv, 3D Hubs or Additively offer a distributed network of companies to produce parts for a very small batch size. Makers have *access to electronic parts suppliers* such as Sparkfun or Adafruit which offer open-source hardware components. The element *raw material in lowest volume (material library)* supports makers in getting the correct raw material for products (e.g. Modular) as well as the best raw material prices.
8. *Get seed capital funding:* The element *crowd funding* includes platforms such as Kickstarter or Indiegogo, where makers can obtain feedback on their ideas as well as

financial support. In contrast, *crowd investing* focuses on equity. For example, Companisto collects cash from the crowd and if a funded project is successful, crowd investors get a return on their initial investment.

9. *Get immediate customers feedback:* The element *peer-to-peer e-commerce* allows makers to sell their products and receive customer reviews. Setting up a web shop is done within minutes (e.g. Etsy, Shapeways). The element *rent a physical space* describes the renting of a shelf in an existing physical store to sell the maker's products (e.g. Kaufhaus Kollective).

Table 1 provides an overview of the maker movement elements according to the categorization of Friessnig et. al (2017).

Table 1: Maker movement elements[4]

Subsystem	Elements	Description
Connect with others – physical	▪ Fairs and events ▪ Maker related facility ▪ Experts' table	Face-to-face networking can provide access to knowledge, resources, markets or technologies
Connect with others – virtual	▪ Crowd based instructions ▪ Open file repositories ▪ Community order platform	Permanent access to open and collaborative networks worldwide which share ideas, insights, and best practices
Gather (hardware) knowledge and skills	▪ Online blog ▪ Online collection of resources ▪ Books or printed magazines ▪ Webinars and workshops	The maker movement fosters and facilitates knowledge sharing, learning, networking and getting support
Use of open source	▪ Open-source software framework ▪ Open-source hardware	Open source software and hardware can support product creation in a shorter time frame; the integration of technology is made easy by prepacked kits with a standardized set of tools
Access to prototyping/ fabrication/ manufacturing facilities	▪ Digital prototyping machines ▪ Wood shop equipment ▪ Metal shop equipment ▪ Electronic workshop ▪ Craft machines ▪ Testing equipment ▪ Cloud computing platform ▪ Renting a micro factory	Offering easy access to industrial manufacturing machinery and equipment
Use of maker (CAx) software	▪ 3D design software ▪ 2D design software ▪ Simulation software ▪ Developer tools for electronics	Computer-aided software for designing and simulating (CAx) is much more affordable today and makers can use this on standard computers
Access to international vendors and shipping	▪ Contract manufacturer for low volume ▪ Platform for distributed manufacturing ▪ Access to electronic parts suppliers ▪ Raw material in lowest volume (material library)	Access to lower-cost, small-batch manufacturing, particularly in hotspots such as Shenzhen (China) has increased, which makes small batch production for hardware entrepreneur's projects more economical and viable
Get seed capital funding	▪ Crowd funding ▪ Crowd investing	Makers get financial support to develop new products; investors provide investment capital
Get immediate customers feedback	▪ Peer-to-peer e-commerce ▪ Rent a physical space	Makers receive customer feedback (e.g. quantity of articles sold, customer reviews)

[4] Author's illustration based on Friessnig, M., Böhm, T. & Ramsauer, C. 2017. The Role of Academic Makerspaces in Product Creation. *ISAM 2017.* Case Western Reserve University, Cleveland.

2.1.5 Impact

The maker movement will change how people live, work and learn (Dougherty et al. 2014). People will produce the products they need by themselves (Aizu and Kumon 2013, pp. 2-3). In the field of education, making will support the learning willingness of consumers and will change them into developers (Hagel et al. 2014).

Importantly, established enterprises should be vigilant, because *"[…] the maker ecosystem will disrupt today's large enterprises."* (Dougherty et al. 2014). Thus, the incumbents should actively participate in the maker movement, try to learn, and thus may react quickly on certain market developments. The maker movement will be responsible for emerging trends and consequently will receive great attention from traditional businesses (Hagel et al. 2014).

European regions such as Iceland and Catalonia invested heavily in FabLabs to accelerate the creation of new startups. Hagel et. al (2014) argues that new companies will arise from the maker movement and help to create new production skills and competences. Makerspaces have the potential to change how startups evolve in the future. The community-shared infrastructure and equipment, and the mutual support offers a breeding ground for upcoming businesses. Access to the technology supports getting the idea off the ground (Maycotte 2016). Time and costs for prototyping are reduced, thus earlier sales and the acquisition of outside funding is more realistic (Holm 2015a, p. 24). Makerspaces facilitate networking with potential cofounders, strategic partners, venture capitalists and investors and thus become the new incubators and accelerators (Zwilling 2014).

Altogether, the maker movement impacts many areas of life such as education, research, economy, society, governments, universities, external research institutions, or grant giving organizations. (Hagel et al. 2010; Gershenfeld 2012, pp. 43-57).

2.2 Makerspaces

2.2.1 Manifestations

Various names, models and manifestations exist for the basic concept of offering a physical space for do-it-yourself (DIY) and do-it-with-others (DIWO) making activities. The first examples of physical spaces for opening production were the shared neighborhood-based machine shops initiated by Karl Hess in the 1970s (Seravalli 2014, p. 109). People living in the surroundings got access to basic tools and knowledge on how to make models or test facilities. Additionally, these workshops were, and still are, a base for community experimentation and demonstration (Hess 2005, p. 96).

Today, such spaces take several forms: libraries (e.g. Willett 2016), museums (e.g. Bevan et al. 2015), schools (e.g. Blikstein 2013), and mobile or pop-up forms (e.g. Barniskis 2014). The most popular initiatives are FabLabs, TechShops, hackerspaces and makerspaces (Mota 2011). The following sections describe these most relevant manifestations and elaborate similarities and differences.

2.2.1.1 Hackerspace

Kostakis et al. (2015, p. 557) define hackerspaces as *"[…] physical, community-led places where individuals, immersed in a hacker ethic, are to be met with on a regular basis engaging with meaningful, creative projects."* 'Hackers' originated in countercultural groups like 'hippies' (Grenzfurthner and Schneider n.d.) in the 1960's, and the first institutions were established in the 1990's. Opened in 1995, the first independent hackerspaces named 'c-base' evolved in Berlin, Germany (Wikipedia 2016). This group of programmers had the intention of sharing an inspiring physical space when engaging in open software development. The initial focus on programming very soon expanded to electronic circuit design and manufacturing as well as physical prototyping (Cavalcanti 2013). In 2007, this concept spread to the U.S. when hackers, excited about the opportunities of having a shared physical space, founded the New York City Resistor (Cavalcanti 2013).

According to Farr (2009), this was the first of three successive waves. The second wave describes the efforts of hackers to make their hackerspaces a more sustainable and official approach by gaining recognition and credibility from the government as well as from the public. The third wave comprises the spaces emerging all around the world today.

Many of today's hackerspaces are organized with an open community model where people with technological background come together and collaborate, share and expand their knowledge (Maxigas 2012). Hackerspaces offer various classes and access to tools. Most hackerspaces are member-driven and membership payments are the primary source of income (Schön et al. 2014). However, 'true' hackers do not consider all registered groups on hackerspaces.org as 'real' hackerspaces, due to their different ideological and historical roots (Maxigas 2012).

2.2.1.2 FabLab

The FabLab (abbreviation for fabrication laboratory) concept originated at the Massachusetts Institute of Technology (MIT), Cambridge in 2002. It was developed by Prof. Gershenfeld with the intention of offering a prototyping platform for learning and innovation (Gershenfeld 2005). This idea goes back to the course 'How to Make (Almost) Anything', when Prof. Gershenfeld realized the importance of the availability of easy-to-use manufacturing equipment for rapid prototyping in the development process of product innovations. Therefore, FabLabs are places, which provide easy-to-use, standard and inexpensive production technologies, primarily for local entrepreneurship and hobbyists (Gershenfeld 2005). Their stock of digital machines (3D printers, laser cutters etc.), enable individual and small batch production of own goods (Gershenfeld 2005).

The Fab Foundation (2017) defines a FabLab as *"[...] a technical prototyping platform for innovation and invention, providing stimulus for local entrepreneurship. A FabLab is also a platform for learning and innovation: a place to play, to create, to learn, to mentor, to invent. To be a FabLab means connecting to a global community of learners, educators, technologists, researchers, makers and innovators."* The FabLab initiative is a trademark name.

All FabLabs together constitute a global network for innovation and research coordinated by the Fab Foundation. Four main criteria are necessary to obtain a FabLab designation. First, FabLabs must provide public open access at least once a week. Second, the FabLab applies the FabCharter, which is a document expressing the commitment to be part of the global network. Third, all FabLabs share a very specific basic set of tools (specified exactly by model and type). Fourth, FabLabs actively participate within the global network. Knowledge sharing and interconnection are the central aspects of the international FabLab community (Fab Foundation 2017). The worldwide FabLabs are a kind of franchise system, in which the Fab Foundation retains no control over the activities and decisions of local spaces (Cavalcanti 2013). As independent spaces, every FabLab is free to setup its own structures and locations.

Lo (2014) describes a FabLab as a workshop dedicated to open and rapid prototyping for innovations – a place open to all, with machinery and tools ranging from very basic (e.g. soldering station) to sophisticated machines (e.g. CNC milling). Creativity and prototyping activities take shape through interactions of active community members with diverse skills. This activity takes place in the absence of hierarchy. A culture of experimentation, trial and error, mutual support and sharing of information and results is dominant. Individuals are free to choose their own projects (Lo 2014).

Commercial activities can be prototyped and incubated in a FabLab, but they should grow beyond rather than within the lab, and they are expected to benefit the inventors, labs and networks that contribute to their success (Morel and Le Roux 2016). FabLabs have different organizational structures, e.g. they are established directly in connection with research institutes or are operated privately based on an independent business model

(Schmidt 2014, p. 6). The various business models of FabLabs are described in detail in section 2.2.1.8.

2.2.1.3 Makerspace

The term makerspace goes back to the first publishing of MAKE Magazine in 2005. Dougherty (Lindtner et al. 2014, p. 3) called his magazine MAKE, because he did not want to get into the semantics of the term hacking. As recently as in 2011, the term became popular, when makerspace started being used to refer to publicly-accessible places, where people can design and create their own products (Holm 2015b; Cavalcanti 2013).

However, only a few resources exist which define what a makerspace is. One of the first attempts to define a makerspace came from the Institute of Museum and Library Services (2012, p. 1). They define makerspaces as *"[...] a growing movement of hands-on, mentor-led learning environments to make and remake the physical and digital worlds. They foster experimentation, invention, creation, exploration, and STEM learning."* Popular press articles on what makerspaces are and how to build one are widely availiable, e.g. *Three makerspace models that work* (Good 2013b), *Here's how we did it: The story of the EPL makerspace* (Haug 2014), or *The Makerspace Playbook* (Maker Media 2013).

The Educause learning initiative (2013) describes a makerspace as a *"[...] physical location where people gather to share resources and knowledge, work on projects, network and build. They are primarily places for technological experimentation, hardware development, and idea prototyping"*. Mark Hatch (2014) describes a makerspace as *"[...] a center or workspace where likeminded people get together to make things."* The mentor makerspace group (2013, p. 1) describes makerspaces as *"[...] gathering points where communities of new and experienced makers connect to work on real and personally meaningful projects, informed by helpful mentors and expertise, using new technologies and traditional tools."* These definitions emphasize the community and prototyping aspect. In these places, people can pursue their own projects, create or make things (Educause Learning Initiative 2013).

Makerspaces are dedicated spaces for individuals to work on their own or together in teams on different projects (Maker Media 2013). These laboratories provide easy-to-use rapid prototyping facilities to ensure that ideas do not just stay ideas but become realities. These spaces thus become new sources for creativity, new products and new businesses. Litts (2014) uses the term makerspace as *"[...] a broad term to describe spaces and organizations that ascribe to this common ethos of hacking, tinkering, and making."*

Makerspaces are equipped with materials and tools in terms of hardware and software similar to a laboratory or a workshop (Maker Media 2013). In addition, there is also material and knowledge for technical and creative work (Bisanz 2015). The space is managed by facilitators in the makerspace (Fuente et al. 2016). This is done by supervising mentors or volunteers in the makerspace, who carry out safety trainings and introductions to the various devices in the makerspace (Fuente et al. 2016). In some makerspaces workshops are held, which are intended to illustrate new technologies and devices (Maker Media 2013). It is also possible to present projects where the makers themselves have worked on, which leads to an exchange of knowledge among the participants.

Makerspaces exist in different forms and sizes, but in general every lab serves as a gathering point for tools, projects, mentors, and expertise. Makerspaces can focus on electronics, robotics, working with wood, sewing, tailoring, laser cutting, programming, or a combination of these topics (Maker Media 2013). For Weinmann (2014), e.g. a small prototyping space in a public library with basic rapid prototyping tools counts as a makerspace as well as a large workshop with multiple areas and various tools and equipment. However, a makerspace is always oriented towards the needs of its users (Weinmann 2014). Makerspaces in other forms have already existed before the maker movement has emerged, the only differences are the unifying platforms of the labs and the support of the community offered today.

2.2.1.4 TechShop

TechShop is the trademark name of a for-profit organization, which provided open access to manufacturing technologies of industrial quality. In 2006, the first TechShop was founded by Jim Newton and Mark Hatch in Menlo Park, California (Cavalcanti 2013). In November 2017, after several years of good times and troubles, TechShops' CEO Dan Woods, announced that the company would down operations at all locations worldwide and file for bankruptcy (Woods 2017b). Apparently, TechShop's business model didn't work out, which was mainly based on monthly or annual membership fees and offered machine trainings and workshops. Dan Woods (2017b) stated that *"the essence of the TechShop vision was to develop a network of makerspaces, members, curriculum, standards, instructors, and learning that would fuel the birth of new technologies, products, jobs, and companies. TechShop has accomplished much of this vision."* In December 2017, only a few weeks later, TechShop reached an agreement with a partnership led by Dan Rasure and Bill Lloyd from BHL Services Inc. of Minneapolis to acquire the assets of TechShop (Woods 2017a).

Looking back, TechShop (2017) described itself as *"Americas first national public workshop with unlimited access"*. Before the terms hackerspace and makerspace became common in the U.S., TechShop was already providing access to digital machines with facilities of up to 1,500 sqm. Back then, the average value of the equipment was around 750,000 USD (Eychenne 2012, p. 36). In 2017, TechShop operated ten facilities in the U.S. and additional three in France, Japan and United Arab Emirates (Techshop 2017). At each location, TechShop worked together with partners such as universities or companies operating in the do-it-yourself movement (Chen 2013, p. 3).

2.2.1.5 Labs at universities

Today, labs at universities focusing on the making and do-it-yourself experience have increased in popularity (Forest et al. 2014). But only at the end of the 2000s, researchers and educators started to consider the use of digital fabrication technologies for educational purposes (Blikstein 2013). The integration of such labs in design curricula at universities are classified as a 'top-down' approach, where the labs are funded by the university or government. The intention is to get a more practice-based curriculum and to breed skilled and creative engineers. The student driven approach of setting up a lab on the university campus are classified as 'bottom-up', where in many cases these initiatives have no grant funding (Forest et al. 2014).

In a study of 127 universities and colleges in the U.S., Barrett et. al (2015) identify three different operation models for DIY labs at academic institutions: *student run, specific staff* and *faculty run*. The most common model is a combination of student support and specialized staff personnel, whereas only a few of the labs appear to be faculty run. Some of the labs appear to be grassroots, student-driven initiatives. But, there are also labs operated in a combination of all three types. The study of Barret et. al (2015) shows that the overwhelming majority of labs at universities are open only to the campus community.

For example, the University of Yale established the Center for Engineering Innovation and Design (CEID), which acts as an educational resource as well as a focal point for design and engineering on the campus. The facility includes an 800 sqm lab space, which combines an open studio, lecture hall, wet lab, and meeting rooms with 24/7 access to the studio space. CEID offers and hosts a variety of activities, events, and organizations. Most CEID members are undergraduates (60 percent), mainly of STEM (Science, Technology, Engineering, Mathematics) studies (CEID 2016).

Another example for the university context is *Project Manus*, which was started in October 2015 at the Massachusetts Institute of Technology (MIT), Cambridge within MIT's Innovation Initiative. The intention of Project Manus is to create the standard in the next generation of academic DIY labs. In the future, MIT will operate over 45 major DIY labs that make up MIT's maker system. Students can already have the possibility to use the *Mobius App* to find relevant information about locations, available machines and materials in the various labs. In addition, Project Manus is leading a partnership with peer institutions including Stanford, Berkeley, Georgia Tech, Yale, Carnegie Mellon, Case Western Reserve, and Olin College to create a guide book for academic DIY labs (Project Manus MIT 2016).

In Europe, for example, the Technical University of Denmark (DTU) hosts the DTU Skylab on its main campus. The space considers itself as an innovation hub, which supports student projects for innovation and entrepreneurship. The goal is to enhance cooperation between students, the business world, and other external partners. One of the focus areas are startups, whereby all registered DTU students can apply for funding. Besides monetary aid, the DTU Skylab offers a wide network of coaches, developers, mentors, and in-house competencies. The Skylab includes an auditorium, a meeting room, a skybox and various workshops (Skylab n.d.).

Wilczynski (2015) reviewed some of the prestigious universities in the U.S. like Georgia Tech, Yale, MIT, and Stanford, whereby he identified a number of best practices that can be incorporated at planned and existing makerspaces (Wilczynski 2015):

- *Mission:* Academic makerspaces must have a clearly defined mission.
- *Staff:* The facility must be properly staffed with educators, design and manufacturing professionals, and administrative personnel.
- *Environment:* An open environment promotes collaboration and idea exchange through dialog.
- *Access:* The alignment of access times with users work schedules increase the utilization of the makerspace.
- *Training:* By providing training sessions to the user, the productivity in the makerspace increases.
- *Community:* Focus on the establishment of a maker community.

In another study, Kurti et. al (2014) highlight the following principles to create an environment in a makerspace that attracts students: invite curiosity, inspire wonder, encourage playfulness, celebrate unique solutions, it is ok to fail, breaking things is not a cardinal sin, and collaborate, collaborate, collaborate.

To summarize, labs at universities need to be established with and for students. These labs act as modern centers of education with the focus on inquiry-based learning. Theoretical input of the educational institution merges with the innovative potential of the students. To attract students to the lab, it is necessary to catch their attention and to inspire them (Kurti et al. 2014, pp. 2-3). The best practices and principles described above (e.g. Wilczynski 2015; Kurti et al. 2014) may also be adaptable for corporate makerspaces.

2.2.1.6 Other platforms

There are a great number of other designations for community-based spaces such as 'co-working space' or 'innovation lab'. Moilanen (2012) mentions several other terms like '100k garage' or 'sharing platform'. Schmidt (2013) uses the term 'innovation center' for a holistic provider for startups by combining a business incubator with a prototyping space. This means, not only are entrepreneurs advised in economic terms but also have, a facility to produce prototypes and small batches. In many cases, especially in the case of projects classified as innovative and with high potential for success, the usage fee is borne by another institution, whether through public funding, banks, business angels or the innovation center itself. Here it is important to note, that this way of looking at an innovation center integrates the physical component of providing a space for rapid prototyping. Often, the goal is to test the market potential of products and to develop innovative business concepts in an application-oriented environment (Schmidt 2014, p. 12).

For Schmidt (2013), such labs are physical or virtual spaces that focus on the exchange of knowledge, ideas and information. Creative and innovative processes are supported in these labs by providing appropriate infrastructures, services and methods of collaborative knowledge generation. Innovation labs are usually characterized by a cross-innovation approach. This means that many labs support working across all sectors and in interdisciplinary teams. The cross-innovation approach also includes the involvement of entrepreneurs and freelancers from creative industries to collaborate within the labs (Schmidt 2013).

These labs form novel organizational structures that differ from established structures. They are not strictly isolated from the outside, but are accessible to different user groups and thus fundamentally interdisciplinary. They enable the community to generate and benefit from the knowledge and skills from different disciplines, thus creating a systematic 'conflict structure'. Such structures allow the gathering of previously separate knowledge stocks, which can ultimately result in innovations (Schmidt 2014, p. 7).

This is exemplified by incubators or accelerators serving as institutions which provide expertise and active help to startups over a certain period of time, often in exchange for company shares, whereby the focus often lies on business matters rather than manufacturing (Schmidt 2014). Furthermore, 'bio labs' (focusing on biotechnology) or 'art labs' are also associated with the maker community, but digital manufacturing does only play a minor role within their concepts.

2.2.1.7 Differences and commonalities

The different manifestations of labs described in the previous sections, developed independently from each other but have similar structures and characteristics. Holm (2015b) investigated the similarities and differences particularly between makerspaces, hackerspaces and FabLabs. The results show that these three manifestations are substantially similar, only small differences are explored. Holm (2015b) illustrates that around 47 percent of the labs within his study consider the terms makerspace, hackerspace and FabLab to be interchangeable.

In the same way, Moilanen (2012) or Kostakis et al. (2015, p. 557) do not identify significant differences between the various terms and organizations. Both studies use the term hackerspace as the overall designation for all such organizations for the sake of clarity. In contrast, Smith et. al (2013) use ‘makerspace’ as a sort of generic term for hackerspaces, FabLabs or TechShops. But in line with the previous studies, they observe no substantial difference between a makerspace and the other manifestations. Also, for Litts (2014, p. 5) the boundaries between these types of spaces are extremely blurred, because all of them are based on a common ethos.

What all initiatives have in common is the goal of democratizing the process of manufacturing and putting power in the hands of individuals to design their own products. The spaces are distinct locations for exchange, using the Internet for networking. All spaces make substantial usage of digital fabrication tools as an interface between digital and material production (Holm 2015b). Some spaces are backed and financed by industry. Here, the common point is seen as providing freedom of experimentation that eventually could lead to new ideas and products for the market (Benkler and Frischmann 2013). Hackerspaces offer classes and access to tools similar to other initiatives like FabLab or Techshop (Schön et al. 2014).

The largest difference relates to FabLabs, which are far more likely to include concepts relating to educational institutions such as colleges, schools, and universities (Holm 2015b). Makerspaces are more targeted at engaging young people, *“[…] whereas hackerspaces are traditionally dominated by ‘white male nerds’.”* (Grenzfurthner and Schneider n.d.). FabLabs and hackerspaces are more technically oriented, while according to Cavalcanti (2013), the term makerspace is more used for very basic places.

In the view of Eychenne (2012, pp. 35-37), one essential difference between a TechShop, makerspace and a FabLab is the available space and the number of machines offered. TechShops offer more space and a high variety of machinery and equipment. FabLabs usually are smaller and have only basic manufacturing equipment. Another difference is the approach regarding membership fees. TechShop is a for-profit organization based on membership fees of the users.

To conclude, the manifestations described are very similar, only with small differences in some areas (e.g. size of space, infrastructure, business model). Within this thesis, *makerspace* is used as general term for all various manifestations (see Smith et al. 2013) and is understood according to the definition of Weinmann (2014, p. 15) as *"[…] physical location with a community, where members build physical prototypes and objects by using manufacturing tools and machines in a hands-on manner."* This definition comprises the main aspects of location (physical space), community (interactions amongst members), prototypes (physical objects), manufacturing tools and machines (to build physical objects), and hands-on (machine operation by members themselves).

2.2.1.8 Business models

According to Troxler and Schweikert (2010), makerspaces require special business models that support collaborative interactions between enterprises and their stakeholders to satisfy today's rapidly changing market needs with innovative products and services. Four key ingredients are essential for a sustainable business model of a makerspace (Troxler 2010):

1. *Openness:* The elimination of closed door thinking, the democratization of new technologies, open source and commons based peer production (knowledge about and access to means and methods of production are available for everybody), and open learning in communities. Makerspaces are the nucleus for communities of practice that allow all their members to develop mastery, to share knowledge and experience with other members in the community. Open organizational formats such as public-private partnerships are important.
2. *Interdisciplinary collaboration:* When everybody is welcome to participate, opportunities for interdisciplinary collaboration emerge.
3. *Effectiveness:* Connecting academics and practitioners on an equal level and allowing them to socially interact directly with each other in various projects.
4. *Transferability:* Exchange of experiences, business models, programs, technical issues and solutions in the worldwide network are beneficial.

Moreover, Troxler (2010) defines two main groups of makerspaces. First, the *lab as a facility* and second, the *innovation lab*. Facility focused labs provide access to digital fabrication machinery and support their members in the production process (e.g. training). In addition, innovation labs provide a product-service-system helping their customers to increase the effectiveness of the innovations (Troxler 2010).

Despite the differences between the two groups, three measures for the success of makerspaces are defined (Troxler and Wolf 2010): First, the protection of interests and creative freedom of makers. Second, the access to new knowledge, processes and products. Third, the extent to which it is possible to appropriately and effectively create and capture value. The consideration of these measures and their meaning for the operational work of a makerspace may support the development of a business model containing the creation of value for both, the maker and the makerspace (Troxler 2013). Value of three different kinds are created: (1) *products and services* by satisfying human needs, (2) *human capital* by sharing knowledge and developing skills and competences, and (3) *social capital* through creating social connections within a network (Seravalli 2014).

For the development of a sustainable business model a closer look at the ecosystem of the makerspace is needed. The requirements of all relevant stakeholders must be considered, e.g. businesses (entrepreneurs, SMEs, industrial enterprises), educational institutions (e.g. schools, universities), students, artists, non-profit organizations, employees, funding agencies, regional governments and the private society (Troxler 2010). Much effort is necessary to build up and maintain such an innovation ecosystem for a makerspace.

The organization 'FabLab Iceland' postulates four possible business models for makerspaces to meet the needs of stakeholders (Menichinelli 2013; FabLab Wiki 2010):

- *Enabler business model:* Providing know-how and physical goods for existing and newly launched facilities. Allowing labs to share best practices, e.g. products, workshops, administration etc.
- *Education business model:* Peer-to-peer learning among users and enforcement of the global network of makerspaces, e.g. Fab Academy, individual lectures etc.
- *Incubator business model:* Providing infrastructure and know-how to enable the evolution from 'zero to maker' to 'maker to market' including, e.g. marketing or back office infrastructure. The goal is supporting makers to create sustainable businesses.
- *Replicated/ network business model:* Providing products and services by the staff and experts to retain sustainable revenues. Products and services can be replicated worldwide.

Obtaining revenues is fundamental to a sustainable business model. The following services are proposed for makerspaces (Eychenne 2012):

- *Space and equipment rental:* Besides the open access hours, membership fees and additional machine rental fees are possibilities to gather income.
- *Contract manufacturing:* Production on demand, e.g. for businesses or individual persons.

- *Training, workshops and seminars:* Knowledge transfer from experts is offered to businesses and individuals.
- *Project support, feasibility studies and prototyping:* Offering support and guidance for startups and SMEs during their innovation processes.
- *Small business incubation:* Provision of expertise on different topics, e.g. intellectual property rights, communication, marketing etc.
- *Makerspace employee as consultant:* Know-how transfer; immediate production or operator of industrial projects

Eychenne (2012) proposes three business models using the revenue opportunities for makerspaces mentioned above. First, *education* makerspaces, which are mainly hosted by universities or higher education institutions with students as the main customer group. Open lab days are combined with paid prototyping or manufacturing services run by students and small business. Second, *private business* makerspaces are privately funded labs providing digital fabrication facilities and machines for hire, plus services such as trainings, and consulting activities. Third, *pro-am general public* makerspaces, which provide access to digital fabrication tools with revenues from services, machine rental, sponsorship and public funding.

Most makerspaces combine several sources of income with grants from governments, universities or regional projects; many makerspaces receive support from local industry partners (Eychenne 2012). Many makerspaces need to be funded by public institutions in the beginning, but most of them share the objective to become self-sufficient within the first three years (Troxler and Wolf 2010). There is, however, a clear need for more research regarding the sustainability of the different models (Schmidt 2014, p. 11).

2.2.1.9 Stakeholders

Makerspaces need to respond to different customer segments with specific offers for the targeted groups (Böhm et al. 2015):

- *Established companies:* Enterprises offer the opportunity for their employees to work during office hours or in their leisure time in the makerspace to develop and fabricate own ideas and products.
- *Small and Medium-sized Enterprises (SMEs):* Due to limited internal resources, the access to a makerspace at an external institution is of special interest for SMEs.
- *Hardware startups:* Entrepreneurs and students with product ideas in the hardware sector need prototypes for testing purposes. Exchanges with like-minded people can boost the development and optimization of own product ideas.

- *Students:* For educational purposes, the makerspace is used within the scope of university courses of various departments for different purposes (e.g. machine components, material science, production engineering, architecture, industrial design, computer science, biomedical engineering, knowledge technology, information technology, electrical engineering). Additionally, lectures and workshops for schools and kindergartens are possible.
- *Researchers:* Depending on the needs and issues, bachelor, master and doctoral theses may need the offerings of makerspaces.
- *Public:* Open access for everyone at least for a certain portion of the opening hours (interested people can use the equipment free of charge).

In a similar way, a makerspace in a university setting has six defined stakeholders (Weinmann 2014):

- *University students:* University students can use the makerspace inside their curriculum for project work or out of the curriculum for personal projects.
- *Teaching staff:* Teaching staff have the task of education and research in the university. A makerspace can give them the possibility to build parts quickly and offer relevant lectures to students.
- *High school students:* High school students potentially become new university students after they graduate. A makerspace helps to prepare them for university.
- *Alumni:* Alumni can appear as guest speakers or mentors.
- *Entrepreneurs and startups:* Entrepreneurs and startups created by students need support because they often cannot afford digital manufacturing equipment. These startups contribute by networking and creating teams with students.
- *Industry partners:* Industry partners may attract future employees at makerspaces or use makerspaces as a means of researching new technologies through open innovation.

2.2.2 Types

As mentioned above, various different makerspaces exist. The University of Southern California distinguishes five types of makerspaces (University of Southern Carolina 2017):

- *Permanently dedicated:* This type comprises all permanent makerspaces that store large and digital equipment. These makerspaces require a lot of planning, promotion and staff.
- *Mobile:* This type of makerspace is moved around and shared by various groups of individuals in many locations via a cart, tubs or anything portable. They are very simple and more affordable to set up, movable and can be positioned in different

locations. Mobile makerspaces have the advantage that the people do not have to come to the space, the space comes to the people (see also Gierdowski and Reis 2015).

- *Clubs:* In clubs, experts can share knowledge and skills with the participants in schools, summer camps, libraries, leisure centers and other places.
- *Kits:* Kits are like a mobile makerspace, but smaller. The equipment and the resources are stored in compact containers. Kits are assigned to a specific topic, for example, 3D printing, electronics, construction, textiles, paint supplies, Lego kits or jewelry.
- *Event-based:* Also known as pop-up makerspaces, event-based spaces use mobile or regular maker kits to enrich experiences during special or seasonal events.

In contrast, Lahr (2013) identifies three categories of makerspaces:

- *Person-related:* These spaces are mainly incorporated at universities and research institutes. The main objective is to support individuals and groups with potential ideas, to review, to develop, to realize, to integrate and eventually to found a startup. The focus lies on the personal development of its participants. Some spaces offer the opportunity to work on real life problems, which are provided by business partners of the makerspace.
- *Business-related:* Such makerspaces are either independent, part of a company or integrated in for-profit institutes. The target group of these makerspaces are businesses that want to use the facility for business development activities and startups. The main objective is to collaborate with companies and work on given problems, rather than personal development measures.
- *System related:* These makerspaces aim to develop approaches for societal, political, and economic problems. Such spaces are often run by non-governmental organizations (NGO's), foundations, or universities. Here 'seekers' (businesses) and 'solvers' (users) act in the public interest.

2.2.3 Categorization

Wilcynski (2017) proposes a five-index classification system, which he has developed based on previous research studies on key factors affecting makerspaces (Barrett et al. 2015; Wilczynski 2015; Forest et al. 2016). The study of Wilcynski (2017) focuses on academic makerspaces:

- *Scope:* This category describes the degree of a makerspace's contribution to the university mission based on education, research and service activities. The parameters vary from grassroots and initial offers to programs that support between one university mission and programs that support three university missions.

- *Accessibility:* The category of accessibility indicates the degree that the space can be used by the university community. This dimension ranges in four steps from access limited only to individuals enrolled in departmental course to open access to the entire university community.
- *User-base:* The number of users is measured with a variety of indicators (e.g. registered users, total number of visits etc.). The number of members helps to estimate the potential energy, engagement and impact of the space.
- *Footprint:* This characteristic focuses on the size of the makerspace, where all areas dedicated to the space need to be considered (e.g. workshops, studios, meeting rooms, storage areas, support spaces, classrooms, staff offices).
- *Management and staffing:* This dimension examines the collaborative community of the makerspace. Proper management and staffing is essential for long-term viability and positive experiences for the members of the space.

2.3 Organizations

The term organization has two meanings. On the one hand, organization designates the activity and function of organizing and shaping – the *instrumental* concept of organization. Here, the goal is to make workflows as effective and efficient as possible and to establish a structure for the organizational rules. On the other hand, organization refers to the result of the organizational activity in the sense of the organizational form that has emerged (e.g. company) – the *institutional* concept of organization. The organization system as an institution is characterized by three core elements: (1) *goal orientation* – organizations are focused on specific purposes; (2) *formal structure* – achieving a performance advantage requires the division of responsibilities and their coordination; and (3) *consistent boundaries* – organizations are separated from their environment but still they are open systems (see Schreyögg 2008, pp. 5ff; von der Oelsnitz 2009, pp. 21f; Vahs 2012, pp. 12ff).

Organizational rules provide structure and guidance on how to behave in certain situations (Schreyögg and Von Werder 2004, Sp. 971). The goal of rules is to ensure that all parts of the organization work together efficiently and purposefully (Schreyögg and Steinmann 2005, p. 440). Organizational rules can have different roots. Regulations introduced by the management (written or oral) are *formal* rules. In contrast, routines brought in from the outside or developed inside the organization by its employees (e.g. cross-departmental communication channels, shared coffee break at a particular time etc.) are *informal* rules. Often these informal rules arise spontaneously, are unplanned and result from the needs of the members of the organization (Lang 2004, Sp. 497f). In classical organizational theories (Weber 1924; Fayol and Reineke 1929; Taylor 1914), these applied informal rules were seen as confounding factors. The neoclassical (Roethlisberger and Dickson 2003; Barnard 1968) and modern organizational theories (MacGregor 1960; Argyris 1964; Likert 1967; Peters et al. 1982; Deal and Kennedy 1982; Luhmann 1968) assume that both formal and informal rules have a strong contribution to the performance of organizations by making the organization more flexible (Schreyögg and Steinmann 2005, p. 440; Schreyögg 2008, p. 12ff).

Organizations have long been cooperative work structures where work was a sequential series of tasks implemented separately and sequentially (Hord 1986). In the last decades, this work organization shifted more towards teamwork and collaboration. Everyone necessarily interacts with other members of the organization (Ribeiro et al. 2011). Employees need to work together to realize innovations (Schirmer et al. 2012, p. 55). Indeed, the challenges to be solved within organizations have become more complex and therefore require the interdependent collaboration of individuals within diverse work teams. According to Knippenberg and Schippers (2007), diversity means the degree of objective and subjective differences between persons belonging to a group or organization. Already Schumpeter argued for a collaborative working model where interacting with people with various skills and iterations of trial and error during the innovation process can lead to successful idea commercialization (Schumpeter 1947; Laursen and Salter 2006).

In today's corporate world, knowledge work is a central component of the value-added processes. Because of the global trend towards a knowledge economy, the usage of methods and strategies for knowledge acquisition, production and processing within organizations is increasing (Castells and Cardoso 2006). Notably, knowledge work is complex, not repetitive, communicative, individual and characterized by novelty. The more complex the processes and technologies, the bigger the proportion of knowledge workers. Therefore, knowledge workers are the central resource of a company (see Probst et al. 2013). Due to the large volumes of available information and the dynamic environment, organizations require multidimensional and timely practices to cope with complex issues. Such practices are collaborative such as task forces, workgroups, community practices etc. Workers meet and try to best articulate their diversified skills to understand, think, decide and act collectively.

In this context, communication is a key factor. The more complex and cross-linked the work, the more important the intense exchange between knowledge workers (Allen 1997; Heerwagen et al. 2004; Toker and Gray 2008). Every organization has to face the challenge of creating a stable environment, that supports the creativity and curiosity of its employees and at the same time enables efficient and systematic management of the organization (see Amabile et al. 1996; Trott 2008). Creating an attractive and function-optimized working environment results in possibilities to motivate employees and to increase productivity (see Becker and Steele 1995; Allen and Henn 2007; Sturm et al. 2012).

The following chapters describe the links of the makerspace concept to scientific theories, its attachment to the resource-based view and to the theory of dynamic capabilities.

2.4 Organizational capabilities

The concept of organizational capabilities has become an important part of strategic management. Organizational capabilities are critical for companies to succeed in reaching their goals (Schreyögg and Kliesch-Eberl 2007, p. 914). The theoretical foundation of organizational capabilities is the resource-based view (RBV) of strategic management. Noticeably, Lo (2014) proposes the resource-based view and more precisely the dynamic capabilities approach as first anchor to scientific theories for corporate makerspaces.

2.4.1 Resource-based view

The resource-based view is a research field intensely studied for over thirty years. The authorship is attributed to Wernerfelt (1984), who assumes that companies can build up a strategic differentiation in the same competitive environment by providing and developing individual resources and combining them into capabilities. It should be noted that the concept of considering the organization as a set of resources and expertise necessary for its survival was developed much earlier by various researchers. For example, Penrose (1959) relates the growth of an organization to the combination of its human resources and internal hardware. The resource-based view is opposed to the classical theory of cost transaction that explains the firm as a set of nodes between individuals through which each company must aim minimizing its transaction costs to achieve the best possible efficiency (Jensen and Meckling 1976). Barney (1986a; 1991), Prahalad and Hamel (1990) and Grant (1991; 1996) have greatly contributed to the construction of this research field and made the resource-based view a central topic in management science.

Resources are everything that is available to the company and what it can access, directly or indirectly. For Barney (1991, p. 101), firm resources are a company's strengths – including all assets, capabilities, organizational processes, attributes, information, knowledge etc. – which allow the company to design and implement strategies that improve its effectiveness and efficiency (Daft 2008; Porter 1981). Resources are either tangible or intangible (Wernerfelt 1984). By differentiating the resources, a company can build up and defend a sustainable competitive advantage over the competition (Müller-Stewens and Lechner 2011, pp. 346ff; Schreyögg 2012, pp. 74-75). According to the resource-oriented approach (Barney 1986b; Barney 1991; Peteraf 1993) companies need to deploy capital, human resources, knowledge, technology and organizational concepts to be able to create innovations.

Prahalad and Hamel (1990) extended the resource-based view through the introduction of core competences. Here, the authors understand core competences as the collective knowledge in an organization, specifically the way in which different production skills are coordinated and several technological streams are integrated. In that way, Prahalad and Hamel build the bridge between the resource-based view and organizational learning theories (Hutterer 2012, p. 186).

Core competences are of a general nature and not confined to a business field, but they can be used in different markets (Prahalad and Hamel 1990). If the resource and capability combination as a core competency is sufficiently complex, unique and difficult to imitate, the company can realize a sustainable competitive advantage (Welge and Al-Laham 2008, pp. 101-104; Müller-Stewens and Lechner 2011, pp. 205-206). Barney (1991) identified four essential attributes to a company's resources to achieve sustainable competitive advantage: *valuable, rare, inimitable* and *non-substitutable*; also known by the acronym VRIN.

2.4.2 Capability-based view

The capability-based view (CBV) is an advancement of the RBV and is different in terms of the value chain. While the RBV generates a return potential by detecting undervalued resources, the CBV builds this potential by the coordinated use of resources – the *capabilities.* These capabilities replace resources as the unit of analysis in the CBV. However, resources are still the basic components that become a product or service through coordinated arrangement (Müller-Stewens and Lechner 2011, pp. 348-349). Because of their intent of using resources, capabilities are seen as a special kind of resource (Makadok 2001, p. 389) that companies have to generate themselves and that are not easily purchasable (Teece et al. 1997, p. 529).

Organizational capabilities are complex patterns of interaction, coordination and problem-solving, and are developed in a long-term process (Nelson and Winter 1982, pp. 99ff; Müller-Stewens and Lechner 2011, p. 638). In contrast to individual capabilities, organizational capabilities are collective, organizationally developed and shared patterns of selecting and connecting resources (Schreyögg 2012, p. 110). These patterns are located on different organizational levels (company, division, strategic business unit, departments etc.). If the coordination of resources is happening in a structured way repeatedly, these capabilities become more efficient and internalized and can therefore be seen as routines (Winter 2003, p. 991; Müller-Stewens and Lechner 2011, p. 349). Schreyögg (2012, p. 110) is speaking of an organizational competence that is recognized as the capability to use and combine the resources of an organization in order to enable the successful solving of specific problems and tasks. To conclude, following characteristics are assigned to organizational capabilities:

- *Coordination:* Organizational capabilities serve the purpose of generating organizational coordination, which means coordinating actions of individuals and groups routinely in order to successfully solve problems (zu Knyphausen-Aufsess 1995, p. 95; Müller-Stewens and Lechner 2011, p. 349).
- *Deep structure:* Organizational capabilities are embedded in the deep structure of the system, that includes group interests, individual interests and culture (zu Knyphausen-Aufsess 1995, p. 95; Müller-Stewens and Lechner 2011, p. 349).
- *Potential character:* Investing in organizational capabilities does not directly guarantee success, but enlarges the opportunity set of the organization, which could lead to success (zu Knyphausen-Aufsess 1995, p. 95; Müller-Stewens and Lechner 2011, p. 349).
- *Dynamic:* Organizational capabilities include a dynamic dimension, that enables the organization to make changes (zu Knyphausen-Aufsess 1995, p. 95).
- *Complexity:* The development of organizational capabilities is complex. Over time, the result of decisions can accumulate to become such capabilities.

Organizational capabilities are embedded in existing organizational routines, structures and processes, and can be seen in a company’s way of working, its organizational structure, its culture and the mindset of the company leadership (O´Reilly and Tushman 2008, p. 188). Every organizational capability is the result of an organizational learning process (Grant 1996). In this learning process, new approaches for selection and combination of resources are developed by organizations (Winter 2003).

2.4.3 Dynamic capabilities

The increasing turbulence and volatility of markets, technologies and environmental conditions led to the need for the dynamization of organizational capabilities and core competencies. This situation resulted in the development of a different approach to achieve this need – the *dynamic capability view* (DCV) of strategic management, with its core element, the *dynamic capabilities*. The DCV is based on the RBV and the development of core competences to achieve competitive advantages.

Teece et. al (1997, p. 516) define dynamic capabilities as *"[...] the firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments"*. Schreyögg (2008, p. 454) provides an overview of the development of the DCV and its concepts of (1) *integration* (Teece et al. 1997), (2) *total dynamics* (Eisenhardt and Martin 2000) and the (3) *development of meta competences* (Zollo and Winter 2002).

According to Schreyögg and Steinmann (2005, p. 262), core competencies tend to create related innovations, but prevent other developments. Successful behaviors are carried out more intensively and others are omitted. In addition, established companies tend to invest in innovations that are associated with existing resources and competencies. Through this pursuit of efficiency, the potential of radical innovations are often not recognized and opportunities are not taken adequately (Teece 2000). This can result in path dependencies that prevent a change to other behavior, problem-solving patterns and technologies. If core competencies do not develop further and are not able to cope with the dynamics of the environment, they can become hindrance factors (Prahalad and Hamel 1990). Leonhard-Barton (1992) describes this phenomenon as the concept of *core rigidities*, Hannan and Freeman (1984) describe it as *organizational inertia* and Levinthal and March (1993) as the *myopia of learning*.

As a result, the main goal of dynamic capabilities is to find a solution for this rigidity paradox and to overcome the problem of solidification of organizational capabilities and competencies to secure a company's sustainable competitiveness (Eisenhardt and Martin 2000; Danneels 2002; Helfat and Peteraf 2003; Schreyögg and Kliesch-Eberl 2007). Organizational capabilities have to be dynamic in order to meet the demand for continuous renewal due to rapidly changing environmental conditions (Danneels 2002, p. 1095; Helfat and Peteraf 2003, p. 998). The quality of dynamic capabilities is seen as the main reason for differences between organizations in terms of their organizational capabilities (Jacobides 2008).

To stay competitive, the organization must possess organizational routines. According to Levitt and March (1988), routines include forms, rules, procedures, policies, strategies and technologies upon which organizations are built and operate. This also includes the structure of beliefs, paradigms, codes, cultures and knowledge that support, develop and contradict the formal routines. These organizational routines enable businesses to respond promptly and effectively to environmental stimuli and market changes (Eisenhardt and Martin 2000). But, these routines can also cause a mismatch between the strategy of a business and its changing environment. Dynamic capabilities are used to avoid this lack of adaptation (Zollo and Winter 2002; Zahra et al. 2006). Moreover, Zollo und Winter (2002, p. 340) emphasize that dynamic capabilities come from learning. Thus, the organization must develop new strategies to create value and new organizational tools to remain flexible to adapt to different market developments (Eisenhardt and Martin 2000). Dynamic capabilities differ from organizational capabilities through their ability to provide innovations outside the organization's current routines (Lee and Kelley 2008, p. 155).

The DCV approach focuses primarily on the internal resources of the company when establishing strategies. Dynamic capabilities emphasize the changing of processes, invention and reinvention of the business architecture as well as asset selection and asset orchestration (Helfat et al. 2009, p. 28). However, external resources are not excluded, they are intended to be integrated into the internal resources to allow the necessary adjustments to the environment (Teece et al. 1997; Teece 2007; Eisenhardt and Martin 2000). Especially, the interactions between people from inside and outside the company with disparate skills and the aim to innovate are considered (Teece et al. 1997; Teece 2007).

To conclude, a corporate makerspace may be a new organizational tool to support sustainable competitive advantage for companies. As described in the preceding sections, a corporate makerspace may better exploit the dynamic capabilities of organizations. According to Zollo and Winter (2002) dynamic capabilities arise from learning, specifically the accumulation of knowledge, the integration of that knowledge and finally the codification of the knowledge. Therefore, it is essential to study the learning phenomenon, because it is a fundamental factor in the activity of a makerspace (see chapter 2.7.4).

2.5 Organizational learning

The knowledge society puts management and knowledge theories at the heart of organizational systems and requires new ways to manage organizations, individuals and the various flows between individuals (Castells and Cardoso 2006). This dissertation builds on the concept of organizational learning as the theoretical anchor for corporate makerspaces.

Most scholars understand organizational learning *"[...] as a change in the organization's knowledge that occurs as a function of experience."* (e.g. Fiol and Lyles 1985). Organizational learning theories help to understand the processes that lead to changes in organizational knowledge. In addition, the theories attempt to understand the effects of learning on organizational behavior and consequences (Schulz 2002). According to Gabler Wirtschaftslexikon (2017a), organizational learning is the process of changing the organizational value and knowledge base to increase the problem-solving competences as well as to change the reference frame of an organization. The focus lies in setting up a company-specific knowledge base, which means the development of shared knowledge by all members of the company. Although organizational learning is about individuals and their interactions, it is not equal to the sum of the individual learning processes and results. This is because not all individual knowledge is passed on (for reasons of power, anxiety, frustration etc.), or because new knowledge can arise during the transfer of individual knowledge (synergy effects). Depending on the team structure, the sum of the individual knowledge is greater or smaller than the organizational knowledge (Gabler Wirtschaftslexikon 2017a).

Argote and Miron-Spektor (2011) provide a theoretical framework for analyzing organizational learning systematically (see Figure 4). They describe organizational learning as an ongoing process in which task performance experience interacts with its context to create knowledge. Here, the out-flowing knowledge changes the environmental and organizational context and therefore affects future experience (Argote and Miron-Spektor 2011).

The environmental context involves customers, competitors and other organizations such as educational institutions or governments. The organizational context comprises strategy, structure, processes, culture, and technology. Argote and Miron-Spektor (2011) differentiate between an active and a latent context The latent context (members of organization, available tools, tasks to perform) influences the active context where actions are taken and learning occurs. The three elements of the members-tools-tasks framework and its networks at the crossings of the elements provide the basic mechanisms for the occurrence of learning and knowledge creation, retention and transfer in organizations (Argote and Miron-Spektor 2011).

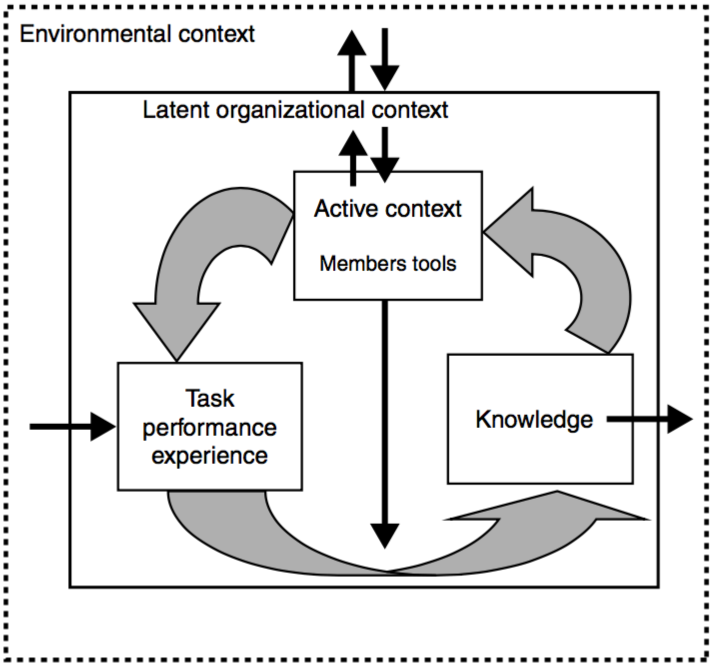

Figure 4: Theoretical framework for analyzing organizational learning[5]

The central question of organizational learning is how individual experiences, insights and knowledge can be transferred into collective or organizational knowledge as a preliminary stage to organizational skills. Collective knowledge means the accumulated knowledge of the organization, which is stored in its rules, routines, shared norms (culture), the physical design of the work environment (e.g. factory design) as well as the approach of problem solving and collaboration of the organizational members (Lam 2011, p. 168). In addition, knowledge can be stored in databases (stock) or can be in a flow state (flow) resulting from the interaction of the members. Collective knowledge exists rather between individuals than within individuals (Lam 2004, p. 14).

2.5.1 Origins

Reviewing the concept of organizational learning, there is neither a uniform theory nor one dominant approach (Lülfs 2013, p. 33). There are numerous attempts at structuring and classification to provide an overview of the research field. Used in management consulting and scientific research, different concepts such as learning organization, learning company or organizational learning etc. have been shaped. The most widely used distinction between the subject matter and the results of organizational learning is

[5] Argote, L. & Miron-Spektor, E. 2011. Organizational learning: From experience to knowledge. *Organization Science,* 22. p. 1125.

between *behaviouristic* (Cyert and March 1963; Levitt and March 1988; March et al. 1991; Argyris and Schön 1978; Argyris and Schön 1996), and *cognitive, knowledge-based* approaches (Cohen and Levinthal 1990; Walsh and Ungson 1991; Nonaka and Takeuchi 1995). The behaviouristic stream describes organizational learning as the adaption of behavior over time (e.g. adaption of goals, rules or search strategies), whereas the cognitive stream bases its theories on changes in one's understanding.

Discussions on organizational learning started in the nineteen fifties, when March and Simon (1958) suggested that organizational processes influence the behavior of organizations significantly. This theory contradicted the existing economic models at that time, which stated that organizational decisions are determined heavily by external constraints. To support their argumentation, March and Simon (1958) proposed several organizational learning ideas, e.g. that organizations adapt their performance level based on the experience of decisions made.

Cyert and March (1963, p. 99) sharpened the concept of organizational learning and attempted to transfer the theories of learning by individuals to organizations. Also, they introduced the concept of the 'learning cycle', which describes the responses of organizations to external events as the adjustments of the organization's specific operating procedures (SOPs). March and Olson (1975) criticized the assumption of rational adaption in learning models, because the existence of ambiguity can also lead to misinterpretations of experience. Here, March and Olson (1975) examine four conditions: (1) *role-constrained learning,* (2) *superstitious learning,* (3) *audience learning,* and (4) *learning under ambiguity.* These four situations together indicate that learning does not always result in improvements.

Most theories on organizational learning emphasize the importance of collective or organizational knowledge as the basis for organizational capabilities. As mentioned above, this is stored in the rules, procedures, routines and shared norms and practices of the organization (March et al. 1991, p. 74; Lam 2004, p. 14; Levitt and March 1988). According to Schulz (2002), organizational rules are formalized routines and the establishment of new or the change of existing rules are the results of organizational learning processes. Three factors drive the dynamics of organizational rules (March et al. 2000): (1) the *generation and recognition of problems,* (2) *the rule ecologies,* and (3) *the accumulation of competences.*

Organizational learning is a continuous process of absorbing, processing, and linking new information, combining it with existing knowledge and experience of individuals, and translating into organizational activity. The result is the enlargement of the organizational knowledge (Lam 2004, p. 14). In addition, organizational learning is understood as a process of testing, feedback and evaluation, which is always influenced by the already existing routines – evolutionary paths (Burmann 2002, p. 171). Here, the question is how new knowledge can produce changes in routines and behaviors of organizations and its individuals. Organizational learning is the basis for solving problems and producing innovations. The organizational members, the organizational context and the processes within the organization are essential (Lam 2004, p. 14)

Marquardt (2002, pp. 24-32) proposes five subsystems necessary to sustain viable, ongoing, organizational learning and ensuing corporate success:

- *Learning:* Learning is considered as a core subsystem of the learning organization.
- *Organization:* The organization itself consists of four key components: vision, culture, strategy, and structure.
- *People:* The people subsystem includes all stakeholders of the organization. All must be empowered and enabled to learn.
- *Knowledge:* The knowledge subsystem manages the acquired and generated knowledge of the organization, e.g. acquisition, creation, storage, analysis, data mining, transfer, dissemination, application and validation.
- *Technology:* Technology means the integration of technological networks and information tools for managing knowledge and enhancing learning. Such knowledge management systems serve as repositories or tools for communication and collaboration to support knowledge transfer across barriers (e.g. distance, organizational unit, specialization) as well as the retention of knowledge (Argote 2013b). Knowledge management systems can also prevent *organizational forgetting* (Smunt 1987).

Senge (1990) identified five elements that transform an organization into a learning organization: (1) s*ystems thinking,* (2) *personal mastery,* (3) *mental models,* (4) *shared vision,* and (5) *team learning.* Argote (2013b, p. 206) suggests linking advances in practice theory to enhance the understanding of organizational learning, because practice theory puts the *doing* as central to organizational outcomes (Feldman and Orlikowski 2011). Here, a link between practice theory and learning by doing is established. Rerup and Feldman (2011) studied the role of trial-and-error learning for organizational routines and schemata. Salvato (2009) argues how learning from experience enhances organizational capabilities. To conclude, organizational learning research provides the theoretical basis for the development of knowledge management tools and practices in the stages of knowledge creation, transfer and retention to become a learning organization (Argote 2013b).

2.5.2 Measures

Researchers suggest different ways to measure organizational learning, e.g. change in practices (Gherardi 2009) or distribution of information within an organization (Huber 1991). The most discussed concept to measure organizational learning are *learning curves* (also referred to experience curves or learning by doing). Basically, a learning curve (see Figure 5) displays a metric of learning relative to a metric for experience (Argote and Epple 1990; Argote 2013b). For example, Wright (1936) considered learning effects on the production costs of airplanes in the form of decreased unit costs in relation to the total cumulative number of units produced. Dutton and Thomas (1984) found that the amount of errors decreases as workers learn over time, but the improvement rate is not constant; it decreases with more experience.

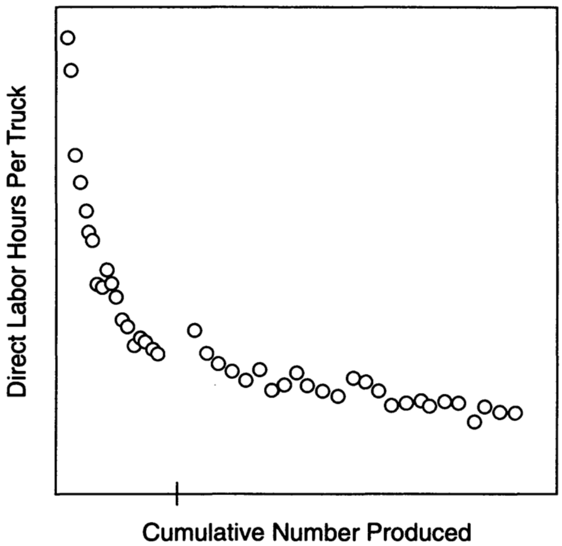

Figure 5: Learning curve[6]

Performance gains (based on experience) following a learning curve can be found at the individual (Mukhopadhyay et al. 2011), group (Shure et al. 1962), organizational (e.g. Rapping 1965) and industry level (e.g. Sheshinski 1967) of analysis. Moreover, the increases in productivity realized can be significant (see Epple et al. 1991). Originally, the concept of learning curves goes back to psychologist Ebbinghaus in the 19th century. According to Argote (2013b), the phenomenon of learning curves can be explained due to (1) increased proficiency of individuals (see also Muth 1986), (2) improvements in an organization's technology or (3) improvements in its structure, e.g. routines, methods of

[6] Epple, D., Argote, L. & Devadas, R. 1991. Organizational learning curves: A method for investigating intra-plant transfer of knowledge acquired through learning by doing. p. 62.

coordination (see also Huberman 2001). More information can be found in reviews of research studies on learning curves (Lapré 2010; Dutton et al. 1984).

It is worth noting that organizations show different rates of learning. Many scholars have focused on identifying various factors to explain the variations in learning rates observed (a.o. Adler and Clark 1991). Nevertheless, learning curves are applied internally for planning, budgeting or monitoring activities (a.o. Ghemawat and Spence 1985; Hayes and Wheelwright 1984) as well as externally, for example, to predict costs of competitors (Henderson 1984).

One major difficulty with classic learning curves is that the model assumes that learning cumulates and persists over time. The consequence of organizational forgetting are inappropriate forecasts if they are based on the classic learning curve model. Several research studies found empirically that knowledge depreciates over time (Argote 2013b). Causes for knowledge decay or depreciation are the loss of organizational records or the difficulty to further access them (Lenehan 1982; Marshall 1989), the fact that knowledge becomes obsolete (Benkard 2000), or member turnover (e.g. David and Brachet 2009). Some researchers argue that forgetting referred to as 'unlearning' (see Hedberg 1981) can also be beneficial for the performance of organizations (Holan and Phillips 2004). Argote (2013b) suggest to consider unlearning as a form of learning, where one figures out what works in which context. Others measure organizational learning based on the number of patents (Alcacer and Gittelman 2006; Alcacer et al. 2009).

As examined in the previous sections, learning has become the critical avenue for understanding and adapting to the ever-increasing speed of change. Scholars and practitioners argue that organizational learning is the only way for a firm to create a sustainable competitive advantage (Reese and Hunter 2016). Organizations, just as individuals, must find and develop ways of systematically integrating learning into all elements of organizational life, otherwise they are doomed to failure (Marquardt 2002, pp. ix–x). Market competition has increased so intensely that the survival of the fittest organization is quickly becoming the survival of the fittest to learn. Those organizations that learn faster will be able to adapt more quickly and thereby achieve significant strategic advantages in the global business world. It is crucial for companies to realize that they must become learning organizations (Marquardt 2002, pp. ix–x). Organizational learning leads, for example, to process improvements, increased efficiency, accuracy, profits, and beneficial investor relations (Argote 2013b).

2.5.3 Learning

Today, different definitions and many interpretations of the process of learning exist. Arrow (1962) found that learning is the product of experience. Thus, learning can only take place through the attempt to solve a problem and therefore only takes place during activity. Schulz (2002) distinguishes between the following three notions:

- *Learning as improvement:* This model focuses on the improvements (e.g. performance, precision) as the learning result, captured usually with learning curves (see Lieberman 1984; Argote and Epple 1990; Adler and Clark 1991).
- *Learning as recording:* This model perceives learning more as a 'process' than an 'outcome' (learning activity). Organizations draw conclusions out of experiences and encode the implications into organizational routines (Levitt and March 1988). Encoding of lessons takes effort, but organizations provide only less resources for that (Schulz 1998). As a result, the mapping of lessons is discontinuous, incomplete and delayed (March et al. 2000).
- *Learning as evolution of knowledge*: This model builds on the recording of knowledge notion and integrates the processes that lead to changes in organizational knowledge. Here, the connections between knowledge elements (actual and potential) are emphasized. Nelson and Winter (1982) argue that the establishment of knowledge connections are a primary source for organizational innovation.

Piaget (1972) focused in his work on experiential learning, which emphasizes the proactive role of the individual on their environment in the act of learning. However, learning is necessary for the emergence of all intelligence, as new knowledge is essential to adapt to the environment (Piaget 1972). Which means, there is no intelligence without learning.

The most effective way to learn anything is to let individuals do it. In manufacturing, for example, the unit cost of produced goods has been shown to decline significantly as more are produced (see chapter 2.5.2). It has been argued that learning by doing is at the cause of this (von Hippel and Tyre 1995). But usually, learners do not understand the relevance of what they learn, and the lessons do not apply to an intrinsically motivating goal (Schank et al. 2013, pp. 164-171). Throughout history, learning theorists have found that we learn best when we are motivated to achieve something as opposed to being motivated to learn about something. Learning is a cyclical and iterative process which gets optimized when we can reflect on our immediate actions (Marquardt 2002, p. 36).

Basically, we tend to index information we learn, this means that whenever the context to the learned lessons is not given, the knowledge cannot be retrieved as effectively when it is needed. Mistakes also need to be indexed properly in order to gain information from failure, and to transfer the knowledge to other problems later on (Schank et al. 2013, pp. 164-171).

Schank et. al (2013) developed a learn-by-doing simulation called goal-based scenarios (GBS) in which learners pursue a goal by practicing target skills and using relevant content knowledge to help them achieve their goal. This model comprises seven components (Schank et al. 2013, pp. 173-179):

1. *Learning goals:* Learning goals consist of process knowledge and content knowledge. Process knowledge is the knowledge of how to practice skills that contribute to goal achievement, and content knowledge is required information to achieve the goals.
2. *Mission:* It is necessary to determine a goal or mission that is motivational and imparts the relevant skills and knowledge.
3. *Cover story:* The cover story is the background which accompanies the mission and creates the need for accomplishment. The story should be interesting and motivational.
4. *Role:* The role defines which part the learner has in the cover story.
5. *Scenario operations:* The scenario operations comprise all activities necessary to work towards the mission goal. Here, the learner practices the skills and learns the information to reach the learning goals.
6. *Resources:* Provide enough resources for the learners. The best way to communicate information is to embed lessons in stories that the learner can understand.
7. *Feedback:* Feedback is provided either through a consequence of actions, coaching, or domain experts who tell stories that pertain to similar experiences.

Such environments enable learners to use their own experiences to solve problems and to achieve goals, interesting scenarios and motivational topics can maximize their effectiveness. Then, it is unlikely that learners forget what they learn, because the lessons will be indexed with other memories of experience (see also chapter 2.5.4). Whenever the individuals work within the domain again, they are likely to retrieve the relevant memories (Schank et al. 2013, p. 181). Time pressure massively influences the learning process. The learning process is promoted only if there are environments for work and learning in the enterprise where the organization and the individuals can develop (Jeschke et al. 2011a, p. 21).

Many different constructs were formed to describe organizational learning processes. Duncan (1979) analyzes the *organizational knowledge base*, Hedberg (1981, p. 6) *organizational cognitive systems and memories*, Daft and Weick (1984, p. 284) *organizational interpretation systems*, Argyris and Schön (1978, p. 11) *organizational* *theories of action*, and Levitt and March (1988, p. 320) *routines* including forms, rules, procedures, conventions, strategies, and technologies.

Organizational learning distinguishes between single-loop learning and double-loop learning processes, a concept developed by Argyris and Schön (1978). Single-loop learning (also referred to as adaptive learning) corresponds to the organization's adaptation to changing conditions of the internal as well as the external environment, which only results from experience. This means that in single-loop learning, identified problems are compared with the given policies, values and objectives to initiate appropriate actions to solve these problems. Single-loop learning deals with all organizational rules that define the structures and processes that are officially documented, authorized, and thus are visible within the organization. Regardless of the new knowledge, there is no sustainable change in the organizational value and knowledge base (Gabler Wirtschaftslexikon 2017a).

In contrast to single-loop, double-loop learning (also referred to as change learning) critically questions and corrects previous experiences of the organization and reinterprets the changing conditions of the organization's internal and external environment. This means that if policies, values and objectives are no longer appropriate, a new frame of reference will be created. Double-loop learning changes corporate culture, cognitive structures and established individual and group interests, and thus changes the organizational values and knowledge base (Gabler Wirtschaftslexikon 2017a).

Common to all learning activities is that they take place in a social context and that the characteristics of this context influence learning success (Lam 2011, p. 169). Thus, a large part of the literature focuses on the importance of social interaction, context, and cognitive patterns for learning and knowledge creation (Argyris and Schön 1978; Wenger 1998; Bartel and Garud 2009). This assumes that large amounts of human knowledge are subjective and implicit and can only be passed on through the knowledge carrier.

2.5.4 Experience

Experience is the basis for organizational learning and is measured in terms of the cumulative number of tasks performed (Argote and Miron-Spektor 2011, p. 1124). Based on Argote (2013a, pp. 35-40), experience has various dimensions:

- *Direct and indirect:* Organizational units can either learn from their own direct experience (Dutton and Thomas 1984) or indirectly from the experience of other units (Darr et al. 1995; Szulanski 1996).
- *Content:* Experience is acquired about tasks or about organization members (Kim et al. 2009; Taylor and Greve 2006).

- *Novelty:* Experience is acquired on novel tasks or on tasks that have been performed repeatedly in the past (Katila and Ahuja 2002; Lampel et al. 2009; March et al. 1991).
- *Success and failure:* Organizations can learn from both, successful and unsuccessful events (Denrell and March 2001; Kim et al. 2009; Sitkin 1992; Haunschild and Sullivan 2002; Madsen 2009; Madsen and Desai 2010).
- *Ambiguity:* The range between ambiguous (Bohn 1995; Repenning and Sterman 2002; March 2010) and easily interpretable experience depend on clear relationship between causes and effects.
- *Spatial location:* An organization's experience can be geographically collocated or geographically distributed (Cummings 2004; Gibson and Gibbs 2006).
- *Temporal:* This dimension characterizes experience along various dimensions: *timing* – acquired before (Pisano 1994; Carrillo and Gaimon 2000), during, or after task performance (Ellis and Davidi 2005; Morris and Moore 2000; Roese and Olson 1995); *recency* – acquired recently or in the distant past (Argote et al. 1990; Benkard 2000; Darr et al. 1995); *frequency* – rare (March et al. 1991) or frequent (Herriott et al. 1985; Levinthal and March 1981); and *pace* – steady or uneven rate (Argote et al. 1990; Benkard 2000).
- *Simulation:* Naturally occurring or simulated through computational methods or experiments (Argote 2013a).
- *Heterogeneity:* The degree of diversity in task experience – similar versus varied tasks (Haunschild and Sullivan 2002).

2.5.5 Knowledge

The outcome of learning is knowledge (Argote 2013b). North (1998) introduces the knowledge ladder. Symbols with syntax are data, which becomes information, when data gets meaning. Information in relation to context, experience and expectations, then becomes knowledge (knowing what and why). Only motivation and application of knowledge leads to actions (know-how), which can become a competence over time and with the right choice. Competences bundled uniquely form a competitive advantage of an organization. According to Argote (2013a, p. 31), knowledge includes declarative (facts etc.) and procedural knowledge (routines, skills etc.). Organizational learning is driven by three key processes: creating, retaining, and transferring knowledge (Argote 2013b).

2.5.5.1 Knowledge creation

The stage of knowledge creation describes how experiences generate knowledge, which is related to creativity (Taylor and Greve 2006). Nonaka and Takeuchi (1995) provide a framework to better understand the individual and collective learning phenomenon through interactions of individuals. They argue that the creation of new knowledge of organizations occurs through continuous interactions between two types of knowledge:

- *Explicit:* This form of knowledge is declarative, factual, systematic, and easy to communicate and transfer (written, verbal or codified), e.g. definitions, instructions and documents.
- *Tacit:* This form of knowledge is personal, context-specific, subjective and difficult to share and transfer. Polanyi (2015) refers to it as the knowledge of procedures. Tacit knowledge is too complex to codify within a document and therefore can only passed on through practice and experience (Nonaka and Takeuchi 1995). Tacit knowledge is difficult to formalize and to transform to explicit knowledge. It brings together the expertise, experience and skills of the individuals that they are not aware of themselves.

In addition to social interaction, diversity of skills and difference of opinions are essential criteria for learning (see chapter 2.5.7). In this perspective of knowledge creation, the organization is considered as a learning entity where learning is at the heart of the evolutionary process. The acquisition of knowledge falls within the individual level and then extends to the organizational level (Nonaka and Takeuchi 1995). Later on, Nonaka and Konno (1998) introduced the concept of 'ba', which means 'place' in English. This concept provides a foundation for knowledge creation in organizations through a shared space, which can be *physical* (e.g. office space), *virtual* (e.g. e-mail), *mental* (e.g. experiences) or any combination of them.

2.5.5.2 Knowledge retention

The stage of knowledge retention describes the process of how and where knowledge is embedded within an organization. Examining existing conceptualization (Walsh and Ungson 1991; Darr et al. 1995; Levitt and March 1988; March et al. 2000; Nelson and Winter 1982; Starbuck 1992), knowledge is embedded in (1) *individuals,* in (2) *routines,* in the (3) *organizational structures,* (4) *technologies,* and (5) *culture*. In the theoretical framework of Argote and Miron-Spektor (2011), both the active context with its members, tools and tasks as well as the latent context such as a company's culture can function as knowledge repositories (see chapter 2.5). However, a significant extent of a company's knowledge is embedded in the outflowing products or services of the organization (Mansfield 1985).

In this context, another important concept is that of *transactive memory* (Wegner 1987; Wegner 1995), which describes the effect when members of a social system (group or organization) gain experience, they acquire knowledge on the skills of others and learn who is good at what. This knowledge allows the social system to allocate tasks according to individual expertise and thus leverage the system's performance. The concept of transactive memory can be applied on group, organizational as well as interorganizational level. Gino et. al (2010) found that groups with well-developed transactive memory systems are more creative than groups with less-developed transactive memory systems (measured in terms of the number of new products developed). Argote and Ren (2012) suggest transactive memory systems as foundation for organizational and dynamic capabilities.

Fundamentally, individuals are able to capture subtle nuances of information that is not possible to store in other repositories (Argote 2013b, p. 103). Researchers showed that individuals could use the experience gained with one task to transfer knowledge to another task, even though they were not able to articulate their knowledge to others (Berry and Broadbent 1984; Berry and Broadbent 1987). When relying on individuals as knowledge repositories, it needs to be considered that individuals can leave the organization and thus take their knowledge with them. Moreover, Weldon and Bellinger (1997) found that individuals forget faster than groups or social systems. Thus, organizations need to capture the knowledge embedded in individuals in organizational structures, routines and technologies such as information systems (see Rao and Argote 2006; Moreland 2006). Technologies are particularly effective for storing explicit knowledge (Argote 2013b, p. 105).

2.5.5.3 Knowledge transfer

The stage of knowledge transfer describes how organizations can use processes and knowledge management systems to spread experience and facilitate its transfer within an organization. For the effective operation of globally distributed enterprises, it is crucial that knowledge transfers continuously between the allocated experts and across the various sites (Argote et al. 2011).

Various factors influence knowledge transfer: the *relational* (Darr et al. 1995) and *cognitive* (Szulanski 1996) context of knowledge; the *motivational* (Osterloh and Frey 2000; Quigley et al. 2007) and *emotional* (Elkjaer 2004; Levin et al. 2010) context of individuals; *social networks* (Hansen 1999; Reagans and McEvily 2003), *personnel movement* (Almeida and Kogut 1999; Kane et al. 2005), *routines* (Argote et al. 1990; Argote 2013b), *alliances* (Gulati 1999), and *technologies* (Argote 2013b, p. 105).

Internal and external networks can provide organizations with access to knowledge, resources, markets, or technologies. Through repeated and enduring exchange of relationships, knowledge is created (Inkpen and Tsang 2005, p. 146). One observed effect is that friendship networks promote knowledge transfer, allowing their members to learn from each other's experience (Reagans and McEvily 2003, p. 241). Especially, knowledge from the outside is an important stimulus for change and organizational improvement (Inkpen and Tsang 2005, p. 146).

In the same way as for knowledge retention, individuals are the most effective media for the transfer of tacit knowledge (Argote 2013b, p. 103). Correspondingly, several studies showed that moving personnel within an organization facilitates the transfer of knowledge to new contexts, especially the difficult to access tacit knowledge (e.g. Galbraith 1990; Rothwell 1978). But, the problem is that individuals may not want or are unmotivated to pass on their knowledge (see Engeström et al. 1990). Typically, that phenomenon can be observed when individuals possess information unique to the them (e.g. Stasser and Titus 1985). The willingness to share knowledge gets enhanced, for example, by rewarding employees at an annual conference (Lin and Svetlik 2007).

The process of knowledge sharing has to be supported by employees, actively as well as passively. Consequently, there must be communication between the staff. Communication skills strongly depend on the individual personalities of the employees. The exchange of knowledge can affect the innovative capability of the firm. Knowledge exchange is dependent on factors such as experience, values, motivation and beliefs of the employees (Lin and Svetlik 2007).

At the organization level, the question is how can an organizational unit learn from another unit or organization. As described above, various factors affect knowledge transfer. Commonly, knowledge transfer between organizational units can happen by moving people, technology and routines from the donor to the recipient unit (Argote 2013b, p. 149). Moreover, external sources (e.g. customers, supplier, other organizations) and competitors' products in the sense of *reverse engineering* and *benchmarking* can be used to acquire knowledge (see also chapter 2.5.5.1).

2.5.6 Levels

The occurrence of learning can be distinguished into different levels, namely the *individual, group, organizational* and *inter-organizational* level (Kozlowski et al. 2010). The following sections describe the different levels in more detail.

2.5.6.1 Individual

The individual level as the smallest learning unit focuses on how individuals learn new skills and gain expertise over time. It is important that individuals decide to share their knowledge, because the organization will lose this knowledge if the individual leaves the organization (Wilson et al. 2007). Thus, the individuals must embed their acquired knowledge in repositories (e.g. databases, routines) to ensure continuing access to the knowledge for other members of the organization (Argote 2013b, p. 20).

Learning by individuals – the improvement of individual performance due to the acquisition of more experience – is considered as the foundation and the key factor for organizational learning (e.g. Hayes and Wheelwright 1984). Various scholars have provided reviews of research on individual learning (Mazur and Hastie 1978; Newell and Rosenbloom 1981; Anzai and Simon 1979). Notably, social interaction is a necessary condition for the creation and diffusion of knowledge(Fillol 2006). People learn by interacting, when group members cooperate to accomplish a common goal.

2.5.6.2 Group

In most cases, learning happens in situations and environments with other learners (Herriott et al. 1985; Levitt and March 1988). According to Argote (2013b, p. 20), groups serve as microcosms of organizations, because many organizational processes like communication or coordination occur at this level of analysis. Argote (2013b, p. 116) defines groups in organizations (e.g. new product development team) along three dimensions (based onGuzzo and Dickson 1996; Cohen and Bailey 1997; Hackman 1990). First, *task interdependenc*e means that each group member affects each other. Second, *social-psychological awareness* describes that group members perceive themselves and are perceived by others as a group. Third, *social embeddedness* depicts the group within a larger social system (Argote 2013b, p. 116).

Like the definition of learning in organizations, learning at the group level is described as the change in the knowledge of the group due experience (Argote 2013b, p. 116). Group learning occurs when individuals acquire, share, evaluate and combine knowledge with each other. There are different beliefs on how learning happens within a group. Either, it is seen as a process of a group taking action, getting feedback and modifying future actions by using the feedback (Sole and Edmondson 2002). Or, learning occurs when a group member shares individual knowledge with others (Wilson et al. 2007). This happens when individuals work together in a team. According to Reagans et al. (2005) increased experience working together leads to better teamwork and coordination. Edmondson, Dillon and Rolloff (2007) provide an overview of research on group learning.

2.5.6.3 Organization

The organizational level comprises all activities of an organization to create and organize knowledge. Organizations can encourage organizational learning by providing a context that promotes curiosity, information sharing, and psychological safety for its employees (Edmondson 1999).

Furthermore, there is a fourth organizational unit of learning, the inter-organizational, which focuses on how organizations can learn from another organization (e.g. through sharing, collaborations, alliances) This includes applying existing ideas from another organization, as well as their modification to create innovations (Tucker et al. 2007). See Miner and Anderson (1999) for a literature review of this level of analysis.

This concept of different learning levels of organizations is used broadly, but more dissent than consensus prevails over their interaction (Lülfs 2013, p. 37), as well as the objects and outcomes of organizational learning. Behavior-oriented theories are, in analogy to the theories of individual learning, focused on the observation of the behavior and the responses of the learner to external stimuli. The cognitive stream, on the other hand, is concerned with the internal processes of the learners. Cognitive learning is understood as a process of reflexive exploration of the environment, in which the cognitive structures of the learning system become more complex (Klimecki and Thomae 1997, p. 2). Most approaches to organizational learning are attributed to the latter stream, whereby there is consensus that organizational learning is accompanied by a change in knowledge and knowledge structures (Lülfs 2013, p. 37). However, Fang (2012) developed a theoretical model that provides a link between individual and organizational learning. Further research is needed to better understand the relationships between the different learning levels of organizations (Argote 2013b, p. 189).

Learning happens at all different levels in an organization (Crossan et al. 1999). Considerably, lower levels of analysis always include the higher levels. For example, the organization is part of the context when studying learning at group level. Notably, individual and group learning mechanisms as well as embedding the knowledge acquired in repositories that others can access is necessary for organizational learning to occur (Argote 2013b).

2.5.7 Collective intelligence

Lo (2014) proposes that the theory of collective intelligence is relevant, when studying the dynamics created when individuals with assorted skills meet with each other, exchange knowledge and have the common desire to be creative. Thus, this section explores the link between corporate makerspaces and the emergence of collective intelligence in organizations.

According to Heylighen (2013), solving abstract problems requires intelligence. When this intelligence is located in one agent it is called individual intelligence, but when distributed within a group of agents it is called collective intelligence. Malone et. al (2009, p. 2) define collective intelligence as *"[...] groups of individuals doing things collectively that seem intelligent."* For Woolley et al. (2010) this concept describes the general ability of a group to perform a variety of tasks. Until today there is no commonly accepted definition of this term (Schut 2010). Lo (2014) elaborated the following key elements of collective intelligence:

- *Natural phenomenon:* Collective intelligence is a natural phenomenon that emerges from the interaction of members within a group. That means, collective intelligence exists by default, it is present in any interactive group, regardless of the formation of the group and the task. Generally, the intelligence of the group is greater than the sum of individual intelligence of the group members (Woolley and Fuchs 2011; Lévy 2010). On occasion the collective intelligence may be lower than that of the individual group members, for example, due to relational conflicts.
- *Cognitive ability:* Collective intelligence includes the capability of a group to ask questions and seek answers together. These capabilities can be divided into four phases: understanding, reflection, decision and action.
- *Process and purpose:* The interaction between the group members follows a certain process. A common purpose of the group members is required.
- *Complexity:* Another key element of collective intelligence is the complex situation. Without complexity, there is no emergence of collective intelligence.

According to Lo (2014), many similarities between the concept of collective intelligence and the approach of dynamic capabilities approach can be seen. Indeed, if external environmental changes to a company are considered as a complex situation to resolve for a company, the concept of collective intelligence is integrated in the approach of dynamic capabilities. Therefore, an improvement in collective intelligence means increased dynamic capabilities of the company.

Organizations need working groups with diverse knowledge and skills to tackle all its challenges (Klein and Harrison 2007; Klein et al. 2011; Van Knippenberg and Schippers 2007). Therefore, the composition of groups in terms of diversity has become a matter of importance. Diversity can refer to a wide range of properties (e.g. age, nationality, political opinions, religious beliefs). The effects of diversity on the group and its performance depends on the type of variety (Williams and O´Reilly III 1998; Van Knippenberg and Schippers 2007; Klein et al. 2011). Thus, research on diversity is dominated by two major streams – the theory of *information and decision making* and the theory of *social categorization* (Williams and O´Reilly III 1998; Van Knippenberg et al. 2004).

The theory of information and decision making relies on the fact that every group member possesses knowledge, certain skills and different capabilities. Therefore, members tend to have different opinions and heterogeneous views, which increases the range of options and perspectives on a topic. Thus, diversity is seen as a catalyst for ideas, creativity and innovation (Williams and O´Reilly III 1998; Van Knippenberg et al. 2004). Indeed, diversity is a critical component for promoting innovation within firms (Østergaard et al. 2011). Holm (2015b) states: *"[…] innovation often requires the combining of seemingly divergent ideas into novel products."*

In contrast, the theory of social categorization classifies individuals according to an established taxonomy – similarities and differences on a selected criterion. Within a group, there are subgroups, which designate themselves as *we*, while those who are not part of their group are referred to *them*. Group members have high confidence within their subgroups and low confidence and mistrust in other subgroups. In this regard, heterogeneity is considered as a limiting factor to performance, because the differences create misunderstandings (Williams and O´Reilly III 1998; Van Knippenberg et al. 2004). Studies show that the team composition is an important factor that affects the performance of workgroups (Woolley and Fuchs 2011; Kearney et al. 2009). The diversity of skills of the team members result in diversity of information, knowledge and perspectives (Haon et al. 2009). Diversity is potentially beneficial or harmful to the dynamics of the community depending on other environmental factors (Kearney et al. 2009).

It is common for members of a collaborative work group to mingle, to share knowledge and to develop a unique culture that is revealed in common knowledge, similar practices, identical routines and comparable approaches on certain subjects. In literature, this phenomenon is entitled *group thinking* (e.g. Janis 1972), which occurs when group members minimize their differences and show maximum cohesion. This phenomenon is beneficial in certain environments and situations.

When it comes to knowledge exchange, the goal is to gather as many divergent views as possible to create value. Divergence in the context of knowledge exchange describes a state of different understanding between two or more individuals on the same subject, a so-called *cognitive conflict* (Díaz and Canals 2004). Scholars argue that creating new knowledge comes from the confrontation of different views and is therefore related to diversity in cognitions and skills of the community members (Díaz and Canals 2004; Woolley et al. 2010). Dealing with divergent and conflicting opinions within a collective, can have positive consequences for the group, but also negative effects are possible (Van Knippenberg et al. 2004).

Nevertheless, research emphasize the importance of constructive confrontations in the expression of opinions and beliefs of individuals within a community (Duncan 1979; Zollo and Winter 1999; Argyris and Schön 1978). When people share their individual experiences, and compare their opinions with those of their colleagues, all group members can achieve a higher level of general understanding through learning and are able to better perform tasks (Zollo and Winter 1999).

2.5.8 Context

According to the framework of Argote and Miron-Spektor (2011), the latent context affects the active context through which learning occurs. The available tools in an organization as part of the latent context have effects on the abilities (e.g. training programs), motivations (e.g. rewards or job design), and opportunities (e.g. social network) of the organization's members. Table 2 provides an overview of contextual factors favorable to knowledge creation, retention and transfer.

Table 2: Contextual factors for organizational learning[7]

Dimension	Facilitation factor	Sources
Focus	▪ Specialist organizations learn more from experience than generalist organizations	(Haunschild and Sullivan 2002; Ingram and Baum 1997)
Culture	▪ Psychological safety	(Edmondson 1999)
	▪ Lack of defensive routines	(Argyris and Schön 1978)
	▪ Learning orientation	(Bunderson and Sutcliffe 2003)
	▪ Shared language	(Weber and Camerer 2003)
	▪ Cohesion among group members	(Wong 2004)
	▪ Social networks	(Burt 2004; Tortoriello and Krackhardt 2010)
	▪ Member diversity	(Macher and Mowery 2003)
	▪ Team stability	(Reagans et al. 2005; Huckman et al. 2009)
Structure	▪ Decentralization, especially in uncertain environments	(Ethiraj and Levinthal 2004; Siggelkow and Levinthal 2003; Siggelkow and Rivkin 2005)
	▪ Semi-isolated subgroups	(Fang et al. 2010)
	▪ Team structures characterized by specialization, formalization and hierarchy	(Bunderson and Boumgarden 2010)
	▪ Internal network structures	(Reagans and Zuckerman 2001; Reagans and McEvily 2003)
	▪ Investment in research and development	(Lieberman 1984; Sinclair et al. 2000)
Process	▪ Performance feedback	(Greve 2003)
	▪ Group training	(Hollingshead 1998; Liang et al. 1995)
	▪ Observation of expert	(Nadler et al. 2003)
	▪ Knowledge management systems	(Boland Jr et al. 1994; Ashworth et al. 2004; Kim 2008)
	▪ Information and communication technologies	(Zammuto et al. 2007)
Strategy	▪ Aspiration level	(Lant 1992; Cyert and March 1963)
	▪ Slack resources	(Wiersma 2007)
	▪ Power and status, only if used for the benefit of the organization	(Bunderson and Reagans 2011)

2.6 Innovation

2.6.1 Definitions, dimensions and types

The term innovation comes from the Latin word *innovatio* which means renewal and change. Basically, innovation is understood as the complete process of new product development including all phases from generation of the new idea to the introduction of the product into the market place. As Trott (2005, p. 15) states: *"Innovation is the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product or manufacturing process or equipment."* For Schumpeter (1934), *"[...] innovation is the*

[7] Author's illustration based on Argote, L. 2013b. *Organizational learning: Creating, retaining and transferring knowledge,* New York, Springer Science & Business Media. pp. 40-46

process of finding economic application for inventions." This definition indicates that innovation and invention have different meanings. It is important to distinguish between innovation and invention as many people tend to confuse these terms. In the perspective of Schumpeter's definition, invention is noticeably the first step towards any new product or process. Consequently, innovation needs not only inventions but also marketing (DeMaria 2013, p. 254). According to Thom (1980), innovation needs to be something *new* and needs to provide *value*.

Modification is the alteration or extension of an existing product or process, mainly in terms of quality improvements, change of configuration or appearance with the intention to prolong the product life cycle. Imitations are replica of successful products, often with a lower degree of quality (Trott 2005, p. 15). For Schumpeter (1934), an imitation is the process by which an innovation is diffused throughout the industry or economy.

Product innovation is the development of a new or improved product (Trott 2005, p. 17) and focuses on the benefit to the customer (market-oriented application). Here, the objective is to increase effectiveness of the product (Hauschildt and Salomo 2007). In industry, product innovation progressively requires process innovation, which is the development of a new manufacturing process (Trott 2005, p. 17). Here, the objective is to increase efficiency (e.g. faster, safer, better quality, more cost-effective manufacturing). Considering the correlation of product and process innovation in a system theoretical way leads to system innovations comprising three parts: the system components, the system itself and the system linkage. Schumpeter (1934) sees the essence of innovation in the enforcement of new combinations which do not occur continuously but rather discontinuously. Innovation needs to be considered beyond technology in various fields (economy, management, society etc.). Postindustrial system innovation comprises innovations in banks and insurance companies (e.g. credit cards, leasing, bar codes, e-business) (Trott 2005, p. 17).

Hauschildt and Salomo (2007, p. 5) describe five dimensions of innovation: the (1) *content-related* dimension refers to the different types of innovation (product, process, system, social etc.); the (2) *intensity* dimension addresses the scope of innovation (e.g. incremental or radical, multidimensional approaches); the (3) *subjective* dimension refers to the question 'new to whom'; the (4) *processual* dimension includes all phases of the innovation process; and the (5) *normative* dimension addresses the question 'is new equal to success'.

Innovation is the main factor for companies to grow economically and to stay competitive. (Jeschke et al. 2011a, p. 14). Importantly, innovation is associated with success, which is reflected mostly in the turnover of the company (Jeschke et al. 2011b, p. 15). Similarly, other studies show that innovative companies improve financial success through increasing their sales (Spath et al. 2006; Schirmer et al. 2012, p. 112). Innovation can be measured with different key performance indicators (KPI). Many of them are related to the factors time and costs. According to Disselkamp (2012, p. 54), the measurement of cost savings is more likely than the measurement of creativity and risk-taking.

Scholars agree that patents are one proxy for measuring innovation, especially technological innovation (Burhan et al. 2017, p. 181). Moreover, patents are a source of information about competitors, because patents are public and companies can measure them against each other (Disselkamp 2012, p. 130). A high number of patents supports a creative and innovative image of the company (Disselkamp 2012, p. 232).

The result of innovation can be high employee satisfaction, which is evaluated through employee surveys (Schirmer et al. 2012, p. 18). High employee satisfaction leads to better services for customers and thus increasing sales (Disselkamp 2012, p. 182). Correspondingly, the collaboration of different departments that lead to more innovation in the company can be measured (Roth 2012, pp. 107-108). The participation in workshops displays the motivation of the employees. Structural innovation is achieved by renewal of working time models (see chapter 2.6.4.2) and work space design (Disselkamp 2012, p. 27). New processes and innovative structures support employees in improving their skills (Disselkamp 2012, p. 182). Expenditure on research and development is a prerequisite for successful innovation, but it is also important that employees have time to work on innovation.

2.6.2 Innovative capability

Innovative capability describes the capability of an organization to introduce innovations into the market place (Gabler Wirtschaftslexikon 2016a). Cohen and Levinthal (1990, p. 128) introduced the term *absorptive capacity* as the ability of a firm to recognize the value of new external information and its application to commercial ends. Neely and Hii (1998, p. 23) define innovative capacity as the potential to generate innovative outputs, where this potential depends on the interrelationships between firm culture, internal processes and the external environment. Lawson and Samson (2001, p. 380) view innovation capacity as an higher-order integration capability, which is the ability to integrate and manage multiple capabilities and resources to successfully stimulate innovation. According to Jeschke (Jeschke et al. 2011a, p. 3), the innovative capability of companies *"[...] comprises the complex interrelationships between the human, organizational and technological requirements to continuously induce innovations."* Wang and Ahmed (2004, p. 304) highlight in their definition of organizational innovativeness, the combination of strategic orientation, innovative behavior and processes. Vahs and Brem (2013, p. 88) emphasize the individual capabilities of the employees, the appropriate organizational structure and innovation process. Innovative capability is a process which connects innovation with the implementation of innovative ideas that contribute to a positive change (Jeschke et al. 2011a, p. 16).

The concept of innovative capability can be approached at three different levels: (1) the *organizational,* (2) the *inter-organizational* and (3) the *macro-economic* level. In the case of organizational innovative capability, the challenges are in areas such as the growing importance of knowledge creation, the successful market implementation of innovations and the use of disruptive inventions, which open new fields and thus open growth opportunities for the business. Essential conditions for ensuring the development of innovation systems are inter- and transdisciplinarity, the break-up of conventional co-operation structures in disciplines, as well as diversity and competition. These factors are equally crucial for inter-organizational innovation systems and the interplay of its elements. Here, the design of cooperation and the integration of innovation partners along the value chain is essential as is how knowledge is prepared and conveyed. Innovation systems extend across schools, universities, research institutes, research-based companies in industry and political-administrative bodies (Dreher et al. 2006, pp. 276-278). On the macro-economic level, the innovative capability is a central lever for securing and expanding the economic position of a nation (Haarich et al. 2011, p. 462).

The innovative capability of an organization is determined by the innovation potential and the innovative climate (Gabler Wirtschaftslexikon 2016a). The innovation potential is the prerequisite and the means to ensure the capability to innovate. The potential is transformed into marketable innovations through the innovation process. Individual and organizational potential is distinguished. The technical potential for innovation as a prerequisite for technical developments and innovations, teamwork, motivation, willingness to cooperate can be attributed to the individual level. At the organizational level, there are aspects such as organizational forms for teamwork, organizational development methods and leadership (Gabler Wirtschaftslexikon 2016b). The innovation climate comprises all positive and negative attitudes, organizational arrangements and measures in the development of innovations. It thus defines the specific conditions or organizational fundamentals for the development of innovations. The internal innovation climate is closely intertwined with the corporate culture and is characterized above all by the leadership style and extent of informal communication (Gabler Wirtschaftslexikon 2016c). The factors influencing the innovation climate have a strong effect on creative power and innovation (Hunter et al. 2007; Hülsheger et al. 2009). The influence of a supporting climate on self-initiative has also been demonstrated (Baer and Frese 2003).

Furthermore, a moderate effect on organizational innovation (Elenkov and Manev 2005) and on individual innovation was proved (Scott and Bruce 1994).

According to Kramer (2011, p. 147), the creation of an innovation-promoting climate can be achieved in the following ways: creation of a creative environment (campus with green areas, lounge area etc.), continuous training of the employees, creative freedom, promotion of cross-divisional cooperation, improvement of internal communication, mentoring and personal support of innovators, admitting mistakes and open feedback culture. The points mentioned show a strong overlap between factors of the innovation climate and innovation culture due to conceptual ambiguity.

Similarly but on a more general level, Steiber (2014, pp. 16-31) describes six fundamental management principles for a successful company's innovation management model for continuous innovation: (1) *dynamic capabilities* (see chapter 2.4.3), (2) *continuously changing organization,* (3) *people-centric approach* by providing settings in which the employees can unleash their creativity, (4) *ambidextrous organization* (see chapter 2.7.2.4), (5) *open organization* (see chapter 2.7.2.6) that networks with its surroundings, and (6) s*ystems approach*.

Cooper and Kleinschmidt (2007) label four areas that lead to successful product innovation: (1) an *innovation and technology strategy* focusing on the right strategic areas, (2) an *environment* (culture, structure, leadership) that promotes innovation (3) an effective *idea-to-launch system,* and (4) *investment resources* allocated via effective portfolio management.

Drivers. Now the question is, how to achieve successful innovation? As briefly mentioned above, many researchers have identified various drivers for the development of a company's innovative capability. The following sections summarize relevant drivers from the perspective of makerspaces (see also Table 3). In general, requirements for corporate innovative capability are procedural, strategic, structural, and cultural aspects at the organizational level as well as abilities and skills (competencies) at the individual level. The complex interplay of technical, human and organizational aspects are crucial for innovative capability (Jeschke et al. 2011a, p. 2). The most important factor to increase the innovative capability of a company is knowledge.

Companies have to be tolerant towards failure and rule violations to a certain extent, because innovations may emerge from untraditional methods and from trying new things. Moreover, it is important that employees are involved in the decision-making process. The company has to be aware, that each employee has potential the company can profit from (Klippert et al. 2009). In order to keep the company and its employees motivated and innovative, modifications to the work organization to boost human capital are needed.

Therefore, companies must introduce innovative ways of working that acknowledge freedom to learn and allow for opportunities to be derived from the worker´s abilities (Trantow et al. 2013).

Knowledge can be passed on faster and easier if unnecessary bureaucratic processes are abolished. Flat hierarchies offer the opportunity to transfer responsibilities to employees and encourage their personal initiative (Bergmann and Daub 2007). The innovation potential of a company can only be fully exploited if the company leadership signals its openness to creativity and the will to invest in innovative ideas. Therefore, the success or failure of innovation projects depends on the importance attributed to it by the management (Hansen et al. 2011). Furthermore, information about customer needs and shifts in the market should be collected constantly to ensure permanent customer proximity. Involving customers directly into the innovation processes of the company may support innovation. Additionally, collaborations with universities, suppliers and external experts is beneficial (Schirmer et al. 2012, p. 77; Trott 2005, p. 9).

Companies must support a process of systematic and life-long competence development for each of their employees. Additionally, long-term knowledge gained from the working experience of older employees that leave the company must be preserved early on in the leaving process and passed on to new employees (see chapter 2.5.5.2). The transfer of knowledge is a key factor for the innovative capability of the company (Lin and Svetlik 2007, pp. 315f). Life-long learning in the working process enables constant knowledge enhancement, knowledge adjustment and the ability to use that knowledge (Hansen et al. 2011).

Supporting social and organizational innovations has a great impact on the productivity, innovative capability and success probability of technical innovations. Social innovations are intentional and purposeful reconfigurations of social practices that are initiated by certain participants in order to solve problems in a better way than by using established practices. Conversely, organizational innovations are focused on structural, processual and human-oriented change or modifications inside the organization (Hansen et al. 2011). Although it is necessary to overcome inefficient routines, it is also important to keep up with routines that proved to be effective in the past. Companies should stick to their core competences and develop a realistic and collective vision and identity (Bergmann and Daub 2007).

From a corporate point of view, diversity management means to integrate, appreciate and uplift the individuality of employees in order to increase corporate success. The exchange of distinct knowledge and abilities could lead to new perspectives and ideas. Even initial differences in opinion can be eventually lead to satisfying results. Diversity also means to redesign work orders to be diverse and varied for the employees (Bergmann and Daub 2007).

Table 3: Relevant innovative capability driver in the perspective of corporate makerspaces[8]

Driver	Description/ Characteristics
Learning-friendly corporate climate	▪ Tolerance towards failure and rule violations to a certain extent ▪ Untraditional methods and trying new things ▪ Open feedback culture ▪ Employees' involvement in decision-making processes ▪ Creative environment
Innovative ways of work organization	▪ Modifications of the work organization ▪ Freedom to learn
Shortening information paths	▪ Abolishment of unnecessary bureaucratic processes ▪ Flat hierarchies ▪ Encouragement of personal initiatives
Integrated Innovation Management	▪ Importance of innovation attributed by the management ▪ Collaboration with universities, suppliers and external experts ▪ Information about customer needs ▪ Involving customers into innovation process
Support of social and organizational innovations	▪ Intentional and purposeful reconfigurations of social practices ▪ Structural, processual and human-oriented changes ▪ Promotion of cross-divisional cooperation ▪ Improving internal communication
Diversity	▪ Integration and appreciation of employees' individuality ▪ Knowledge exchange leading to new perspectives ▪ Exploring contradictions ▪ Redesign of work orders
Continuous competence development	▪ Systematic and life-long competence development process for all employees ▪ Constant knowledge enhancement and adjustment
Development of successful routines	▪ Overcome inefficient routines ▪ Strengthen effective routines ▪ Stick to core competences ▪ Realistic and collective vision and identity

The scientific literature provides a great variety of conceptualizations to describe innovative capability (e.g. Spath et al. 2006, p. 55; Bullinger et al. 2005, p. 35; Wagner et al. 2005, p. 48; Neely et al. 2001, p. 118; Hii and Neely 2000, pp. 4-5; Lawson and Samson 2001, p. 388; Guan and Ma 2003, p. 740; Sammerl 2007, p. 308; Salomo et al. 2008, p. 17; Globocnik 2014, p. 57). For Busch et. al (2011, p. 13), innovative capability comprises three overlapping circles: the *individual,* the *institution,* and the *interaction.* Correspondingly, these elements represent the levers that allow innovative capability (see Figure 6).

[8] Author's illustration based on various sources (see chapter 2.6.2)

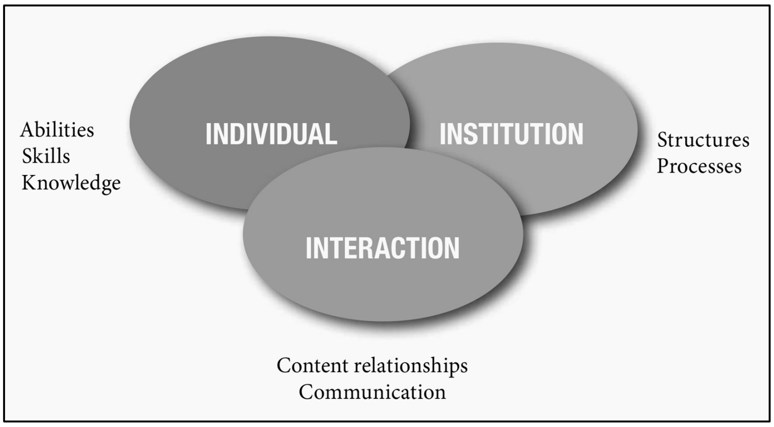

Figure 6: Innovative capability levers[9]

For Spath et al. (2006, p. 59), innovative companies have strong abilities in the areas of innovation culture, innovation process, market, structure and network, product and services, competence and knowledge, technology, strategy and project management (see Figure 7).

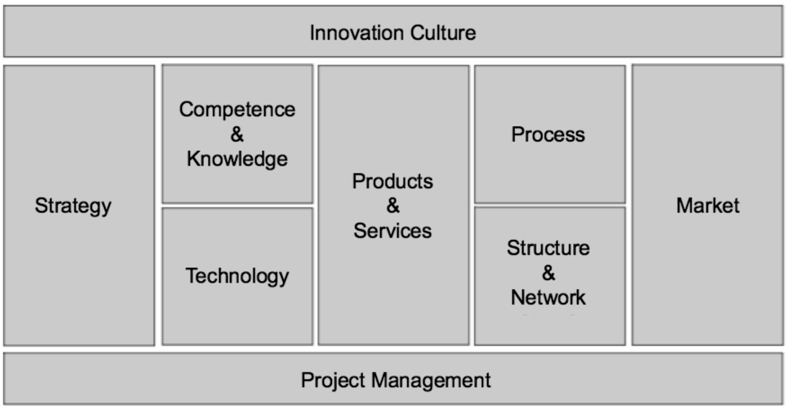

Figure 7: Innovative capability model[10]

The influences on innovative capabilities are very complex, thus the operationalization of innovative capability is a highly difficult task. As of today generally accepted empirical-based comprehensive system of indicators for operationalizing innovative capability does not exist (O´Raghallaigh et al. 2012). Every attempt to measure innovative capabilities depends on the area of application, the topic of the study and the chosen research method. However, all current approaches have in common, that the personal and organizational

[9] Busch, S., Lammert, C., Sparschuh, S. & Hees, F. 2011. *A discussion of innovative capability - Research needs and recommendations for action,* Berlin/Aachen. p. 13.

[10] Translated from Spath, D., Wagner, K., Aslanidis, S., Bannert, M., Rogowski, T., Paukert, M. & Ardilio, A. 2006. Die Innovationsfähigkeit des Unternehmens gezielt steigern. *In:* BULLINGER, H.-J. (ed.) *Fokus Innovation. Kräfte bündeln - Prozesse beschleunigen.* München. p. 59.

characteristics are considered as the key factors for the innovative capability of a company (Trier 2011, pp. 250f). Success factors are context-sensitive and therefore dynamic and distinct for different companies (Spath et al. 2006, p. 66).

Explicitly, the European Management Forum applies the following twelve criteria to assess the innovative capability of companies (Gabler Wirtschaftslexikon 2016a): high growth rate in comparison to companies of the same industry, remarkable social performance, behavior in economic crisis situations, quality of planning mechanisms, external relations, rational use of material resources, organization of production, business dynamics, scope of research and development, and personality of the company's top management.

2.6.3 Process

Innovation is a complex, non-linear and individual process. It is individual in two ways: first, different companies organize the process of innovation differently. Second, innovation is largely influenced by the individuals involved (Trott 2005, p. 12). For this reason, innovation will always be a matter of chance to some degree as the role of individual people is difficult to theorize and generalize.

During economic growth in the 20^{th} century, many companies institutionalized their innovative capabilities in R&D departments with standardized innovation processes. Companies that applied a structured approach were quite successful, but they face three basic problems in the 21^{st} century (Radjou et al. 2012, pp. 6ff):

- *Increased development costs:* In the Western world, product development is becoming extremely expensive and resource consuming. Quite often, the output of R&D does not correlate with the input anymore.
- *Lack of flexibility:* A structured approach for innovation processes seems to be too inflexible for a fast changing environment.
- *Elitist acting:* Western companies make innovation into an elite affair in the belief that the control of access to knowledge means power. Thus, only a few could be innovative and new innovations are strictly protected.

Kumar (2012) highlights four principles for companies to fail less in achieving continuous innovation: (1) *build innovation around experiences,* (2) *think of innovation as a system,* (3) *cultivate a culture of innovation,* and (4) *adopt a disciplined innovation process.* The design process by Kumar (2012, pp. 32-42) consist of seven modules: (1) *sense intent,* (2) *know context,* (3) *know people,* (4) *frame insights,* (5) *explore concepts,* (6) *frame solution* and (7) *realize offerings.* It is important to emphasize two points. First, even though the process is a sequence of several stages, the innovation process can contain iterations, which means the process is non-linear and iterative. Second, the working methods can differ greatly in the different phases of the innovation process (see also Brockhoff 1999; Herstatt and Verworn 2007b; Ehrlenspiel 2009; Cooper and Edgett 2010). For the 'Human-Centered Design' process, ongoing feedback and adaptions to products are essential for a project to become a success (Kelley 2001). Literature provides numerous process models (e.g.Thom 1980; Cooper 2001; Verworn and Herstatt 2002; Herstatt and Verworn 2007a; IDEO 2015).

2.6.4 Culture

Bleicher (1991, p. 731) describes corporate culture as a collection of *soft factors* of the organizational structure. Krulis-Randa (1984, p. 360) defines corporate culture very generally as the entirety of traditional, changeable, time-specific ideals, mindsets and norms that can be experienced and learned by symbols, and that shape the behavior of employees of all levels and therefore the manifestation of a corporation. This description includes aspects that are similar to the culture plane model of Schein (1985) with its artifacts, values and basic assumptions. Schein's model divides the corporate culture into three planes with different levels of abstraction and consciousness. According to Osgood (1951), cultures display two categories: *perceptas* and *conceptas*. Perceptas are empiric, observable, cultural artifacts or specific behavior results such as clothing or architecture. Conceptas are collectively shared values, norms and attitudes that evolved from a social entity in a historic process (Mayrhofer and Meyer 2004, p. 1027).

Corporate culture contributes to the willingness of employees to identify themselves with the company and therefore to an expansion of the integrative effect. According to Tushman and O'Reilly (1996), corporate culture 'glues' the organization together. Corporate culture is related to the employees of the company, meaning that the culture shapes the employee's behavior and vice versa (Kleitsch 2011). Corporate culture develops evolutionarily rather than willingly. Therefore, making changes is a very complex, time and resource consuming process that becomes even more difficult for long-established corporate cultures (von der Oelsnitz 2009, p. 166). Changes often require well-planned and radical adjustments that can include the replacement of company managers or the selective promotion of subcultures, for example, by highlighting the efforts and methods of creativity-focused departments (von der Oelsnitz 2009, p. 167). According to Schein (1985), the corporate management gets a special role in the evolution of the corporate culture, because they have to initiate and promote an orientation towards innovation.

The corporate culture is a set of directly or indirectly perceived work environment properties, which influence the behavior of the employees (Ivancevich et al. 1990). Here, a supportive learning environment and leadership that reinforces learning and promotes a learning culture based on norms, behaviors, rules, processes and tools is essential (Garvin 2003; Garvin et al. 2008).

Organizations represent an autonomous community and develop their own specific culture (Schreyögg 2008, p. 364). Researchers agree that a corporate culture supporting innovation is directly connected to corporate success (see Krulis-Randa 1984; Cooper and Kleinschmidt 1995; Jaworski and Zurlino 2007; Vahs and Schmitt 2010; Turró et al. 2014). Cultural aspects are decisive for shaping the ability and willingness of employees to create and execute innovative ideas (Spath et al. 2006, p. 60). There is no consensus as to the relative importance on the dimensions and content-related aspects of innovation culture. According to Kirner et al. (2007), innovation culture includes the components of the corporate culture that are particularly important for innovative actions, because they can either support or inhibit them.

The more knowledge-based a company is and the more its success depends on knowledge-based products and services, the more impact the quality of its leadership has on the climate of performance and innovation. In the context of innovation, it is of great importance that the corporate management signals its openness to ideas and creativity, the willingness to invest in innovative ideas and that innovations are of high priority in the company (Hansen et al. 2011). Innovation-promoting corporate culture consists of norms, values and basic thinking patterns that support the generation and evolution of innovations. The aim is to create an atmosphere that appeals to the creativity and commitment of employees. Central components of an innovation culture are the creation and promotion of specific patterns of thoughts and habits, that could be described using attributes such as initiative, conducive to change, entrepreneurial, creative and self-responsible (von der Oelsnitz 2009, p. 163), or with enthusiasm, enjoying one's own and other's success, the willingness to try out new things, tolerating failure and freedom (Jaworski and Zurlino 2007, p. 28). Concepts of innovation culture (see Liebeherr 2009, pp. 102ff; Vahs and Schmitt 2010, p. 43; Hauschildt and Salomo 2007, pp. 65ff) are very distinct and difficult to assess.

Basically, an innovation-oriented culture is supported by creating incentive systems, by reasonable selections of personnel and through the role model function of the corporate leadership (Hauschildt and Salomop. 512). A high degree of openness to uncertainty and unpredictability is necessary for a flexible innovation culture (Jeschke et al. 2011a, p. 20). Essentially, a leadership culture handling new ideas openly and in a constructive way promotes the creativity of its employees (Trompeter 2011, p. 55). Here, offering the opportunity to work on the employee's own ideas including individual time management at work as well as freedom concerning rules and decisions are beneficial models (see chapter 2.6.4.2). The existence of innovation promoters at the management or operational level is an essential element of a practiced innovation culture (Thom and Etienne 2000; Spath et al. 2006; Liebeherr 2009; von der Oelsnitz 2009).

Practicing an innovation culture depends (besides leadership aspects) heavily on organizational methods such as the environment and routines. Some of these aspects can only be created by specific organizational methods (e.g. innovation-oriented incentive systems). For example, in terms of incentives, one way is the introduction of rewards for innovative products for employees and projects (Costello and Prohaska 2013, p. 62). Hardt (2012) studied innovation-promoting environments in an innovation culture, based on a four-phase innovation process (problem detection, idea generation, idea valuation and idea implementation). Most remarkable is the high importance of a trusting culture and good working conditions throughout all phases. The frequently mentioned importance of structural freedom is only considered significant in the phase of idea generation (Hardt 2012, p. 41).

2.6.4.1 Failure culture

Wherever humans are involved, mistakes can happen. Under the high pressure to innovate and compete, these mistakes become relevant as a part of the value chain. The more a company positions its innovative power as a central competitive factor, the more important is the support of this power by an adequate failure culture and professional failure management (Kleitsch 2011, p. 13). Failure culture describes the handling of the risks and effects of failure by organizations (Kleitsch 2011, p. 15). Failure cultures cannot be realized independently from their environment. The social systems, in which the organization, the organizational units or its members are embedded, are important. That leads to significantly diverging failure cultures in different countries, for example, U.S., China or Germany (Kleitsch 2011, p. 15).

In companies with high demand for innovation and high-quality standards, little openness towards failure could lead to the creation of knowledge monopolies and to a culture based on fear. If information cannot be transferred seamlessly, the maxim 'knowledge is power' could manifest in the company. The higher the level in the hierarchy that showcases this maxim, the more destructive are the effects due to the multiplication effect (Kleitsch 2011, p. 19). The transfer of knowledge in such cases is connected to the hope of gaining advantage, and therefore information is passed on in a selective or exclusive way. In such environments, the interest in sharing knowledge of failure prevention is very low. The failure of others is seen more as a potential growth of the individual's own power.

A culture of fear impedes learning and therefore has a negative impact on innovative capabilities. If employees must consider bad consequences resulting from failure, a constructive learning process is obstructed and the willingness to take risks is minimalized. An innovator must be willing to take a risk and to make mistakes. The permission to make errors needs to be incorporated into the innovation culture and can become a barrier for success if it is handled wrongly (DeMaria 2013, p. 253). Finding new ways or trying new things is avoided due to the fear of failure. Especially in safety-critical business areas it is necessary to clearly distinguish between real safety areas and areas that allow more freedom. This way, the willingness to take risks and the creativity of employees can be increased by failure-friendly systems (Kleitsch 2011, p. 19). Failure-friendly processes such as test by machines or other employees (e.g. four eyes principle) are capable of supporting innovations, because they enable learning for the company and its employees while minimizing risks (Kleitsch 2011, p. 20).

Most important is a practiced failure culture that should reach from top management to employees including all levels of leadership. The capability of company leaders to openly deal with failure without protecting themselves through accusations or cover-ups is displayed by the handling of their own mistakes in critical situations. Only if company leaders acknowledge their own mistakes has failure culture a chance to evolve and have a positive impact on innovative capabilities (Kleitsch 2011, pp. 20-21).

2.6.4.2 Working time models

Rigid working time models are an obstructive concept, especially when performing creative tasks (Trompeter 2011; Julmi and Scherm 2013). Creativity does not comply with certain times and therefore a high degree of flexibility is necessary to avoid a *must feeling*. Introducing creative breaks can lead to increased motivation (Holtbrügge 2010, pp. 170-171). Flexible working times have a considerable influence on work performance and satisfaction. Flexible working times in combination with task autonomy support revolutionary innovations (Beugelsdijk 2008, p. 821).

In practice, there are different forms of flexible working time models, that can be distinguished by the timeframes and the decision-making scope of the company and employees. The model of trust-based working time offers employees that work outside of collective contracts the flexibility to arrange work according to their preferences without time control (e.g. highly-qualified employees in research and development and project management). This supports self-responsibility and a shift from time-oriented to result-oriented work control (Holtbrügge 2010, p. 175)

Dedicated times for employees to support creativity and innovative capabilities has been around for a long time, especially in companies that are considered as highly innovative (Google, Apple etc.). 3M Corp is a company, that excellently realizes innovation-cultural aspects by their 15 percent rule (since 1948), which allows employees to use that amount of time to work on their personal ideas and projects (see Nonaka and Takeuchi 1995, pp. 153ff; Lawler 2006, pp. 39ff). Another example is provided by an Australian Software company that came up with the so called 'FedEx Day', where the employees get 24 hours free to work on whatever they want. After this time everybody presents what they have achieved to their colleagues. This free time enables employees to broaden their view that is limited by daily business and to avoid getting 'dull'. Employees develop new things, are creative and work on ideas and projects they are intrinsically motivated to. This working model shows positive impact on morality and innovative output (see Baldwin 2012).

Opposing opinions often criticize that it is impossible to switch to creativity mode instantly, especially when at risk of missing deadlines. Such a time model requires ambidextrous capabilities of the individual person and the organization. On the other hand, most companies don't have fixed times to work on innovation projects, but rather let the employees arrange these times flexibly in less busy phases. The effort made in these times is surely valuable for companies, although not directly accountable to innovation output (Marko 2014).

2.6.5 Intrapreneurship

The concept of intrapreneurship is also discussed in literature as corporate entrepreneurship or corporate venturing (Brizek 2003). Pinchot (1985) refers to intrapreneurship as *"[...] employee initiatives in organizations to undertake something new, without being asked to do so".* Pinchot (1985) also defines intrapreneurs as *"[...] dreamers who do. Those who take hands-on responsibility for creating innovation of any kind, within a business."* Often intrapreneurship projects evolve to become separate companies, in this case it is crucial to define assets and capital early on. Real cases show that employees act in a self-responsible manner and in a motivated way to pursue a company's aims. They improvise and invent because the project they face requires cutting-edge technology and a step into unknown territory (Rich and Janos 2013). Numerous companies consider intrapreneurship to be among their top priorities (Hisrich and Kearney 2011).

According to Antoncic and Hisrich (2001), intrapreneurship consists of the following four dimensions: (1) *new business venturing* – pursuing and entering new businesses related to the firm's current products or markets, (2) *innovativeness* – creation of new products, services and technologies, (3) *self-renewal* – strategy reformulation, reorganization and organizational change, and (4) *pro-activeness* – top management orientation in pursuing enhanced competitiveness, initiative and risk taking.

Intrapreneurship is an organizational process that evolves through the interaction of people at various levels. To support intrapreneurial activities, it must be rewarded, and organizational restrictions need to be removed. According to Menzel et al. (2007), there are five important organizational factors promoting intrapreneurship and facilitating its sustainability: (1) *physical environment* for intrapreneurial action and cooperation; (2) *reduction of organizational hierarchy and bureaucracy*; (3) *top management encouragement* by making human and financial resources available and allocated; (4) *advocates*, who are key stakeholders; and (5) *resources* in terms of people, time and room to maneuver. Intrapreneurship is mainly about facilitating the process and the interaction between individual and organizational level. If a company is keen on facilitating intrapreneurship, the company must have internal regulations on how to distribute internal resources. A full authority commitment should be applied and a free pass to operate under secured salary and job position, because freedom is fundamental for success (Menzel et al. 2007).

2.7 Related work

First, diverse approaches and models for established companies on how to react to the maker movement and makerspace trend are explained. Second, the term corporate makerspace is reviewed and how this concept is understood and used within this thesis. Linkage between concepts of organizational ambidexterity and open innovation are drawn. The subsequent sections discuss makerspaces at a general level in the perspective of third places, learning environments and rapid prototyping.

2.7.1 Organizations and maker movement

The maker movement has grown at a rapid pace and has caught the attention of major players in the tech and corporate worlds. Many companies such as Intel, AutoDesk, Oracle, Ford, NASA, Texas Instruments and 3D Robotics see the maker movement as very important and thus support it. In the words of Intel's CEO Brain Krzanich, *"This is where innovation is occurring."* (Bajarin 2014). Geyer (2015) puts it even more drastically: *“The next great hardware products won’t be born within the walls of large, traditional corporations, but in garages, makerspaces, and hardware incubators.“*

Bhatia (2014) notes, if companies want to stay in business they can’t resist the maker movement trend and need to explore ways to cope with the new generation of DIY creators. Bhatia (2014) depicts three ways how established companies can take part in the maker movement trend:

- *Hosting maker events:* Companies including Autodesk, GE, Intel, and even the U.S. government have hosted maker events (e.g. hackathons) and provided workspaces and tools that allow makers to tinker.
- *Investing in maker products:* One of the main reasons to hold these events is that the big companies, as well as venture capitalists, can get the scoop on investing in promising new ideas and products (e.g. Microsoft, Dell, Google).
- *Adopting new methods:* One of the technologies enabling the maker movement is 3D printing. With 3D printers becoming more affordable and available, anyone can design and create new products. Large companies also started to explore the possibility of using these methods, e.g. GE uses 3D printing techniques to build a new type of fuel nozzle. Instead of assembling the nozzles from 20 different parts, GE creates the units in one piece (Catts 2013).

2.7.2 Organizations and makerspaces

While some companies have professional prototyping factories, only a few companies are engaged with open and creative makerspaces. Based on Eychenne (2013), three basic models exist: *corporate, cooperative* and *external* makerspace. The following sections describe the most relevant aspects of the three models.

2.7.2.1 Corporate makerspace

In organizations, the exploration of topics and ideas is usually restricted by the organizational innovation process to a few individuals in the design and R&D departments. Now, a company can develop its own corporate makerspace with the focus on providing a creative space primarily for its own employees. Other participants such as partners, suppliers, researchers, and customers can be invited, but only in certain contexts and for specific purposes. Lo (2016) defines the objectives of a corporate makerspace as to *“[…] promote the use of all resources and human and technological skills of the organization and beyond, to stimulate exploration, creativity and innovation.“* Here, a corporate makerspace constitutes a kind of incubator to support employees with ideas to realize their projects.

An advantage of this model is that the company maintains the control over ideas and projects, but on the other hand, by not opening the space to others, lots of ideas from outside are ignored. The main success factor for this model is the capability to attract diverse people from different business units inside the company to participate in projects and to give them a real chance to develop these projects – including the possibility of failure. Then, a community of regular users may develop, consisting of people who consider the makerspace as a place of personal expression, motivation, creativity, and professional exchange. (Eychenne 2013)

One of the first companies that created a makerspace inside the firm was the French car manufacturer Renault with the *Creative People Lab* in 2011 (Lo 2016). Renault's intention was to change the corporate culture to a more agile and fun way of working and to introduce a try and learn attitude. The makerspace should create innovative dynamics between the employees, take them out of their comfort zone and put them in real-life situations. In general, the makerspace is intented to support the way to become a learning company. The makerspace offers the opportunity to boost innovations within the company (Bry 2014). Other examples are Dassault Systems, Seb, Safran Snecma, Schneider or Saint Gobain (Eychenne 2013). Today, more and more large organizations are getting interested in the makerspace concept and are trying to establish a makerspace within their organizational structure.

2.7.2.2 Cooperative makerspace

This model is semi-open, often created and operated by several partners in cooperation, for example, companies from a specific industrial sector. From the perspective of a company, a space of this kind promotes the interaction with its ecosystem and the collaboration with research institutions, startups or companies from other sectors. Likewise, design projects with contractors are important. Each of the participants activates its own ecosystem and as a result the makerspace creates rich interactions and unexpected results. (Eychenne 2013)

2.7.2.3 External makerspace

This model focuses on the collaboration of internal research and development, design and production with an existing makerspace nearby, rather than developing one's own lab. The collaboration can take two distinct forms. First, the establishment of a partnership between the company and the external space. In this case, the aim of a company is to experiment with other forms of collaboration by meeting makers from the existing community. For example, a company contributes its experience and expertise to interesting projects and in return, it can rely on the community to seek answers to difficult questions and to explore new ideas together. Besides, a company may detect talent within the community. (Eychenne 2013)

Another possibility is to offer selected employees time to develop their projects at an external makerspace such as the example of the Ford Motor Company shows. In 2002, Ford invested $ 750,000 into a partnership with TechShop in Detroit to offer its employees a free three-month membership if they invent something that the company ends up patenting (Ford's Employee Patent Incentive Program). Ford employees can work either on projects related to work or personal interests. Those who create patentable projects for the automotive industry get a share of incomes generated from the patent. The Ford Motor Company reported a 30 percent increase in patent registrations within a single year. (Flaherty 2012)

Another example is BMW, which has established a makerspace in cooperation with the Technical University of Munich. The makerspace is part of *UnternehmerTUM*, a center for innovation and business creation including a hardware incubator. UnternehmerTUM offers digital production machinery for prototyping or small batch production in the makerspace, but also supports potential founders and entrepreneurs methodologically and financially from the idea to market and beyond. (UnternehmerTUM 2017)

External makerspaces are also accessible to company-externals, and precisely this openness makes such facilities special. Due to the interactions of different disciplines and the exchange between diverse users, new knowledge is generated in a more effective and efficient way. (Eychenne 2013)

2.7.2.4 *Organizational ambidexterity*

The interest in the parallel development of incremental and radical innovations has become more important in management science during the last decades (Burgelman 1991; Tushman and O'Reilly III 1996; Danneels 2002; Andriopoulos and Lewis 2009). In this context, incremental innovations are small developments or adaptations to existing products, services and business concepts with a lower degree of novelty. In contrast, radical innovations are fundamental innovations that lead to a transition from existing to completely new products, services and concepts (Raisch and Birkinshaw 2008, p. 378).

Tushman and Smith (2002) added the aspects of customer needs. They state that incremental innovations satisfy existing customer needs and are therefore exploitative; and radical innovations address new emerging needs and are therefore exploratory (see also Danneels 2002; Benner and Tushman 2003; He and Wong 2004; Smith and Tushman 2005; Jansen et al. 2006). Another distinction between incremental and radical innovations can be made regarding *technological trajectories.* According to Benner and

Tushman (2002, p. 679), exploitative innovations make use of existing, while exploratory innovation includes changing to a different technological trajectory (s-curves).

The development of new, different approaches and capabilities is hampered by the continuation of successful, but potentially sub-optimal practices (Leonard-Barton 1992). Companies fall into a *competency trap* (Levitt and March 1988). There is empirical evidence for both effects: on the one hand, for the displacement of exploration by exploitation (Leonard-Barton 1992; Benner and Tushman 2003), but also for the direct competition and displacement of existing (exploitation) by new products (exploration) (Tripsas and Gavetti 2000). Therefore, many studies focus on solution approaches, factors and organizational dimensions that can help to overcome the tension in organizations that are trying to operate both types of innovation (Raisch and Birkinshaw 2008, p. 378). To ensure the organization's competitiveness, it is important to develop products based on current and future customer requirements. The mastery of both types of innovation is seen as the basis for the development of dynamic capabilities (Ancona et al. 2001; Wollersheim 2010; Güttel and Konlechner 2007).

From the innovation perspective, ambidexterity can be described as the *"[...] ability to simultaneously pursue both incremental and discontinuous innovation"* (Tushman and O'Reilly III 1996, p. 24). Organizational ambidexterity is the concept which explains the challenge for any organization of balancing exploitation and exploration activities to realize long-term sustainability (Benner and Tushman 2003; Andriopoulos and Lewis 2009; He and Wong 2004; March 1991). For March (1991), exploration *"[...] includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery, innovation."* Exploitation *"[...] includes such things as refinement, choice, production, efficiency, selection, implementation, execution."* (March 1991). To maintain competitive advantage, organizations are expected to develop incremental innovations as well as disruptive innovations by reconciling exploitation and exploration activities. Organizational ambidexterity describes this tension between short-term development deadlines and advanced research activities.

Ambidexterity is classified according to various organizational designs: *structural, contextual*, *sequential* and *network* ambidexterity. Structural ambidexterity is the basic type of organizational ambidexterity (Duncan 1976; Tushman and O'Reilly III 1996). This strategy relates to a top-down approach, where the top management decides and passes down the social dynamics to the employees. Structural ambidexterity has a dual logic which separates exploitation and exploration into two distinct and exclusive structures. Exploitation dedicated units are characterized by a hierarchical coordination and a high degree of formalization (Burns and Stalker 1961). Traditionally, most of the workforce is allocated to these units (Benner and Tushman 2003). In contrast, the exploration dedicated units mostly are considered as less important in the organization (Burns and Stalker 1961). Here, a more flexible business logic with wider goals and processes are necessary (Benner and Tushman 2003). Zimmermann et al. (2015, p. 1122) recognized that *"[...] change in organizations does not just happen through a top-down process"*.

Contextual ambidexterity, as the second type of ambidexterity, is defined as *"[...] the behavioral capacity to simultaneously demonstrate alignment and adaptability across an entire business unit."* (Gibson and Birkinshaw 2004, p. 209). Alignment refers to exploitation activities and adaptability refers to exploration activities. In contrast to the first type, this strategy is more a bottom-up phenomenon where individuals implement strategic activities autonomously (Burgelman 1983). In social science, such a dynamic is called methodological individualism (Schumpeter 1909; Weber 1968), which argues that social phenomena are the result of individual actions. The ability to conduct both exploitation and exploration activities is an individual capacity, which some authors describe as individual ambidexterity (Bonesso et al. 2014; Gupta et al. 2006; Mom et al. 2009; Rogan and Mors 2014). That means, employees can undertake, exploitation activities while, at the same time proactively engage in exploration activities. Here, the decision for balancing between exploitation and exploration is made at the individual employee level and not at the top management level. Particularly, managers in intermediate positions between employees and top management can encourage and support the ambidextrous behavior of employees through their actions and decisions (Gibson and Birkinshaw 2004).

An important role is played by the organizational context, which is characterized by four attributes of the members of an organization (Gibson and Birkinshaw 2004, p. 213): (1) *discipline* – meet expectations, (2) s*tretch* – strive for ambitious objectives, (3) *support* – lend assistance, and (4) *trust* – rely on commitments.

According to Lo (2016), a corporate makerspace as a kind of quasi-structure can support the development of contextual ambidexterity and consequently lead to continuous and sustainable innovation. Basically, quasi-structures (also called semi-structures) are management tools which are suitable for solving the internal tension between exploitation and exploration by encouraging employees to engage in ambidextrous behavior (Jelinek and Schoonhoven 1990; Brown and Eisenhardt 1997). Thus, employees must be able *"[...] to make their own judgments as how to best divide their time between the conflicting demands for alignment and adaptability."* (Gibson and Birkinshaw 2004, p. 211). In most cases, the innovation process focuses on exploitation routines, but there is evidence that employees can develop autonomous strategic initiatives that can generate breakthrough innovations (Burgelman 1983). These ambidextrous employees are referred to as intrapreneurs (see chapter 2.6.5) (Nielsen et al. 1985). Employees use the corporate makerspace to develop their ambidextrous behavior.

March (1991) initiated the discussion about the connection between exploitation and exploration with learning activities. The views are divided into two groups. First, the group that sees exploitation as a pure application of existing knowledge and ascribes all learning activities to exploration (Rosenkopf and Nerkar 2001; Vermeulen and Barkema 2001; Danneels 2002). Second, those authors who are more concerned with the learning type and learning level than with the presence or absence of learning activities (Benner and Tushman 2003; Gupta et al. 2006; Baum et al. 2000; He and Wong 2004). Schulze (2009, p. 22) provides an overview of studies and their assignment to the groups mentioned. Gupta et. al (2006) argue that both exploitation and exploration generate new knowledge. Baum et. al (2000, p. 768) refer to exploitation as the learning gained via local search, experiential refinement, and selection and reuse of existing routines, whereas exploration refers to learning gained through processes of concerted variation, planned experimentation and play. Today, organizations require both approaches, exploration of new as well as exploitation of existing knowledge (March 1991; Eisenhardt et al. 2010).

2.7.2.5 Parallel structure

In addition, Lo (2016) argues that corporate makerspace is a *parallel structure* (see Figure 8), which allows employees to move back and forth between formal primary structures (designed for routine tasks and to ensure efficient operations) and supplementary network structures that are flexible enough to support innovative activities (Raisch 2008, p. 3).

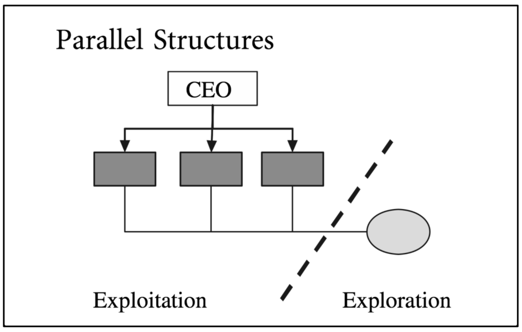

Figure 8: Corporate makerspace as parallel structure[11]

[11] Lo, A. 2016. The development of contextual ambidexterity through a quasi- structure: exploratory case study of Renault's corporate Fab Lab. *32nd EGOS Colloquium 2016 – Organizing in the Shadow of Power.* p. 12.

2.7.2.6 Open innovation

The concept of open innovation (OI) has drawn considerable interest from both, management researchers and practitioners and is considered as highly important for companies (Chiaroni et al. 2010). Chesbrough (2006, p. 1) defines open innovation as *"[…] the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation."* Chesbrough (2006, pp. 36-38) states that within an open innovation model, a company commercializes both its own ideas as well as innovations from other firms and seeks ways to bring ideas outside of its current businesses to the market. The boundary between a company's R&D department and the surrounding environment is more porous, thus enabling innovation to move easily between the two areas.

Open innovation is categorized as either inbound practices (external ideas and technologies flows inside the firm) or outbound practices (internal ideas and assets flows outside the firm). Moreover, the various practices (inbound and outbound) are distinguished in pecuniary incentives (financial rewards) and non-pecuniary incentives with no direct financial compensation (Chesbrough and Brunswicker 2013, p. 9). Figure 9 displays various open innovation practices according to the mentioned classification above.

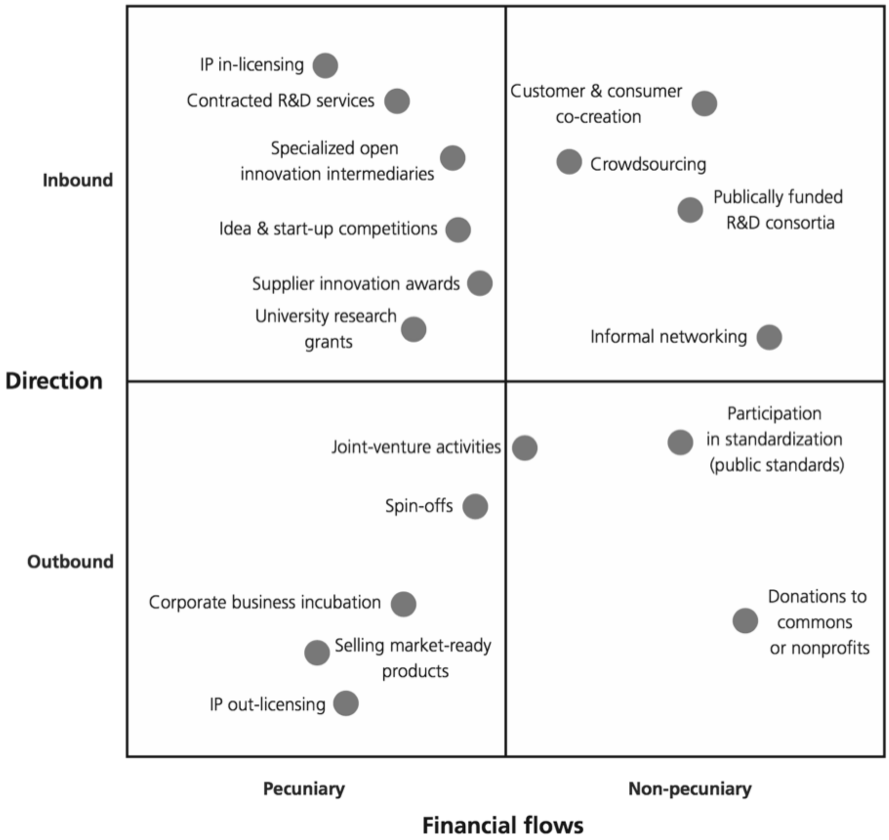

Figure 9: Modes of open innovation[12]

According to a study of Chesbrough and Brunswicker (2013), inbound practices (e.g. customer and consumer co-creation) are more commonly practiced than outbound practices (e.g. joint ventures). The most important source for innovations are the internal employees of the companies. Predominantly, large firms engage in open innovation to establish new partnerships and to explore new technological trends (which can be done in makerspaces). However, the study also reveals that the biggest challenges in managing open innovation is the change process from closed to open innovation.

During recent years, more and more companies have set up their own labs within their companies, thus gaining external knowledge into their organizations (Schmidt 2014, p. 9). For example, companies implement corporate accelerator programs to use startups as an external source to close innovation gaps, solve business challenges, expand to new markets, rejuvenate corporate culture and attract and retain talent (Kohler 2016, pp. 347-351). Other studies have investigated incubators and pre-incubators (Barbero et al. 2012; Carayannis and Von Zedtwitz 2005; Gassmann and Becker 2006). There are a great number of similarities between incubators and makerspaces in terms of their

[12] Chesbrough, H. & Brunswicker, S. 2013. Managing open innovation in large firms. Fraunhofer. p. 10.

administrative structure and type. Incubators offer work areas, infrastructure and services, whilst makerspaces can also provide support during the idea generation phase and realization in terms of workshops over a shorter but more intense period of time (Lahr 2013, p. 139).

If the main attributes of corporate makerspaces are openness, sharing and collaboration, these spaces can be seen as a specific practice dedicated to open innovation within the company's boundaries to invite customers, competitors, collaborators, and consumers to participate in projects within the space. Allowing contact between the organization, entrepreneurs and others from the outside, leads to exchanging expertise and the creation of something new for all participants. Looking beyond the boundaries of the organization by involving interested individuals from the outside increases the diversity of skills within a project supported by the corporate makerspace.

Innovation labs offer certain benefits such as acceleration of innovation speed, generation of fresh ideas, enhancing risk-taking ability, attracting talent, driving employee engagement and building a culture of innovation (Solis et al. 2015). But, most innovation labs at big companies fail (Howard 2017). To be successful, the main important aspects are the focus on right people, commercial intent of the projects, separation of innovation teams in terms of responsibilities, collaboration with external parties and customer insights. Furthermore, the creation of an innovation lab can only be one part of a general shift towards innovation orientation (Howard 2017).

2.7.3 Makerspaces as third places

The term 'third place' was firstly introduced by the American sociologist Oldenburg (Oldenburg and Brissett 1982; Oldenburg 1989). From Oldenburg's (1982) point of view, the industrialized American society of the 1980's was heavily focused on two places which were supposed to be crucial to society and development: the home – *first place* – and the workplace or job environment where people served a certain purpose – *second place*. In this environment, similar-minded or similar-specialized people are usually brought together. Oldenburg (1982) considered this as a root cause for a qualitative decline in society, because people didn't want to invest their energy and time in matters that were not related to their homes or their jobs at all. According to them, society was subject to a very small and predictable world of boredom, where social status and personal problems dominated living, and the unity between people in the sense of belonging decreased, and where individuality was soon subordinated.

To resolve the problem and to have a stable community, Oldenburg (1982) recognized the necessity of introducing a third component – *third place*, which complemented the two other places, but was clearly distinct from the others. This place has democratic, very colorful and playful characteristics. It should be a place, that offers pure sociability to the people that come to visit, and would become an open space for novelty, diversity and entertainment.

Oldenburg (1999) articulated eight main traits that are supposed to kick off community building (McArthur and White 2016):

- *Neutral ground:* A place outside of the home and workplace.
- *Leveler:* The place is inclusive by nature. There are no ranks or hierarchies allowed – everyone is equal.
- *Conversation:* Communication and dialoguing are essential activities.
- *Accessibility and accommodation:* Everyone is welcome to be there anytime, whenever they have the urge to be in good and soothing company.
- *Regulars:* A third place attracts people in a way that they will visit it on a regular basis. They form an exclusive group and are separated from outsiders. The only criteria to be a regular member is that one should be familiar with people and the environment of the place.
- *Low profile:* In terms of physical appearance, the building should be plain in order to discourage pretensions between individuals.
- *Playful mood:* The attitude of the members shapes the place's culture and atmosphere. It makes it easier for everyone to engage and creates bonding.
- *Home away from home:* Everyone wants to be there.

Regarding to Oldenburg and Brissett (1982), a third place enables and supports creative interaction between all attending individuals and creates new, spontaneous and freewheeling social experiences. Goals and interests are shared. At a third place, people relax, after they were at their second place and where they connect with others, before they come back to their first place.

One notable indicator of whether a third place is appealing or not, is the effect it has on people's time perception. If time just slips by unnoticed, it means that people enjoy what they are doing. Historically seen, this kind of informal meeting place, where people could just leave their daily routine behind, to meet and interact with each other, were already well known in many societies around the world, e.g. in Germany (Gasthaus) or Austria (Viennese Coffee House), but the benefits that they provided were not really perceived at that time (Oldenburg and Brissett 1982).

According to Oldenburg and Brissett (1982), a third place cannot be planned rationally, because rationality interferes with its nature. In the past fifty years, concepts of utilizing public places in a concept of a third place have increasingly been in the focus of architects and space planners (Zamiri and Reza 2016), as social city life was weakened by industrialization and digitalization.

Since the emergence of the Internet and the rise of social media in general, one can distinguish between physical (e.g. coffee shops) and virtual (e.g. Twitter) third places (McArthur and White 2016). A digital third place is established when users create simultaneous opportunities for conversation on a regular basis. Users can be at two places at the same time (e.g. virtual third place and home).

But there are two sides of the coin. Oldenburg, for example, did not mention the negative impacts that such settings could have. It is stated, that the happy gathering places are fragile, thus not necessarily bound to remain stable in its core. Third places host three different forms of conflict scenarios, which are (1) *misuse* of space through the abuse of acceptable norms, (2) *misappropriation* where people from outside disrupt the calm of the space, and the (3) *misalignment* of mainstreaming place, where the participants do not like efforts made by the management to offer mainstream activities in the space. (Goode and Anderson 2015)

Today, makerspaces with their space, tools, and community are critical third places for makers all over the world. Lo (2014) argues that a corporate makerspace can be treated as an organizational tool in the sense of a third place according to Oldenburg (1982; 1989). Therefore, in addition to the function as a space of exchange and non-hierarchical freedom within the company, the corporate makerspace is different from other working communities especially by the originality of the space and its equipment. Although, makerspaces have different member demographics, financial structures, machinery, equipment, and projects, they serve an overarching role in their communities (Litts 2014; Lo 2014).

2.7.4 Makerspaces as learning environments

According to Litts (2014), there are various learning theories that support the spirit of learning through making such as the *constructionism* of Papert (1980) or the *multiliteracies* of the New London Group (1996). Constructionism argues that learning is most effective when people actively make tangible objects (Cakir 2008). Multiliteracies focuses on how people use their created artifacts to communicate meaning to others (The New London Group 1996). Litts (2014) developed an activity-identity-community framework based on the theoretical foundations of constructionism and multiliteracies learning theory to study learning in makerspaces. Figure 10 displays the relationship between maker, makerspace and making where making is separated into the making trajectory (process) and the artifact (product). The maker-artifact relationship draws from constructionism whereas the makerspace-artifact relationship draws from multiliteracies. For both making trajectories, the artifact created becomes the physical evidence of learning (Litts 2014, p. 52).

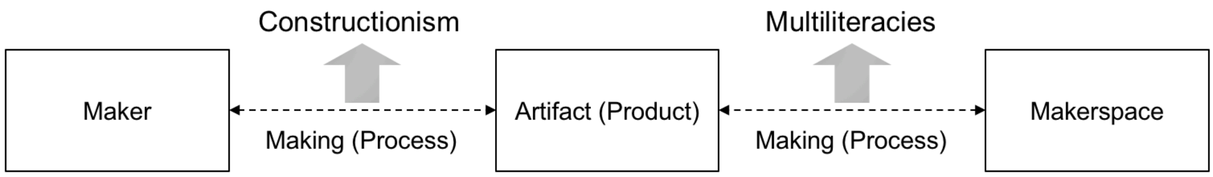

Figure 10: Relationship between maker, makerspace and making based on constructionism and multiliteracies learning theory[13]

The emergence and usage of new technologies have fundamentally enlarged possible learning types (Litts 2014, p. 9). The intersection of physical and digital making with fabrication tools such as 3D printers or laser cutters, construction kits and microcontrollers such as Arduino (Buechley et al. 2008) and accessible programming languages such as Scratch (McManus 2009) have changed the way learning happens.

According to various researchers (Johnson and Thomas 2010; Qi and Buechley 2010), the usage of these new technologies support engineering thinking (e.g. Eisenberg 2008; Peppler and Glosson 2013; Haug 2014; Fields and King 2014; Lee et al. 2014) and make complex problems tangible and transparent. Before the maker movement not everything was possible because the necessary tools were not available to the public (Litts 2014, p. 10).

Makerspaces are new centers for learning, which can be illustrated by their exponential growth at universities, schools and libraries. Makerspaces are places with a culture for learning, originality, and most of all making. Thus far, most scholars have focused on the activity of making and its connection with learning. Recently, some books about making have been published (e.g. Anderson 2012; Dougherty 2012b; Honey and Kanter 2013; Martinez and Stager 2013; Walter-Herrmann and Büching 2014; Dougherty 2016; Sennett 2008), which describe different examples of making activities in various settings. Here, the effectiveness of making is described through stories, which provides only anecdotal evidence. Research projects on learning through making are in progress (Litts 2014).

According to the Makerspace Playbook (2013), five areas need to considered to foster and facilitate learning in a makerspace:

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[13] Author's illustration based on Litts, B.K. 2014. *Making learning: Makerspaces as learning environments.* University of Wisconsin-Madison. p. 52.

- *Learning lab:* The maker community generates a large body of knowledge and provides better ways for learners to discover and access relevant content.
- *Network:* Permanent access to the open and collaborative network of educators and members worldwide allows to share ideas, insights, and best practices.
- *Training and support:* Ongoing feedback, support, and workshops are provided to all stakeholders of a makerspace. The goal is to nurture a vibrant community of practice.
- *Project library:* The project library provides knowledge and information in terms of modular, flexible projects which allow new makers to filter projects based on their own interests, abilities, and the available equipment.
- *Tools:* The integration of technology is made easy by prepackaged kits with standardized set of tools, and advanced kits with expansion modules.

2.7.5 Makerspaces and rapid prototyping

The term rapid prototyping (RP) describes a methodology where a final system is not created immediately, but first one or more prototypes are created. This approach goes back to the field of software engineering. In the case of a classical software development model, the phases are done successively. The end user can only use and evaluate the resulting software product at a very late stage. Subsequent necessary adjustments to user requirements cause considerable changes. In contrast, prototyping makes a first version available at a relatively early stage which allows for changes and improvements (Gabler Wirtschaftslexikon 2017b).

Ranson and Lahn (n.d.) describe rapid prototyping as *"[…] the act of creating a low-fidelity object for the purpose of testing a concept. Through rapid prototyping, a designer is able to quickly test and adapt a design with minimum investment in time and the cost of failure."* Boling and Bichelmeyer (1998) found that rapid prototyping has been used in different approaches such participatory design process (Goodrum 1993), rapid collaborative prototyping (Dorsey 1997), or user-centered design (Sugar and Boling 1995; Corry et al. 1997). What all these approaches have in common is the iteration aspect in terms of a rapid series of tests and revision cycles in combination with user participation until an acceptable and satisfactory version of the product is created (Baek et al. 2008, p. 665). Tessmer and Wedman (1995) as well as Jones and Richey (2000) emphasize the aspect of a quick, incomplete but essentially working version of the final product, which means that a prototype does not have to contain everything in the final version. In contrast, other scholars (Sugar and Boling 1995; Dorsey 1997) define a prototype as tangible ideas for possible solutions, which can have a different degree of fidelity (from low to high). Here, even a very basic conceptual version can be a prototype (Rudd et al. 1996).

Low-fidelity prototypes are designed in a pragmatic and straightforward way, which is of great value in the early phases of product development. Low-fidelity prototypes help to specify and iterate the requirements while working with customers. The prototypes are normally easy and cheap to make, for example, out of paper or storyboard tools, and require little programming skills. Disadvantages of those simple prototypes are missing error detection and the overlooking of important design decisions. High-fidelity prototypes are much more complicated in the making and already include the core functionality of the product's user interface. Those prototypes are sometimes so accurate, that they look and feel like the finalized product, but are more expensive and time-consuming to create than low-fidelity prototypes (Rudd et al. 1996).

The goal of a prototype is (1) the *exploration* of a particular application or problem, (2) the *experimentation* with different solutions, or (3) a successive *development* of several versions of a system (evolutionary prototyping) (Gabler Wirtschaftslexikon 2017b). According to Tripp and Bichelmeyer (1990), the purpose of rapid prototyping is to demonstrate possible solutions quickly by building inexpensive mock-ups to obtain early feedback, which allows designers to respond to user requirements. There are three types of situations where this is particularly true: *"(1) cases that involve complex factors, which can make predictions difficult; (2) cases already examined by conventional methods without satisfactory results; and (3) new situations, which do not offer a lot of experience to draw from."* (Tripp and Bichelmeyer 1990). Rapid prototyping requires the tools for building prototypes efficiently, the methods to design and to evaluate prototypes optimally, and experienced designers (Tripp and Bichelmeyer 1990).

Building prototypes allows a team to rapidly generate an output which contains the essentials of a project. Prototyping can have many forms depending on different situations. Tripp and Bichelmeyer (1990, p. 38) emphasize modularity, which refers to flexibility and the ability to change aspects with minimal time and with low cost. The main benefits in product development when using rapid prototyping are reduced cost and time due to the discovery of errors in the design early on, reduced fabrication costs, increased customer involvement and improved engineering designs as the designs are visualized (Iliescu et al. 2009, p. 124).

Various production techniques are used for rapid prototyping. For example, additive techniques such as additive manufacturing (Fritz and Schulze 2012, p. 106), which creates geometries by adding up elements (mostly in layers) (see Gebhardt 2016, p. 1). 3D printing is a technique of additive manufacturing. The process uses pulverized material that is built up in layers using a binding material (Fritz and Schulze 2012, p. 112). Iliescu (2009, p. 118) distinguish between three main rapid prototyping systems: (1) *liquid-based* RP systems, an initially liquid material is converted into a solid state, e.g. Stereolithography (SLA); (2) *solid-based* RP systems, an initially solid material is transformed into a new shape, e.g. Fused Deposition Modeling (FDM); and (3) *powder-based* RP systems, the initial material is powder, e.g. Selective Laser Sintering (SLS). Prototyping is not done solely by layer-building techniques, but also by using modern high-speed techniques.

According to Schrage (2013), prototypes are perfect tools to communicate the character and intentions of proposals. The most important aspect is to clarify who will benefit from the prototype. Capturing the insights gained from prototypes is critical (e.g. wishes of users). Here, *fail early and often* allows problems to be unraveled and solved early, at a time when going back still is possible at a relatively low cost. Managing a diversified portfolio of prototypes can also be a good strategy. Thus, one can emphasize the interaction between different types of prototypes which represent the same problem from different perspectives. Naturally, the benefits of a prototype should offset the cost of its manufacture and use. A prototype is an invitation to play, it creates a dialogue and encourage stakeholders to explore new possibilities and offer suggestions. Adopting the client's perspective creates a collective consciousness. Organizations must learn from their own prototyping, looking at how they are built and used (Schrage 2013).

Typically, in a traditional system of product development a prototype is the ultimate representation of the ideas of a project. It appears at the end of a chain of abstract ideas. Studies show that prototyping and experimentation is quite effective in the early stages of developing an idea (Thomke 1998; Thomke 2003). But for this to happen, a change in mentality is necessary to understand prototyping as a process step and not only as a representation of the object in high-fidelity.

2.8 Interim conclusion: State of knowledge

The term *makerspace* is understood within this thesis based on the definition of Weinmann (2014, p. 15) as a *"[...] physical location with a community, where members build physical prototypes and objects by using manufacturing tools and machines in a hands-on manner."*

Corporate makerspaces are primarily dedicated to exploratory activities and rapid prototyping which implies organizational improvisation and bricolage (Gershenfeld, 2012). In addition to function as a space of exchange and non-hierarchical freedom within the company, the corporate makerspace is different from other working communities especially in the originality of the space and its use of various machines and tools, which allow a first phase of rapid realization of ideas.

At the intersection of the two main areas of interest – organizations and makerspaces – the concept of organizational learning and in particular the attachment to the resource-based view and the theory of dynamic capabilities provide the theoretical anchoring to scientific theories of the corporate makerspace concept.

Considering the theoretical organizational learning framework from Argote (2011), the implementation of a corporate makerspace may extend the context of an organization (see chapter 2.5), because its members get the possibility to use a new environment and additional tools to gain new experience, create knowledge, share and transfer it within the organization. This environment may provide the supportive context for learning by doing at individual, group as well as organizational levels (see chapter 2.5.6). A corporate makerspace can be treated as an organizational tool in the sense of a third place (see chapter 2.7.3), which is a space of freedom, inspiration and exchange; and which is between the formal and the informal sphere.

A corporate makerspace can have various roles within an established company. Lo (2016) proposes three main roles for a makerspace: (1) *rapid prototyping,* (2) *innovative design* and (3) *openness.* Another study from Neves (2014) introduces five basic strategies on how to establish a maker culture within a company: (1) *hands-on,* (2) *collaboration and openness,* (3) *speed and low cost,* (4) *collaborative environment,* and (5) *prototyping.* Neves (2014) labels this strategy as *Maker Innovation*, which describes the need of institutions to incorporate more methods that support actually *doing.* The study of Neves (2014) argues that using maker practices during the innovation process, leads to reduced development times, more concreteness, deeper connection with users, increased team motivation, new knowledge, cost reduction and agility.

Eychenne (2013) investigated French companies that operate a makerspace. According to Eychenne (2013), joining maker practices and innovation processes in companies means to innovate differently, looking for more ideas from the outside of a company, encouraging intersections, experimenting as soon as possible, providing collaboration and exchange of experiences. Standardized innovation processes in established companies make the occurrence of unconventional ideas quite difficult. A makerspace with its practices can attract transdisciplinary teams motivated by trial and error. Detaching these teams from bureaucratic hurdles gives a chance to develop more open and agile projects in collaborative manner. Independent projects that arise during the process, can be supported, e.g. by the creation of spin-offs. The establishment of a makerspace can help to build a regular user community that considers this environment as a space for personal expression.

2.8.1 Research gap and relevance

Until today, only little academic research has been conducted on makerspaces. Existing studies are focusing mainly on education (Schön et al. 2014) and learning sciences (O´Conell 2014; Litts 2014; Sheridan et al. 2014). Chen (2017) found that research in the area of making comes from computer science, engineering and education science. In scientific literature, mainly public makerspace and makerspaces at schools and universities are discussed (Farritor 2017; Mortara and Parisot 2016; Taylor et al. 2016). The first International Symposium on Academic Makerspaces (ISAM), organized by leading universities in the U.S., was held in November 2016 in Boston (ISAM 2016).

In management literature, there is a lack of studies on the contemporary phenomenon of makerspaces in a corporate context (Lo 2016). Little knowledge is established about the roles, best practices and effects of corporate makerspaces. According to Lo (2016), studies on the role of corporate makerspaces in companies could greatly contribute to the improvement of innovation strategies.

Launching a makerspace inside the corporate boundaries for its employees promises to be a new way to foster the creativity of employees, support organizational learning capabilities and thus increase the innovation output. Meanwhile, some established companies have recognized the inherent benefits of makerspaces and are trying to skim this potential (see chapters 2.7.1 and 2.7.2).

There are a few guidelines available on how to design, establish and operate a makerspace (e.g. Noenning 2014; Weinmann 2014; Maker Media 2013; Honey and Kanter 2013), but not within the corporate context (Lo 2016). Little conceptual work is published for theory building and the testing of corporate makerspaces. An inquiry on *Scopus* with the terms 'maker movement', 'makerspace' and 'FabLab' reveals that scientific work has only just begun and is on the rise (see Figure 11).

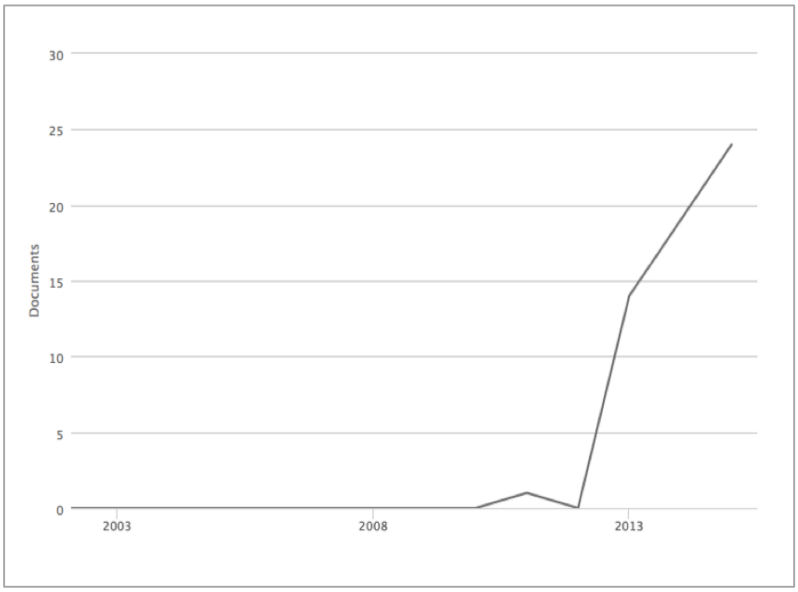

Figure 11: Search result for ‘maker movement’, ‘makerspace’ and ‘FabLab’[14]

Lo (2014) was the first researcher, who addressed the topic of corporate makerspaces in management science. Today, makerspaces have been implemented by some large industrial organizations. Indeed, the corporate makerspace concept is quite new and at an embryonic stage (Lo 2016). However, there are studies on constituent key phenomena and components of all makerspaces, e.g. collective learning (see chapter 2.5.7) or prototyping (see chapter 2.7.5).

2.8.2 Objectives and research questions

This dissertation is one of the first attempts to get empirical insights on corporate makerspaces. Because there is no knowledge on corporate makerspace available, the first objective is to provide information and analysis on existing facilities in established enterprises. The first research question is:

> *RQ1: How are corporate makerspaces designed and operated in practice?*

Based on the theoretical foundation elaborated in the sections above, the objective is to empirically identify and substantiate the different roles of a corporate makerspace for the organizational learning of an established enterprise (see Figure 12).

[14] www.scopus.com. 22.01.2016.

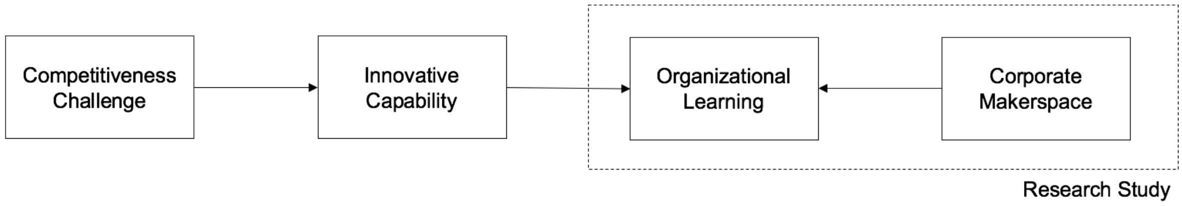

Figure 12: Focus of the 2nd research question[15]

That seems to be valuable, because no studies on how a corporate makerspace supports organizational learning currently exist. Therefore, the second research question is formulated as follows:

RQ2: How can a corporate makerspace support organizational learning in an established enterprise?

Based on the insights of the first and second research question – knowing possible design and operation models and how corporate makerspaces support organizational learning to become more innovative – the question arises of how a company can realize such a concept. Consequently, the third objective is to introduce an implementation procedure for launching a corporate makerspace within an established enterprise as well as relevant aspects that need to be considered during that process. That is of special interest for managers and practitioners. Thus, the third research question arises:

RQ3: How can a corporate makerspace be implemented in an established enterprise?

The results of this thesis contribute to existing knowledge in various areas. First, this thesis provides detailed information on various operation models of corporate makerspaces including best practices and internal requirements. Secondly, the question of why the companies have implemented this concept is answered. Thirdly, the findings show how the concept of corporate makerspaces promotes organizational learning capabilities. Finally, the proposed implementation procedure as well as considerations and challenges during establishment support managers and practitioners when setting up a makerspace within the company's specific context and when defining the appropriate operation model.

[15] Author's illustration

2.9 Chapter summary

In the first decade of the 21st century, the maker movement has emerged as a trend in which people get engaged in developing and making products. People meet in makerspaces to exchange ideas and work in a 'do-it-with-others' manner on projects they are interested in. The emergence of the maker movement is based mainly on the fact that the people have easier and more affordable access to innovation tools such as prototyping machinery, software tools or open designs in online repositories. Thus, modern makers can draw on global networks (physical or virtual), open source software and hardware, international vendors, e-commerce platforms and seed capital funding to gather the necessary knowledge and skills to commercialize their own product ideas.

Makerspaces come in different manifestations and with various designations (a.o. FabLabs, hackerspaces) but show lots of commonalities. For the sake of clarity, the term makerspace is used as an overall designation for all the physical spaces, which provide access to digital manufacturing technologies. Makerspaces as a major commercial trend, have found their way into the academic and corporate world. Literature suggests that in the corporate context these initiatives operate on an open innovation basis by calling upon cross-disciplinary skills, breaking out of the job boundaries and designing, prototyping, and experimenting in the startup spirit. A corporate makerspace as an open third place, looks beyond the boundaries of the organization by involving interested individuals from the outside. Thus, a corporate makerspace aims to increase the diversity of skills and divergence of views to provide a fertile ground for learning by doing.

Regarding organizational learning, corporate makerspaces can provide the supportive context that members of an organization can learn through task performance by using the assets and tools provided in the makerspace. The knowledge created at the individual or group level is made explicit and stored in the prototypes produced. Thus, it becomes easier to share and transfer the generated knowledge within the organization.

Today, organizations need to balance their exploration and exploitation activities (organizational ambidexterity). Consequently, it is necessary to establish an innovation-friendly company culture by offering appropriate working time models for the employees of an organization to develop their ambidextrous behavior. A corporate makerspace can be seen as the organizational tool which offers the supportive environment for employees to work creatively on innovations. Thus, the organizational learning capabilities may be leveraged. A corporate makerspace may support the way to becoming a learning organization. From that perspective, the corporate makerspace may function as the meeting place in the company where learning emerges and boosts the creation of new knowledge. ‘First mover’ companies report a beneficial impact on innovation process and culture.

Corporate makerspaces are still neglected in management science. To fill this gap, this dissertation aims to contribute to existing knowledge by exploring three research questions. First, how are corporate makerspaces designed and operated in practice. Second, how can a corporate makerspace support organizational learning in an established enterprise. Third, how can a corporate makerspace be implemented in an established enterprise. The answers to these questions are definitly fruitful for scholars in various fields as well as managers and practitioners looking for new ways to increase the innovation output of their organizations.

3 Research design and empirical approach

This chapter describes the research design, the empirical approach, and the methods on how to investigate and make a contribution. In general, research studies distinguish between qualitative and quantitative approaches (Töpfer 2012, p. 237). Because there are no detailed scientific empirical studies on corporate makerspaces available, it is appropriate to base the research design on qualitative methodology (Yin 2009). After introducing the multiple case study research methodology and specifying the sample for this study, two conceptual frameworks are derived. These frameworks provide the lens with which the data set is examined. Both frameworks are derived from literature. Furthermore, the sample and how data is gathered and analyzed is described. Finally, the research study is evaluated against quality criteria for qualitative research approaches.

3.1 Multiple case study research

Previous studies are based on single case studies (see Neves 2014; Lo 2016), both within the same company, including only a very superficial description of the corporate makerspace. This dissertation is the first cross-industry study in terms of multiple case study research with the goal of a more concrete and substantive investigation of the phenomenon of makerspaces in companies.

The research design is based on exploratory and descriptive case studies (Yin 2009) in organizations, which operate corporate makerspaces. Case studies represent the methodological approach needed to explore and understand a complex phenomenon. According to Yin (2009, p. 18), case studies are relevant for *"[...] an empirical inquiry about a contemporary phenomenon (e.g. a 'case'), set within its real-world context."*

Leonard-Barton (1990, p. 249) describes a case study as the story of a *"[...] current phenomenon, drawn from multiple sources of evidence. It can include data from direct observation and systematic interviewing as well as from public and private archives. In fact, any fact relevant to the stream of events describing the phenomenon is a potential datum in a case study, since context is important."*

Similarly, for Benbasat et al. (1987, p. 370) a case study *"[...] examines a phenomenon in its natural setting, employing multiple methods of data collection to gather information from one or a few entities (people, groups, or organizations). The boundaries of the phenomenon are not clearly evident at the outset of the research and no experimental control or manipulation is used."* Meredith (1998, p. 442) adds that case studies are *"[...]*

one example of an alternative research paradigm known as interpretivism and uses both quantitative and qualitative methodologies to help understand phenomena."

The case study approach is appropriate for this thesis because the goal is *"[...] to understand as fully as possible the phenomenon being studied."* (Bonoma 1985, p. 203). According to Benbasat et al. (1987), there are several reasons why case study research is a worthwhile research strategy. First, the case method allows the researcher to answer *how* and *why* questions. Second, the researcher can study the phenomenon in a natural setting and thus learn about the state of the art. Third, the aim is to understand the nature and complexity of the processes taking place. Fourth, the case method is an appropriate research approach when few previous studies have been carried out in an area. Additionally, Mintzberg (1979) argues that the richness of theories comes from anecdotal data. It is possible to find all kinds of relationships in the hard data, but only through the use of soft data can that be explained (Mintzberg 1979).

Especially, the following key characteristics of case studies are relevant for this thesis (see Benbasat et al. 1987). The phenomenon is examined in its natural setting, data is collected by multiple means, a few entities are examined, and the complexity of the unit of analysis is studied intensively. Other characteristics of case studies are that they are more suitable for exploration and classification development stages of the knowledge building process. Furthermore, the investigator should have a receptive attitude, no experimental controls or manipulation are involved, the results derived depend heavily on the integrative power of the investigator, and the focus is on a contemporary phenomenon.

3.1.1 Scope

The units of analysis are makerspaces in large-scale established enterprises from distinct industries (operating one or more corporate makerspaces). Buckley and Casson (1985, p. 2) define a multinational enterprise as *"[...] a firm which owns output of goods or services originating in more than one country."* Such enterprises are structured, organized and spread internationally, for example, in terms of the number of foreign subsidiaries (Buckley and Casson 1985). In contrast, SMEs are companies that have less than 250 employees and revenues lower than EUR 50 million or a balance sheet total less than EUR 43 million (see European Commission 2018). Because of possible differences in structures, processes and cultures in SMEs, these entities are out of scope of this dissertation.

Furthermore, this thesis focuses on companies with physical products in their portfolio. Service providers only and software technology companies are neglected. Especially, companies within highly dynamic environments and high pressure to continuously deliver innovation to the market are considered.

3.1.2 Conceptual frameworks

Weinmann (2014, p. 33) investigated various academic makerspaces according to two dimensions – *external* parameters which are user-centered (integration, classes and safety, activities and events, culture); and *internal* parameters which are space-centered (history and future plans, equipment, staff, challenges). Litts (2014, p. 64) develops an activity-identity-community framework to investigate public youth makerspaces. Additionally, Litts (2014) notes that makerspaces are primarily made up of community, space and tools.

Evaluating the relevant literature in the research field of interest shows that makerspaces consist of three fundamental dimensions (see Figure 13). First, the *infrastructure* (space, tools and technology offered to the individuals that they can work on ideas and projects). Second, the *facilitation* (operation of the space and support of the users). And third, the *community* (bunch of individuals as basic resource for the development of innovations). Within these three dimensions, the community aspect seems to be the most important one (Baichtal 2011; Britton 2012).

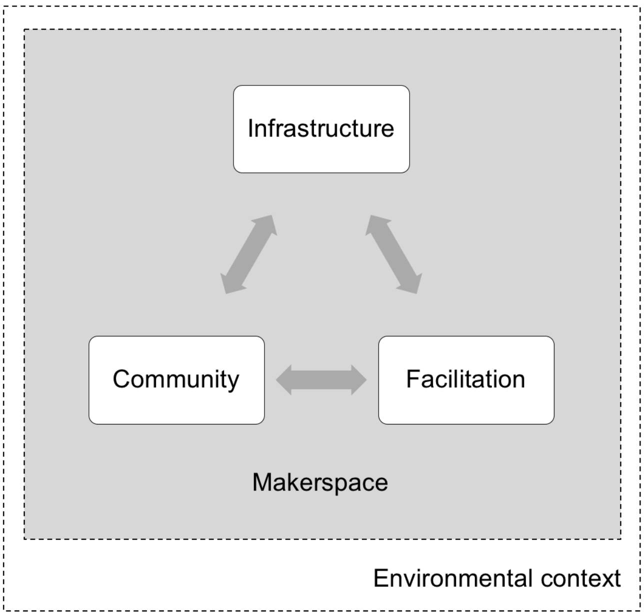

Figure 13: Infrastructure-facilitation-community framework[16]

To answer research question 1, the *infrastructure-facilitation-community* framework is used to structure the examination and comparison of the cases investigated.

[16] Author's illustration

The second conceptual framework is drawn from literature in the area of organizational learning. To answer research question 2, the available data set is evaluated based on the main processes of organizational learning (see Figure 14) – *knowledge creation, retention and transfer* (see chapter 2.5.5).

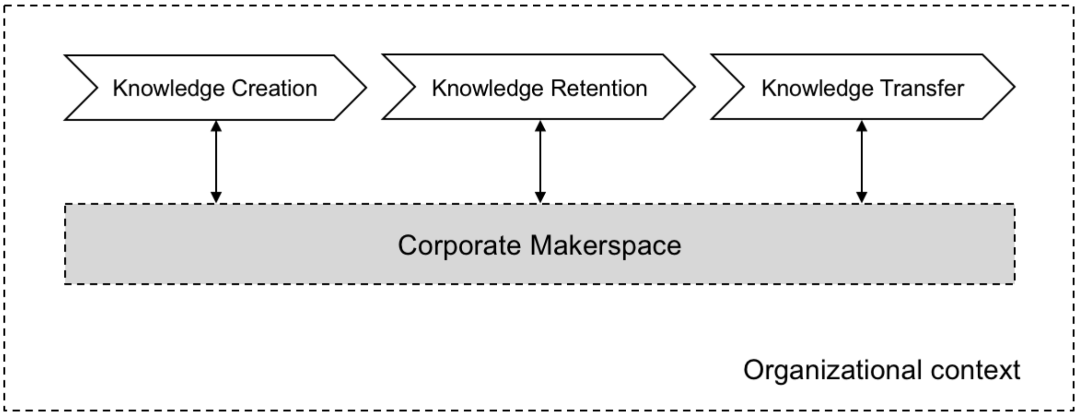

Figure 14: Knowledge creation-retention-transfer framework[17]

To answer research question 3, the available internal data on the implementation process of the corporate makerspace in one of the case studies is analyzed. Together with the findings of the first and second research questions as well as insights from the other two case studies, an implementation procedure for the establishment of a corporate makerspace is developed.

3.1.3 Sample

The sample consists of four corporate makerspaces in three different companies. Some considerations during sampling needed to be taken into account such as the availability and access to data due to personal contacts and proximity (German-speaking countries). The entities had to be established enterprises according to the scope of the study and, in order to get a broad data set, a variety of distinct industries were sampled. At all three companies investigated, the makerspace is located at sites with product design and R&D departments. The following sections provide a short introduction to the three case studies.

3.1.3.1 Company ALPHA

Facts. Company ALPHA offers high-quality sporting goods. The company employs more than 50,000 people worldwide in over 160 countries. The headquarters is in Germany.

[17] Author's illustration

Industry. The international sporting goods market is dominated by only a few companies which have been shifting the production of footwear and apparels mostly to Asia. However, ALPHA wants to bring production back to its sales markets. The demand for high-quality sporting goods is growing steadily, but consumers are sensitive in terms of prices for the products. Likewise, customer loyalty to the company is decreasing, because new competitors are entering the market and putting pressure on established sporting goods manufacturers. In response to increasing customer requirements such as the trend towards lifestyle products and individualization, many of the sporting goods manufacturers expanded their product range.

Makerspace. Since October 2016, ALPHA has been running a corporate makerspace at its headquarters. In addition, two additional makerspaces are set up in the United States. The three makerspaces are located at company product design sites and all together comprise a network. For this dissertation, the first launched makerspace at the headquarters of company ALPHA is described and evaluated.

3.1.3.2 Company BETA

Facts. Company BETA is a technology group that operates in various core business segments. The company was founded in the 19th century and is present nowadays in 190 countries. BETA employs several hundred thousand people worldwide, including about 30,000 engineers and researchers.

Industry. The main part of total revenue is generated in the European region, in the power and gas business segment, which comprises the building of facilities, production of components and supply of services concerning oil and gas. Besides the power and gas segment, BETA is a worldwide leader in the automation business. This includes products, systems and services for manufacturing and process automation. In terms of networking and digitalization, Industry 4.0 is an important part of the industrial business segment. Annually, BETA invests around 4 billion euros in Research and Development. Additionally, BETA is considered as one of the most valuable brands in its home country and as a popular employer for engineers.

Makerspace. Company BETA operates two corporate makerspaces at two locations in Germany. The first makerspace was opened in 2015, the second in 2016. For this study, both sites have been visited.

3.1.3.3 Company GAMMA

Facts. GAMMA is one of the worldwide leading aircraft manufacturers, employing over 100,000 people worldwide. The corporate headquarters is located in Europe.

Industry. The industry for aircraft with a capacity of more than 100 people has existed since around 1950. Back then, there were several manufacturers worldwide, but due to the high development costs the market situation transformed into a duopoly. Entering the market as a new company is close to impossible, since the costs for developing products are massive. Developing innovations and new concepts usually takes several years, manufacturing orders also can take years or even over a decade. The revenues in the aircraft industry have reached all-time highs in the last years, and further growth is expected.

In the aircraft industry, it is generally difficult to experiment with new ideas and concepts, because even prototypes normally have a high level of complexity. Revolutionary innovations are rarely seen in the aircraft industry, because they often require complex and expensive testing. Aircraft manufacturers and their customers like to rely on working concepts. New projects can take several years to generate profit.

Makerspace. In 2013, GAMMA opened its first corporate makerspace. Company GAMMA operates a total of seven makerspaces, mainly in Europe. The makerspace that was visited for this study is located near to a company site at a research center with about 12,500 employees. This makerspace was opened in 2016. A second makerspace is located on the same site, which was opened as the fifth one of its kind in 2014.

3.1.4 Data collection

The case studies conducted follow the replication principle (Eisenhardt 1989; Yin 2009). Several data sources are used for all case studies namely; (1) semi-structured interviews with makerspace staff and employees of the company (different perspectives and involvements to the makerspace), (2) internal documents, (3) publicly available information, (4) informal discussions and exchange with makerspace staff and employees of the company, (5) non-participant observations in the makerspaces, (6) field notes, and (7) photos. Data collection followed the principles of triangulation and data saturation. Table 4 provides an overview on data collection at the three companies.

Table 4: Data collection[18]

	Company ALPHA	Company BETA	Company GAMMA
Industry	Sporting Goods	High-Technology	Aerospace
Makerspaces worldwide	3	2	7
Makerspaces visited	1	2	1
Country of makerspace visited	Germany	Germany	Germany
Opening of makerspace visited	2016	2015 and 2016	2016
Duration of observation	5 days	3 days	3 days
Date	13.-17.02.2017	07.-09.03.2017	14., 15., 17.07.2017
Interviews	8	4	2
Audio material	5 hours	3,5 hours	2 hours
Internal documents	300 pages	30 pages	30 pages
Photos	35	104	40
Publicly available information	Little	Little	Little

At company ALPHA, seven employees at different levels within the company were interviewed in eight interviews. About five hours of recorded interviews were available as audio material for the evaluation. The author was present in the makerspace for five days between 13.02.2017 and 17.02.2017. Lots of informal discussions and exchange with employees took place during these days. At the time of investigation, the corporate makerspace had been in operation for four months.

At company BETA, four interviews with a total of 3,5 hours of recorded audio material are available. The author was present in two makerspaces at different sites of the company (different cities) for three days between 07.03.2017 and 09.03.2017. During these days, the author participated in a design thinking workshop with around 50 people (mainly employees of the company from various departments, but also internal and external consultants and partners) to design the future workplaces in the company. At the time of the interviews and observations, the corporate makerspace had been in operation at one location for two years and at the other location for two months.

At company GAMMA, two interviews took place with two hours of recorded time in total. Additionally, informal discussions with the interns working in the makerspaces took place. During the stay at the makerspaces (three days in July 2017), the author realized that data saturation in the main areas of interest for this study was reached. Only some deviations from the findings of the two previous case studies could be observed. At the time of investigation, the visited makerspace had been in operation for one year.

All formal interviews were conducted face-to face and on-site in the three companies. The interviews followed a pre-established guideline (see Appendix A). Depending on the

[18] Author's illustration

position and responsibilities of the interview partner within the makerspace or the company, relevant questions were selected and discussed. The goal was to obtain detailed insights within the areas of responsibility and the resulting perspectives on the distinct corporate makerspaces. The interview guideline consists of specific questions to get detailed information on certain areas of interest. In addition, there are open questions with the intention to get personal insights and motivations and to learn through the narratives of the interview partner. The interviews were held in English or German language. Table 5 provides an overview on the interviews conducted. All interviews were transcribed.

Table 5: Interviewees[19]

Company	Code	Position	Language
ALPHA	A1	Makerspace Network Manager	English
	A2	Engineer	English
	A3	Product Designer	German
	A4	Administration	German
	A5	Project Manager	German
	A6	Product Designer	English
	A7	Makerspace Network Manager	English
	A8	Makerspace Manager	English
BETA	B1	Makerspace Manager	German
	B2	Student Intern	German
	B3	Engineer	German
	B4	Technology Manager	German
GAMMA	G1	Makerspace Manager	German
	G2	Makerspace Manager	German

3.1.5 Data analysis

The subsequent data analysis and synthesis is based on triangulation technique. Data collection and data analysis followed an iterative loop between empirical evidence and literature statements, which provides a more rigorous collection and analysis of qualitative data (see Corley and Gioia 2004). All information collected is evaluated according to the established research frameworks (infrastructure-facilitation-community, knowledge creation-retention-transfer) and within the scope of the research questions of this study.

Data analysis is based on a heuristic approach by coding and categorization of data with the software tool maxqDA. Analysis started with conceptual coding of data used in-vivo (see Strauss and Corbin 1990), followed by comparing initial data analysis to the

[19] Author's illustration

literature. Based on a recursive approach between the literature and the empirical data, a clear codebook was established until data saturation was reached (see Miles et al. 2014).

Case ALPHA provides the most content for the analysis, because it was possible to stay for five full days in the makerspace for observations, to attend workshops and creativity sessions, to conduct several interviews and to access lots of internal information allowing to grasp details on organization, operation and implementation of the makerspace.

3.1.6 Quality of research study

The classical quality criteria of quantitative research (objectivity, reliability, external validity and internal validity) are inappropriate for qualitative research because of the basic epistemological and methodological assumptions. Thus, new criteria for qualitative research need to be formulated (Kruse 2014, p. 55). Miles et. al (2014) suggest the following criteria to evaluate qualitative studies: conformability instead of objectivity; dependability and auditability instead of reliability; credibility and authenticity instead of internal validity; transferability and fittingness instead of external validity; Yin (2009) recommends considering several tactics when doing case studies to ensure the quality of research designs (e.g. using multiple sources of evidence, having key informants, using replication logic in multiple case studies, using case study protocol, developing case study database). Table 6 displays the application of four quality criteria based on Miles et. al (2014) for this dissertation.

Table 6: Quality of research study[20]

Criteria	Application
Objectivity/ Conformability	▪ Methods and procedures are described explicitly ▪ Multiple sources of evidence are used during data collection ▪ Key informants of companies reviewed draft case study report ▪ The researcher is aware of personal assumptions and biases
Reliability/ Dependability	▪ Replication logic in multiple case studies is used for research design ▪ Same methods and reasoning was applied to all collected data ▪ Case study protocols and a case study database are developed ▪ Debriefing with members of the institute and participants of different colloquiums and conferences took place
Credibility	▪ Descriptions and explanations are context-rich and detailed ▪ Findings make sense and are plausible ▪ Rival explanations are considered
Transferability	▪ Sample characteristics are sufficiently described ▪ Limitations of the study are considered ▪ Findings are connected to prior theory ▪ Other settings where findings may be fruitful are suggested ▪ Findings are transferable to other contexts

3.2 Further contemplation

In 2014, a new research group at the Institute of Innovation and Industrial Management at Graz University of Technology started focusing on makerspaces, including the author himself. In the same year, FabLab Graz was established as the first academic makerspace in Austria and started operation in one small room (36 sqm). FabLab Graz is located at the Campus Inffeldgasse of Graz University of Technology. The makerspace is equipped with laser cutters, high-resolution CNC milling machine, 3D printers of various technologies, 3D scanner and electronic working stations to build functional prototypes. Every Thursday from 2pm to 8pm, FabLab Graz is openly available to everyone. Very soon the initiative became quite popular among the students as well as the university faculty which led to the design and establishment of a new makerspace with around 800 sqm. Furthermore, research papers and conference contributions were published. The author has visited various makerspaces (in addition to the corporate makerspaces of three case studies) in Europe and the U.S.

[20] Author's illustration based on Miles, M.B., Huberman, A.M. & Saldana, J. 2014. *Qualitative data analysis: A method sourcebook,* Los Angeles, CA, Sage Publications.

3.3 Chapter summary

The applied research design of this thesis is of qualitative nature and based on multiple case study research. The data set consists of three case studies with corporate makerspaces in different established enterprises as units of analysis. During data collection, various methods are applied. Data analysis and synthesis are based on two conceptual frameworks (infrastructure-facilitation-community, knowledge creation-retention-transfer) and follow the principle of triangulation. The quality of this dissertation is reflected.

4 Data analysis

This chapter provides the analysis of the three investigated cases in descriptive mode by applying the infrastructure-facilitation-community framework.

4.1 Case ALPHA

4.1.1 Infrastructure

Location. The makerspace is located directly in the headquarters (all business units are present), which is an open building with lots of glass indoors. In addition to the offices, there is a canteen offering fresh food, a cafe, meeting rooms to discuss projects and exchange ideas, and small relaxing rooms. The architecture and design of the building aims to provide the necessary preconditions for an open exchange. The access to the makerspace is on the ground floor and it is very easy to enter for each employee – like coming into to a store in a shopping mall (the glass sliding doors open automatically).

Layout, design and interior. The layout of the makerspace is separated into the following basic areas: workshop and dust room, where the machines are located; creativity area with flipcharts, boards and material such as post-its; workplaces for various activities; material storage; work tables suitable for meetings; and a photo studio offering the opportunity to make professional photos of the finished pieces with modern equipment. For the interior of the makerspace, a dedicated design scheme was developed with special emphasis on the implementation of a creativity-promoting and innovation-friendly environment. The rooms are colorful, the walls are covered with graffiti and the work benches are self-designed by the makerspace staff.

There are four large benches which serve as working areas. It was planned that a maximum of eight employees could work simultaneously. But very soon it was realized that a user needs almost half of the table when working on a project. Since this happens quite often, additional work benches are needed. Sometimes people have to work on the floor because there are not enough free places at the work benches.

Fabrication and technology. The makerspace offers a variety of machines, mainly sewing machines, two 3D printers, laser cutter, thermoforming machine, heating cabinet, spray cabinet and clay oven. During data collection, there were also some machines which had not been used, because the makerspace staff had not received training yet. The most commonly used machine in the makerspace is the laser cutter.

Moreover, a variety of tools are available. The storage concept is structured in three different marked drawers. The necessary tools for the respective application are in the respective drawers. The tools are marked with a colored sticker to show the affiliation to the respective drawer. This immediately shows which tool belongs to which drawer. Because of this structure, it is easier for the user to find the necessary tools and to put them back again in the correct spot. This structure was adopted and implemented in response to an improvement proposal of the makerspace community.

Complementary labs. In addition to the makerspace, there is a sample shop with professional tailors (experience of more than 25 years). Designers can hand over their designs along with their visions, which then get produced as physical samples. Small adaptions on already existing garments are done rather quickly. In contrast to the makerspace, the sample room has stricter procedures, but both facilities work closely together. Furthermore, there is another lab, which deals with projects five to seven years ahead in the future. New concepts are developed as part of research projects. Here, the makerspace offers the possibility to produce prototypes of components for test beds. Within the organizational structure of the company, the corporate makerspace is connected to the global operations department.

4.1.2 Facilitation

Staff and responsibilities. The makerspace staff consists of one makerspace manager and three subordinate employees. Furthermore, there is the makerspace network coordinator and his assistant responsible for all issues related to the makerspace concept. On Mondays at noon the entire makerspace team meets for a jour fixe. In addition, every day at 9 am everyone together has a stand-up meeting, where the staff members briefly (five to ten minutes) explain what they are working on that day. The makerspace manager explains what additional activities or tasks are planned. To track the various tasks of all team members, a software tool is used. But the makerspace team does not want to have an overly detailed and thoroughly structured system, since there should also be time for private projects. There are also teleconferencing sessions every week for cross-site communication and exchange between the makerspace managers of the network and the three makerspaces worldwide.

All staff members have a goal agreement, which is discussed every three months between the makerspace coordinator and the staff members. They discuss if personal targets have been reached, how satisfied the coordinator is with the work done and in which area one could improve. The employee is encouraged to openly express their own opinion on all aspects.

In addition, each individual staff member is responsible for the operation and cleanliness of a particular area and for a certain number of machines with the mission to learn and understand the respective technologies intensively, giving initial training and supporting the users with the operation of the machines. They are also responsible for the maintenance and operational readiness of these machines. Furthermore, they create different samples with the machines to show what is possible with these technologies. The items are then displayed on the *open source wall* with the aim to inspire visitors and users. In addition, each employee must perform dedicated tasks, hold workshops and conduct guided tours. Basically, the makerspace team is very much focused on self-organization.

Guiding principle. The makerspace team works according to their basic principle '*train, inspire and consult'*. Train means that the makerspace team trains the users to handle the entire equipment of the makerspace so that not only the laser cutter or the sewing machines are used for projects. Inspire means to develop a creative atmosphere and show the services offered in the makerspace to inspire users to new ideas. At time of data collection, the makerspace staff was still busy with the achievement of these two aspects train and inspire. In the future, the focus will be on researching new product possibilities and increasing the number of consultations. Then, business units can contribute their own ideas and approach the makerspace team with questions such as how to market a product idea.

Access. Employees can use the makerspace during the opening hours, Monday to Friday between 9 am and 6 pm for professional purposes. It is important for the employees to recognize that prototyping and making are an important part of the design process, therefore open access during the whole work week is ensured. Fridays in the afternoon, there are *casual Fridays*, where people can use all machinery and equipment to work on private projects.

Instructions, safety and training. First, an employee must have a tour with a safety briefing (including introduction to the house rules) to be allowed to use the makerspace as a formal user. There are two official dates every week. The participants of the introduction tour have to sign a waiver to declare that they have completed the safety training. After that, employees get a sticker on their own identity card, so it is easy for the makerspace staff to recognize if a person has already done the safety briefing and has signed the waiver. Then, employees can join three trainings (3D printer, laser cutter, sewing machine), which can be booked online. There is one training offered every day. The training sessions are necessary for the employees to get to know how the machines work and how they must be operated and so that they are allowed to use the machines independently. Noticeably, the trainings are very well attended.

There is an online form for the reservations of machines, which the employees must fill out. This is intended to counter a flood of e-mails and phone calls to the makerspace staff. For the most frequently used machine (laser cutter), there is a list where employees must register each day personally. Because this list is renewed every day, people who want to use the laser cutter have to visit the makerspace beforehand and put their name on the list manually. The laser cutter can only be booked for a maximum of one hour.

Materials. In the makerspace, the staff members must ensure that a sufficient number and variety of materials are always available. The users can take the materials in the makerspace free of charge for their own use. Basically, company ALPHA gets a lot of materials from their suppliers free of charge. It is seen as an investment by the suppliers, because if an innovative new product is created with a certain material, the supplier can receive large orders and may become a long-term contract partner. In addition, the makerspace gets provided surplus material from the individual business units or defective pieces from production. The material is fully financed by the operations department. Since the makerspace has only been in operation for a few months, there are no financial limits for material costs. In the future, however, there is the idea to finance the provision of the materials based on a crowdfunding approach, by charging each business unit a share of the total costs. The team meets once a week to place all the material orders.

Basically, the material used for private projects must be paid by the users themselves. The material and cloth residue in the recycling boxes are still available for free for private purposes. Employees also bring their own material. They can start private projects if it does not interfere with the professional work flow.

4.1.3 Community

User and culture. There is a significant amount of coming and going throughout the day in the makerspace. At the time of observation, the makerspace had only recently been brought into operation, hence many employees were interested in the opportunities the makerspace offers. Due to the high degree of diversity at company ALPHA, employees with different backgrounds, cultures and nationalities meet in the makerspace. This is also noticeable in the corporate culture. Employees are very open and friendly to each other, there is no clothing constraint recognizable, mainly English is spoken.

Also, the makerspace staff is diverse (six staff members from six different countries). The atmosphere is very open and pleasant, music is played, all staff members are very flexible and help where it is needed, everyone takes care of each other. Primarily, designers work in the makerspace, but also employees from other departments visit the makerspace. Interestingly, some employees spend their breaks in the makerspace to simply get inspired, as an alternative to other options such as running or going to the fitness center. Users support each other and are willing to share their experiences and knowledge. For example, there is the possibility for everyone to deposit the individual competencies that they would like to share with others.

Workshops and events. Twice a week, there is a workshop on a specific topic, which can also be booked online. The topics are varied, ranging from design methods to prototyping techniques. If there is sufficient demand for topics requested by the employees, workshops are organized. Importantly, the workshops serve as a platform for networking between employees from different departments. In the future, interesting workshops for external visitors will be developed and expanded to better exploit the creative potential of the makerspace community.

Online. Generally, company ALPHA offers an internal social network platform, where employees can access the makerspace website to get an overview of all trainings offered. It is possible to book the trainings online. At the time of observation, the function of a waiting list had just been integrated, because sometimes registered users canceled quite late. Thus, it became necessary to inform other interested employees that they could participate if someone had canceled the reservation. Furthermore, the internal social network provides the possibility for the employees to inform others about what they have done and experienced. In addition, an idea management software tool existed, where ideas could be submitted. Unfortunately, that was ineffective and thus discontinued. As one of the employees mentioned, it is probably because there was no way to place tangible examples.

4.2 Case BETA

4.2.1 Infrastructure

Location. The two makerspaces are located in one building at two different sites of the company. The first makerspace is on the sixth floor, while the second makerspace is on the ground floor. Basically, both makerspaces are quite hard to reach due to the size of the company site. In addition, access is only possible with a key.

Layout, design and interior. On the first site, the makerspace covers 70 sqm, the room at the second site is about half this size. In the beginning, the makerspace area was supposed to be larger, but had to be switched to a smaller room at short notice. On both sites, the makerspace is one single, flexibly adjustable room without dividing walls. The room is separated into different areas (creativity, 3D printing, electronics, workplaces, materials etc.) and can be modified according to technical developments (e.g. virtual reality was mentioned). The layout of the room was planned by an external agency.

The makerspaces have their own design, which is realized by the color scheme, especially in the room in the second facility. In the future, it is planned to replace the walls with windows at one site, to open up the room to the exterior. The two makerspaces are different from classic office spaces and other laboratories of the company. The walls display keywords (learn, lean, participate, share, cross-function, change, collaboration, support, innovate) that are considered to be of great importance for the activities in the makerspace. Because the makerspace is operated as a laboratory, safety regulations do not allow food or drinks inside. That also means, that no coffee machines are allowed in the makerspace. To its users, the makerspace appears as a kind of meeting room (supporting design-thinking approach) with an integrated workshop.

Fabrication and technology. The makerspace provides various types of 3D printers, laser cutters, drilling machines, CNC machines, and other electrical devices. The machines are available for employees only after attending safety training. If the makerspace does not provide the required equipment to build a specific prototype, or for larger prototypes, external contract manufacturing is still necessary. All common CAD programs and other software tools (MS Office, Adobe, Skype, WebEx etc.) that are used in the company are available on on-site PCs. In order to connect with other sites, there is an iPad and a webcam available.

Complementary labs. The makerspace can be used as a meeting room and for after-work networking, although it is rarely used for that. The room has enough space for meetings with 20 to 25 attendants. For bigger meetings, other co-creation spaces are mostly used. Usually, many meetings take place in the *meet&talk* area in the office space. In addition to the makerspace, company BETA operates Design Thinking spaces, a Lean Factory space and various other innovation facilities worldwide. For example, the company pushes the founding of spin-offs. The goal is to support employees with new ideas as well as possible by enabling them to work individually or as a team on their own ideas (e.g. development of prototypes) for a specific period of time. In this process, the company tries to eliminate many formalities, but there are still many problems in the execution.

4.2.2 Facilitation

Staff and responsibilities. Basically, one person is responsible for the whole operation and further growth of the makerspace project. This person has a design background and supports the users of the makerspace in the area of idea development. Principally, users who need support in the makerspace can reach out to a laboratory worker (student intern). The student intern works in the second makerspace for 20 hours a week and mainly supports users with manufacturing their prototypes. The student intern is responsible for maintaining the machines and for keeping order and cleanliness in the makerspace.

Guiding principle. New users are supported when starting to work in the makerspace (mainly during operation of the machines). However, the users are expected to learn fast and soon start to work independently on their projects using the opportunities given. If users would like to attend (or offer) workshops, tutorials or trainings, the makerspace manager arranges these events.

Access. All employees of the company have access to the makerspace. On the first site, there are no staff present, so everyone who wants to use the space has to get the key in the administration office. Company BETA is still searching for an easy and flexible way for users to access the makerspace, probably using coded keys. There are no fixed opening hours. Access is regulated by the operating times at the company site (Monday to Friday, 6 am to 8 pm). After launch, the makerspace opened three times a week from 6 pm to 8 am, but with staff being present. On weekends, it is not possible to enter the space.

Instructions, safety and trainings. All users must attend safety training before being allowed to work in the makerspace independently. This training usually takes place once a month, but also in case of urgent need. Signing in for the training is done by e-mail, but the development of an online booking system for training and workshops is in progress. Safety is an important issue. All visitors to the makerspace are instructed to keep the workplaces clean and tidy and stick to the safety regulations to minimize the risk of injuries.

Materials. Standard materials are provided for free in the makerspace. There is no clearly defined limit for each user, but the material usage should not be exaggerated. If there are requests for explicit materials that are not on stock, the makerspace manager has the permission to purchase. Besides, many users bring the materials by themselves.

4.2.3 Community

User and culture. The first implemented makerspace accommodates mainly a self-organized community that consists of a group of 15 to 20 young engineers from R&D departments. The users mutually help as well as control each other, and the community points out defective machines. Most employees visit the makerspace after work. Sometimes, project groups and local networks hold their meetings in the makerspace. A future goal is to establish the makerspace as a place for cross-linking the company-wide community. An idea was to open the makerspace for students, but the current internal processes do not allow for that. Collaborations with externals are intended in the future (e.g. workshops with universities).

However, from time to time the makerspace stays completely empty during the whole day. On average, four to five individuals use the makerspace per day, without any peak hours. Only before Easter or Christmas do employees use the makerspace more frequently. The makerspace is primarily used for professional projects, but employees are also allowed to experiment for private purposes, even during their working hours. Employees can retain their ideas in the makerspace by using post-its, whiteboards or flip charts. A notebook is used to document projects where users can write their ideas and projects on a voluntary basis.

Workshops and events. After launching the makerspace, the initiators organized workshops, many of them originating from ideas of makerspace users. Workshops take place roughly every one and a half months. The topics of the workshops are widely-spread, for example, there have been workshops dealing with 3D printing, Arduinos, home automation, sensors and actuators, Internet-of-Things, laser cutting or soldering.

Online. There is a wiki-page in the internal social network (ISN) that provides information about the opportunities in the makerspace, including available machines and their instruction manuals. The ISN is the main communication platform and serves as a cross-link between different sites. The network is intended to connect people, enables global discussions about projects and gives users the opportunity to ask for help with specific problems. New ideas are presented, so employees get feedback on their ideas to develop these further. Due to data protection, the ISN is preferred over external networks, but the usage of external platforms for knowledge acquisition is allowed.

4.3 Case GAMMA

4.3.1 Infrastructure

Location. The makerspace examined at company GAMMA is located off-site at a research center where other companies are also situated. Altogether about 400 employees work at the research center. The makerspace is part of a large hall area (about one third of the size is dedicated to the makerspace). Access is secured by electronic access restriction.

Layout, design and interior. The makerspace visited consists of a workshop, a laboratory with workplaces, a creativity area, an event room, a meeting area and a small kitchen. The factory hall for working on projects covers about 300 sqm. The design and interior is company-standard, except for self-made furniture out of pallets, where the daily meetings of the staff take place.

Fabrication and technology. The makerspace offers a variety of machines: different types of 3D printers (FDM and Stereolithography), laser cutters, a portal milling machine and a foam cutting machine. At the time of data collection, it was planned to buy a CNC milling machine. Bigger machines that are not frequently needed in the makerspace are accessible in the company's general workshop area.

Complementary labs. At the company site next to the research center, there is a second makerspace, which is one big room separated into smaller areas. This makerspace is more production-oriented. Since the new makerspace opened in 2016, the older one became less frequented and has been turned into a production workshop instead of a creative workplace. In contrast, the newer makerspace hosts nearly all innovative projects. GAMMA offers a variety of spaces and labs for its employees to work on projects. Furthermore, there is a space with focus on collaboration with startups (like a corporate accelerator), and a virtual space for online exchange and joint development of ideas with colleagues from all sites worldwide.

4.3.2 Facilitation

Staff and responsibilities. Three people are employed full-time in the makerspace, having a common supervisor. Their tasks include the operation and organization of the makerspace, as well as the allocation of project tasks. Every morning a meeting takes place (15 minutes at 10 am). In this meeting, the three makerspace managers and all other members (18 student interns/ trainees worked in the makerspace at the time of data collection) meet at the Kanban board. This board displays all projects and tasks and is divided into different areas, to quickly see which tasks are in preparation, in progress or already finished. All together they discuss the most relevant issues and try to make progress as fast as possible. Tasks on hold are further discussed to find reasons and possible solutions so that these can make progress again. In the past, there was a weekly agile breakfast, in which a Scrum coach joined the discussions of the makerspace team about the projects.

The daily business of the makerspace managers includes strategic, operational, administrative and project-specific tasks. Examples for administrative tasks are creating processes, distributing project tasks, leading the team of student interns or developing the makerspace further. The work of the makerspace managers is very versatile and challenging because the team consists of many different characters and because the projects are very diverse. The subject areas to be covered range from abstract topics to engineering projects. The team tries to optimize the equipment, the structure, the concept and the topics of the makerspace. Working on projects is the main task of the student interns. The budget is provided by the company's R&D department.

Guiding principle. The mission of the makerspace is the acceleration of innovations. The customers are employees with innovative ideas. The projects are developed mostly in collaboration between the customer and the makerspace team. After specifying the concept, the makerspace team does the engineering, manufacturing, prototyping and patent registration. The refined and accelerated idea is then handed back to the respective customer (department), where a project team is deployed for further progression. Projects in the makerspace are incremental as well as disruptive. Initially, the aim of the makerspace was agile work and open innovation in the sense of more cooperation with startups, universities and other companies.

Each of the seven makerspaces at company GAMMA has a certain focus, often related to the main area of expertise at the respective site. The makerspace visited has a strong focus on 3D printing, whereas the makerspace on other sites includes other special machinery and equipment (e.g. large workshop, virtual or augmented reality). Furthermore, the number of staff members between the seven makerspaces differs considerably. The makerspaces do not directly work together on projects, but they have weekly exchanges in which they discuss projects, developments and new structures.

Access. The makerspace is open from Monday to Friday from 8:30 am to 6 pm. Generally, only makerspace staff have access to the makerspace in the research center. Due to safety reasons, the door remains locked for all others. Getting access is quite simple though, only a signature of the person responsible for the building is necessary. Also, many employees come along with the staff members and visit the makerspace together with them. The makerspace at the company-site is open to employees.

Instructions, safety and training. Only makerspace staff members are allowed to operate the machines. Interestingly, there are rarely requests for machine training from employees. It is planned though to find a way to enable all employees to use the machines independently, without violating working safety guidelines. Generally, a major challenge is the topic of occupational safety. Since communication is very important in the makerspace, the staff would like to organize more events to bring people together, or simply meet for a coffee break, but due to safety regulations, this is forbidden. At regular intervals, an inspection takes place to ensure compliance with the rules.

Materials. The makerspace managers are authorized to purchase project-related stuff, although the supervisor has to approve each order. Purchasing used to be a quite complicated issue, especially through portals such as Amazon or Aliexpress. Thus, the makerspace team simplified the purchasing process compared to the company's standard ordering process.

4.3.3 Community

User and culture. At the time of data collection, three operations managers and 18 student interns were working on different projects, mostly as part of an internship or a thesis. Those full-time assignments usually last for three to six months. The operations managers organize the projects and tasks. The student interns spend part of their free-time in the makerspace. The age of the managers is almost the same as of the interns, they understand each other quite well and they also meet up at the weekends sometimes. The working language is normally German, although communication in English is necessary to deal with international colleagues.

Some customers contribute actively and present ideas that they could not refine earlier. Others behave more passively and just spend some time there and get inspiration from the makerspace's atmosphere. Most of the customers are employees of the engineering departments, but also colleagues from less technical departments (e.g. human resources) use the creativity space for meetings and project work. The makerspace is considered as an open space intended to motivate the employees. A goal is the creation of a co-working atmosphere. Additional support for projects can also be gathered from external persons. The atmosphere in the makerspace is quite relaxed but also immediately productive. Many things happen in a short period of time. According to one operations manager, the second makerspace at the company site has lost its creative atmosphere as a consequence of shifting its focus to production.

If an employee comes up with a new idea, their line manager decides whether and for how many hours the employee can develop the project in the makerspace. There is no specific working time model for such projects. If new solutions and concepts are created in the makerspace, professionals are there to help with patent-related tasks. Student interns, who develop a patent during their work get recognized as co-inventors in the patent application. In general, no private projects are handled in the makerspace, although some small bricolage as a favor for colleagues is done sometimes.

Workshops and events. Workshops with technical specialists are offered, but they often take place outside the usual working times. Company-wide, the makerspace is very popular as workshop location and as host of events (lasting one or more days). Often, events are organized in cooperation with external institutions. One of these external partners is the MIT (especially Prof. Gershenfeld). Regularly, new and creative techniques are suggested and applied in the makerspace (e.g. paper cutting and folding method kirigami).

Online. In addition to the staff at the makerspace, an online platform enables contact with experts inside and outside the company. Ideas that need specific know-how can be submitted to experts by using the platform. Furthermore, a forum has been implemented to present new ideas and discuss them with colleagues. Some of those ideas are then developed further in the makerspace. Putting ideas in the forum is also protected for employees in terms of patent regulations.

4.4 Cross-case evaluation

This section compares the different approaches of corporate makerspaces according to the infrastructure-facilitation-community framework (see chapter 4 for detailed information). Furthermore, this section provides interpretations in terms of best practices. Table 7 shows an overview of the most relevant aspects of the three cases studies (structured according to the categories infrastructure, facilitation and community).

Table 7: Case analysis overview[21]

		Case ALPHA	Case BETA	Case GAMMA
Infrastructure	**Location**	ground floor main building on-site	sixth floor; ground floor random building on-site	ground floor research center off-site
	Size	400 sqm	70 sqm; 40 sqm	700 sqm
	Layout	several separated rooms	one single room	several separated rooms
	Design and interior	dedicated design language, colors, graffiti, furniture, work benches	standard, no special design, some colors visible keywords	factory hall, self-made furniture
	Fabrication and technology	standard (3D printer, laser cutter) sewing machines well-equipped	standard (3D printer, laser cutter) electronic equipment moderate equipped	standard (3D printer, laser cutter) testing facilities moderate equipped
Facilitation	**Staff**	1 network manager 1 administrative assistant (part time) 1 operations manager 3 staff members	1 operations manager (part time) 1 staff member (part time)	3 operations managers 18 student interns
	Guiding principle	train, inspire and consult	independent and individual usage	accelerate innovations
	Access	open weekdays (9 am – 6 pm)	closed weekdays (6 am – 8 pm)	closed weekdays (8:30 am – 6 pm)
	Projects	professional and private	professional and private	professional only
	Machine usage	all employees	all employees	makerspace staff only
	Instructions and trainings	every day	monthly or on demand	not applicable
	Reservation	online and manually	not possible	not applicable
	Materials	free to use	free to use	free to use
	Purchasing process	standard	standard	simplified
Community	**Makerspace team**	diverse, multinational	national	diverse, multinational
	Clients	designers and engineers	engineers	individuals and departments
	Workshops and events	weekly	on demand	no
	Collaboration with externals	no	no	no
	Internal social network	own website	wiki-page, online exchange platform	online exchange platform

[21] Author's illustration

4.4.1 Infrastructure

Location. The case studies reveal that the location of the corporate makerspace is one of the most important factors. The proximity to employees (especially designers, researchers, engineers and technicians) is considered as crucial. For example, at company ALPHA, the makerspace is located directly in the headquarters on the ground floor and thus very easy to enter for all employees. In contrast, the first built makerspaces in company BETA is located on the sixth floor in a random building at this company site and thus much more difficult to find. It could be observed that in company ALPHA, many people drop in just by accident, because they come past the door, whereas this is not the case and even not possible at company BETA. The makerspace investigated at GAMMA is located outside of the company at a research center. Here, it is quite easy to enter for the employees working in this building, but for all other employees it becomes quite burdensome to reach this makerspace. Nevertheless, there is a second makerspace on-site, which is easier to reach for them. Basically, for a makerspace with focus on creativity and innovation, the preferred location should be next to design and development.

Layout, design and interior. The layout of all four corporate makerspaces investigated is different. However, all makerspaces comprise the same fundamental areas, which fulfil certain functions: *workshop and prototyping*, where the machines are located; *creativity space* with flipcharts, whiteboards and the like; and *workplaces* for various activities such as project work, assembling or meetings. Due to the different industrial sectors of the companies studied, there are additional areas, e.g. sewing in company ALPHA, electronics in company BETA, or testing in company GAMMA. At all makerspaces, there are large tables (even areas), where the users can work on their projects. However, in many cases it was underestimated how much space users really need when working on their projects. Examples from company ALPHA demonstrate this, when users had to work on the floor because there was not enough space at the work tables. Initially, these tables were intended to host up to eight people. But as later realized, people need almost the half of the table when working on their projects. This has already indicated the need for enlargement of the makerspace, even though the makerspace has only been in operation for several months.

The makerspaces investigated have different sizes ranging from less than 40 sqm up to a few hundred square meters in total. Depending on the size and local conditions, the various areas are integrated in one single room or separated into several rooms. It is important to note that all makerspaces allow the arrangement of the space in a flexible way (except the heavy machinery). Depending on the usage of the makerspace (workshop, event etc.), the setup can be adapted to the specific format.

All three companies offer more than one makerspace at different sites. It was observed, that each company implements a common thread in the design of its own makerspaces (logo, colors, furniture, equipment etc.). In terms of design and interior, it is intended to be different (alternative design) compared to the usual office space of the employees and thereby stimulate alternative thinking and foster creativity. It is vital that users of a makerspace feel comfortable immediately when entering the space. Thus, makerspaces should offer an inspiring and appealing atmosphere.

Fabrication and technology. In addition to standard machinery and equipment such as 3D printer, laser cutter and basic tools, the corporate makerspaces should offer additional technologies depending on the product and service portfolio of the company (industrial sector). When selecting machines and tools, it is also important to reflect the requirements, needs and wishes of the users. Moreover, an assessment of which machines are used and how often is needed to avoid capacity bottlenecks. For example, the completion of prototypes (e.g. 3D printed patterns) can take a long time and can lead to waiting intervals with an insufficient number of devices available. Company ALPHA learned that it is dispensable to have a large 3D printer in the makerspace, a small-sized printer is sufficient, since only little objects are printed by the users. As a result, two smaller 3D printers were purchased, resulting in a doubling of the capacity.

Complementary labs. All companies studied provide additional facilities and platforms next to the corporate makerspace concept. These are conventional meeting rooms (with different designations such as co-creation space or design thinking space), other workshops (e.g. professional production of prototypes), or innovation and research labs. In addition, there are also incubator and accelerator programs with focus on collaboration with startups. Here, the employees get the opportunity to apply for the programs once their ideas have been developed in the makerspace. Furthermore, there are online platforms, where employees can place, discuss and develop ideas. This option can be considered more as starting point for new projects in the makerspace.

4.4.2 Facilitation

Staff and responsibilities. Differences between the makerspaces investigated are significant in terms of dedicated personnel. The higher the number of staff members the more projects can be handled. Reasonably, a high number of projects and staff members require larger size of the makerspace. The staff members are responsible for the whole operation of the space and split up their duties. One may be responsible for certain activities (giving training), projects (developments for customers), or machines (trashing and trying out technologies, maintenance). Overall, the makerspace team members are quite self-organized. Here, it is important that the team members exactly know their responsibilities and the tasks to be carried out.

Meetings. The investigated makerspaces with dedicated personnel apply agile methods such as daily stand-up meetings. Additionally, the makerspace team in company ALPHA holds a jour fixe once a week while the makerspace team in company GAMMA uses a Kanban board to visualize all tasks of the team members. These kind of team meetings are well received by the makerspace staff members in both makerspaces and are necessary for everyone to stay updated. In company BETA, meetings between the operations manager and the student intern take place informally.

Guiding principle. The makerspaces investigated operate based on different guiding principles. The makerspace at ALPHA focuses on training, inspiration and consulting of its users, especially in terms of idea generation for new designs outside the standard innovation process. Makerspace BETA is more intended to be a platform for self-learning and experimenting with new technologies in a professional as well as private context. Makerspace GAMMA focuses on accelerating innovation by developing specific topics in the structure of agile projects as fast as possible for the customers (service-orientation).

Access. Basically, the makerspaces studied are available for all employees from all departments, but not to external people. Since the makerspace of company ALPHA has dedicated opening times, access is only possible during the daily working hours between Monday and Friday. Individual access is not allowed. Comparably, the investigated makerspace at company GAMMA has similar business hours, but in contrast here it is not allowed for the employees to use machinery and equipment by themselves. Notably, company GAMMA also operates other makerspaces where this is allowed. At company BETA, there are no fixed opening hours. To enter, the users need to get the key from the administrator. Here, the access to the makerspace is regulated by the opening hours of the company site. In all three cases, there is no possibility to use the corporate makerspace at the weekend. Generally, during working hours the employees can use the makerspace for professional purposes. However, in some cases it also possible to work on private projects (e.g. one afternoon per week). Due to the fact that in company BETA no personnel is present in the makerspace, it is not controlled to see if a user is working on professional or private projects.

As mentioned above, the three investigated makerspaces do not allow access for external persons currently. As a result, intellectual property rights (IPR) do not play an important role at the moment. However, if external persons get access to the facilities in the future (in terms of open innovation), this issue needs to be addressed and regulated.

Instructions, safety and training. At ALPHA and BETA, all employees can acquire the authorization to use the makerspace. For that, it is necessary to complete an introduction tour including safety instruction on the machines. Employees are only allowed to use the machines if they know how the machines work and when they are able to operate them without any safety risk. One user mentioned that *"[...] it is important that workshops are offered so that users know how to operate the machines."* In company ALPHA, there are two official dates weekly, which are very well visited. In company BETA, such introductions take place randomly, only if there are enough registrations. Thus, the frequency of the training sessions on the machines depends on the demand. In both companies, the participants sign a waiver to attest that they have made the safety training and have understood the safety instructions. In company ALPHA, one gets a sticker on the identity card that the staff members can easily recognize if this person has already done the safety training. The makerspace in company GAMMA does not offer any machine training for the employees, because usage is restricted to makerspace personnel only.

Safety measures such as safety training or visible safety guideline sheets must be put in place for the machinery and tools offered to meet legal regulations. This is necessary in case of accountability questions, e.g. when accidents happen and employees hurt themselves as well as for replacing or fixing machinery in case of wrong usage.

Materials. All makerspaces provide basic materials to operate standard equipment such as 3D printer and laser cutter. Depending on the variety of projects and the company's product portfolio, the makerspaces may offer various additional materials. For example, makerspace ALPHA provides a great variety of textiles. For professional purposes, all materials needed can be used for free. At company BETA this is only possible to a certain extent, although this is not exactly defined (they call it 'fair use policy').

Storage. The cases reveal that the aspect of material storage is generally underestimated when designing the space, which later can lead to issues during daily operations. In some cases, the users need storage to accommodate their projects, so that they do not have to take everything with them. If there is only little space where materials and projects can be stored properly, the makerspace easily become messy. For example, due to the intense use of the corporate makerspaces in company ALPHA, keeping tidiness is a major challenge – a structured concept as well as enough storage space is missing. In contrast, at GAMMA, the makerspace is quite large in size, therefore the storage issue is not of great concern. Nevertheless, for all makerspaces storage of the tools should be structured and orderly. Tools and materials must have a defined place and must be easy to find, access and store.

Machinery reservation. The three makerspaces have three different approaches. Users at makerspace ALPHA can reserve a machine by means of an online form or a manual job list (only for the laser cutter as the most frequently used machine). In contrast, there is no reservation at company BETA. And as a survey among the community shows, there is also no great interest in that.

Funding. At company GAMMA, everything that is needed for the projects is purchased on demand (e.g. augmented reality kit). Currently, all three makerspaces are fully financed by the responsible department. At ALPHA, there is the idea to spread the funding across all business units taking a kind of crowdfunding approach.

Marketing. Internal marketing of the makerspace is important for all three companies to reach more employees (e.g. posts of developed prototypes, pictures, success stories). External communication is generally kept quite low.

Challenges. The case studies show that operations managers try to find an appropriate balance between order and creative chaos in the corporate makerspace. Easily, it can get messy in the makerspace, which may distract people from doing productive work. However, too strict regulations may affect the creativity potential in a negative way. In both ALPHA and GAMMA, a great challenge is the organization, delegation and supervision of all the tasks of the staff members.

In company ALPHA, the main challenge for the staff of the makerspace are the number of interruptions and distractions which occur during daily business due to the traffic. Thus, it is hard to stay focused and concentrated. Many possible distractions make it difficult for the staff members to plan the day and to find time to do dedicated work.

A major challenge is dealing with company internal processes and regulations. For example, usual purchasing processes take far too long and are not appropriate when applying agile working methods in the makerspace. Another example observed at makerspace BETA and GAMMA is that it is prohibited to install a coffee machine in the makerspace because the makerspace is declared as a laboratory and in laboratories it is not allowed to eat or drink. To conclude, it is difficult to adapt existing regulations to new working environments such as corporate makerspaces. This can also be seen as a major opportunity of such a tool, because new working methods are applied and tried out.

4.4.3 Community

User and culture. While a number of people use the makerspaces regularly, the cases show great differences in the number of visitors. At company ALPHA, lots of people (internal as well as external) visit the makerspace daily. Quite often employees just want to spend their breaks in the corporate makerspace to simply enjoy the nice atmosphere, having a little conversation and getting inspired. In total, in the first two months of operation (mid-November to mid-December 2016) 2,500 different people visited the makerspace at company ALPHA. About 5,000 people work at the company site.

In contrast, only 500 different people visited the corporate makerspace in company BETA during the first two years of operation. The main reason for that is the secluded location of the makerspaces at company BETA and the fact that the makerspaces are mostly locked. Likewise, makerspace GAMMA is locked, but much more traffic is experienced there compared to makerspace BETA. The reason for that is on the one hand again the location aspect, and on the other hand, at makerspace GAMMA many projects are running simultaneously due to the large number of staff members. Here, the customers meet regularly with the staff to discuss the progress of the projects.

Although the makerspace in company ALPHA has only been in operation for a few months, traffic and usage were high during the observation period. In summary, there are many more people working in the makerspace in company ALPHA than in BETA and GAMMA. This means that there is always a lot of activity happening in the makerspace, and consequently, most available workplaces and machines are occupied. The makerspace network manager at company ALPHA emphasized that *"[…] it is good when its busy and crowded, because if the space is empty for two days then I get nervous. There must be action, but sometimes it is necessary that my team has time to come down."*

Predominantly, there is an open atmosphere in the makerspaces with everyone taking care and supporting each other – among the users as well as within the makerspace staff team. According to one makerspace manager, it is not easy to create an open atmosphere where employees share their ideas and knowledge with others, because people generally want to get rewarded for their own ideas and concepts, which they have spent a great amount of time on. That is why many people are more closed in the beginning and do not want to speak openly about their own ideas. But soon, as the users build trust, they begin to discuss their projects with others, because they realize that they can also learn and improve.

Workshops and events. All makerspaces offer workshops and organize events on specific topics. In addition to the learning content, the workshops mainly serve as a platform for networking within the community or with employees from different departments. Especially, the makerspace team in company ALPHA conducts several workshops on diverse topics during each week. Employees are encouraged to submit their interest and proposals for workshops to the staff members. If there is sufficient demand on these topics, workshops are organized. In comparison, at company BETA workshops are only held if someone from the community is motivated to do that. Since in company GAMMA only staff members work in the makerspace, workshops and events for employees are not held for the employees on a regular basis.

Online. All makerspaces have their online presence in the internal social network of their companies. At company ALPHA, the website offers various opportunities to inform oneself about the makerspace, to register for training courses and workshops, or to make machine reservations. In contrast, the website of makerspace BETA is designed as a wiki-page only offering basic information and descriptions of the available machines. Makerspace GAMMA's online presence is connected to the company's online exchange platform. Overall, the website of the corporate makerspace is an important touchpoint for the employees (following word-of-mouth recommendation). Therefore, the website should be engaging and make the users interested in the makerspace concept.

5 Interim conclusion

Most employees visiting the corporate makerspaces for the first time are rather impressed by the possibilities offered. But also, there are critics who are not convinced of the potential of such a facility. On average, the makerspace concept is well received by the employees in the investigated companies. But, what are makerspaces all about? The following words of one instructor of a creation workshop with designers from various business units at company ALPHA summarizes that quite well: *"Think beyond! How could the future look like? The makerspace is a safe place with no limitations and restrictions."*

Data comparison of the three cases shows differences in the infrastructure (e.g. location, layout, design, interior), facilitation (e.g. staff responsible for user support, access to machines) and community (e.g. diversity, user base) of corporate makerspaces. On the other hand, commonalities are found in the areas of fabrication machinery and equipment, material usage, safety standards, content of trainings and workshops. For all three cases, the funding of the resources (machines, tools, materials etc.) are provided by one responsible department. The following sections summarize the relevant aspects from the perspective of the infrastructure-facilitation-community framework. The empirical findings from the conducted case studies are connected to existing literature.

Infrastructure. A necessary and foundational component of a makerspace is the physical space (Litts 2014, p. 6). The space design should allow high flexibility of all equipment to enable various settings (e.g. equipment placed on standardized and mobile work stations, which can easily be moved around within the whole space). However, the layout needs to fulfill particular functions to support new ways of thinking (Böhm et al. 2015). In addition, tools and technologies represent all tangible and intangible resources present at a makerspace, which are needed to engage the people in making. The tangible aspect primarily refers to the access to the physical space, tools and technologies. Typically, a makerspace integrates the following main areas:

- *Fabrication workshop:* All makerspaces include an area with machinery and equipment for rapid prototyping. The equipment offered in each makerspace depends on context-specific boundary conditions (focus, projects, community, funding etc.).
- *Idea generation zone:* Importantly, dedicated areas, where individuals and groups can work together and apply creativity techniques are crucial. It is important that the necessary tools are available to capture ideas and to visualize them immediately.
- *Co-working space:* The users need certain areas where they can work on their projects, alone or in small teams. According to Welter and Olma (2011), co-working spaces do

not have clear boundaries. The working environment normally consists of equipment that is used together (Welter and Olma 2011).

In addition to the tangible aspects covering the relevant physical properties of a makerspace, software technologies and access to virtual spaces are needed for making activities:

- *Technical software:* This type comprises all software tools which are needed to design the inputs for and to control all technical machinery (e.g. CAD programs for designing objects). Also included are tools for coding (e.g. to program microcontroller). Providing easy to use graphical user interfaces (GUI) is relevant.
- *Virtual collaboration:* High-speed information and communication technologies (ICT) in terms of data exchange and video conference systems make it possible for people all over the world to participate and collaborate with each other in real time.

Facilitation. A makerspace cannot function without structure, management and leadership, which takes on the responsibilities to develop and grow the makerspace (Wilczynski 2017). Here, three main dimensions need to be considered:

- *Functional:* The makerspace managers ensure that the makerspace fulfills its guiding principle and provides the relevant programs, equipment and processes that address the user's needs (Wilczynski 2017). One goal is to provide the best customer experience possible to every user. Furthermore, the makerspace managers provide the network and the connections to experts in various fields (e.g. technical, methodical or business competence).
- *Operational:* This dimension refers to the operational tasks in the makerspace. The staff members need to maintain all machinery and equipment, promote the space (e.g. newsletter), and offer workshops, activities, training and events to the community. Additionally, machines, materials and other consumables need to be purchased.
- *Methodical:* One essential task for the makerspace staff is to support the users with the application of innovation and design methods. This is required because many people with ideas do not know how to further develop them. Therefore, it is crucial that the staff can offer the necessary methodical competence along the path of idea commercialization.

Community. The most essential part and heart of a makerspace are the people (makers), who build the local community. As Litts (2014, p. 1) puts it: *"Makerspaces are places where making happens in community."* Kurti et al. (2014) formulate: *"A makerspace without makers is just a workshop full of lonely tools."* Consequently, the community is ultimately what molds und sustains a makerspace (Baichtal 2011; Britton 2012). Or with the words of Good (2013a): *"A makerspace without a community is a soulless place."* An active and lively community shares certain values and thus creates the unique maker spirit, which is creative, open-minded and action-oriented based on mutual support and a sharing attitude.

Kuznetsov et. al (2010, p. 5) conducted a survey with over 2,600 members of six different online maker communities (Instructables, Dorkbot, Adafruit, Ravelry, Craftster, Etsy) to capture the topic of do-it-yourself as a multi-faceted movement. The result shows, that the three main motivations of the participants for contributing to the community are (1) *inspiration and new ideas for future projects,* (2) *learning new concepts,* and (3) *meet people who share similar interests as me.* These are followed by the aspect of information exchange such as *receive feedback about my own projects* and *educate others and share information* (Kuznetsov and Paulos 2010, p. 5).

Usually, a makerspace hosts a wide range of people with various backgrounds, ages and in some cases also different nationalities and cultures. Therefore, it is essential that all staff members have the necessary social competence to deal with the challenges which occur within a diverse user base. From this perspective, intercultural awareness and conflict management are very important topics.

5.1 Operation models

Significantly, the three corporate makerspaces investigated apply dissimilar operation models. The most important difference between the operation models is the aspect of facilitation, which mainly addresses the number of makerspace staff members. The more staff members the higher the budget provided by the company for the operation of the makerspace. Based on the case analysis three operation models are identified: (1) *service orientation,* (2) *self-reliant usage,* and (3) *combined model of service orientation and self-reliant usage.*

5.1.1 Service orientation

This operation model focuses on service-orientation towards the customers of the makerspace. Within this model, the employees of the company do not have the authorization to use the machines in the makerspace by themselves. Machine operation is restricted to the makerspace staff, although, the facilities can be used for meetings and teams working on projects for a dedicated period of time. Thus, for this model it is essential that sufficient staff are available to the customers.

The guiding principle for this operation model is to further develop and realize the ideas of the customers and thereby accelerate innovations. The ideas come from different channels (e.g. company employees, customers, idea management tools or competitions). On the one hand, the makerspace team picks up these topics and develops them for the clients (in the sense of *customer pull*). In contrast, projects are started and implemented by the staff members themselves. The concepts and prototypes created (products, services, business models etc.) are then offered to potential customers for further development (in the sense of *technology push*). In this way, a corporate makerspace is different to an internal prototyping workshop. The only task of such workshops is to manufacture already existing designs and concepts, which is done by dedicated professional staff.

A company with a demand for prototypes or completion of smaller fabrication projects can approach the makerspace staff and let the makerspace community handle this request. In this way, this operation model allows the outsourcing of tasks in the product design process to the corporate makerspace. For example, in company GAMMA many internships and thesis projects are conducted with students on topics which come from the design departments.

5.1.2 Self-reliant usage

This operation model positions the self-responsibility and independent learning of the users of the makerspace as the central aspect. Within this model, it is not necessary that staff members are present in the makerspace. It is only the infrastructure (space, machines, technologies etc.), which is offered to the users. The users support each other in operating the machines, continue their self-education in the community, work together on projects, and organize different trainings and workshops according to their own interests. Depending on the individual situation, the users can or may not get involved in the community and use the machines for professional as well as private projects. The makerspace in company BETA is an example of this operation model. Here, the community with its members uses the space independently.

5.1.3 Combined model

This operation model is a combination of the models *service orientation* and *self-reliant usage*. Within the makerspace, users can work independently on their projects as well as approach staff for help when dealing with problems. The users receive advice in areas such as product development or choice of materials. The makerspace team offers methodical expertise and know the persons and experts that can be contacted for support in the respective problem areas. They act as a kind of hub and connect relevant people and departments with each other.

As an example, makerspace ALPHA operates based on this model. They provide support to the users and pursue their own projects as well as let the users work with the machinery and equipment by themselves. Here, it is specifically important to support the employees in the further implementation of their projects and to advise the users with new product ideas on how to commercialize these concepts.

5.2 Taxonomy framework

In addition to the different *operation models* of a makerspace, the dimension of *accessibility* (who has access to the makerspace) is central. These two dimensions are used to develop a new taxonomy framework, which allows to better compare and display the different existing approaches of makerspaces (see Figure 15).

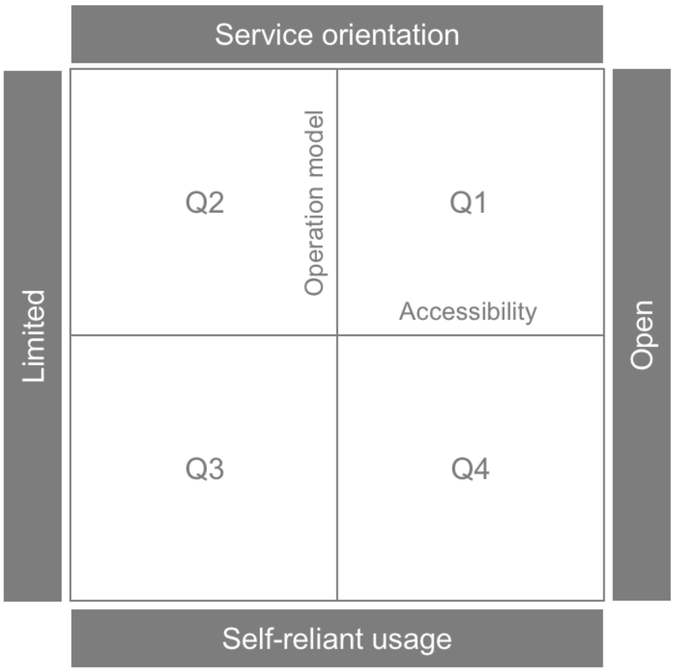

Figure 15: Taxonomy framework[22]

The horizontal axis represents the *accessibility* to a makerspace, which can be limited to specific groups or open. The vertical axis represents the operation model of a makerspace, which can be service-oriented, based on self-reliant usage or a combination of both in-between (see chapter 5.1) Theoretically, for the combined model various forms are possible, depending on the main activities in the makerspace (see Figure 16).

[22] Author's illustration

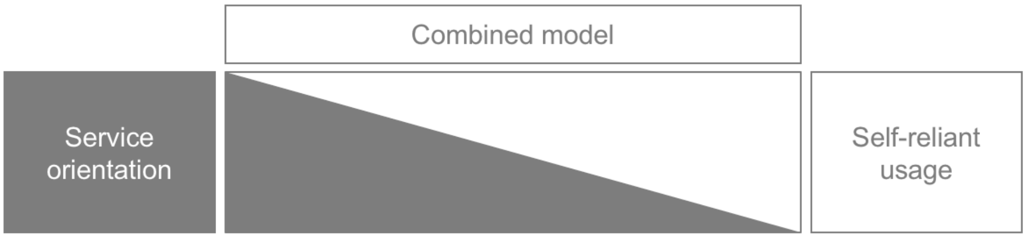

Figure 16: Operation models of makerspaces[23]

5.2.1 *Corporate perspective*

In the context of corporate makerspaces, the dimension of accessibility ranges in four steps from limited to open access. The first step is that the usage of machinery and equipment is restricted to the makerspace staff only, although, employees can use the space for workshops or team work if personnel are present in the makerspace. The second step allows all employees of the company to get the permission to work in the makerspace and to use all machinery and equipment. The third step allows access to selected external groups such as specific customers, clients, partners or suppliers. The fourth step is open access to all company-externals (see Figure 17).

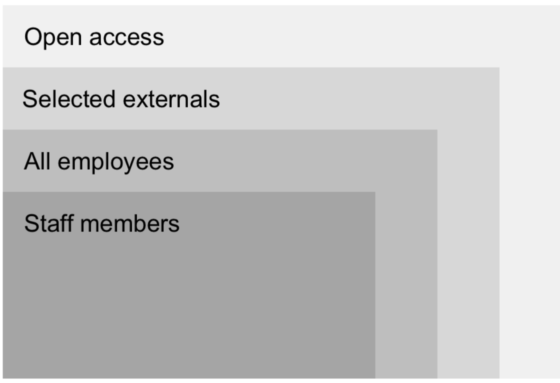

Figure 17: Four steps of accessibility[24]

The operation model indicates to which extent staff or professionals are present in the makerspace. In facilities based on self-reliant usage, there are no staff available during daily business. The members of the makerspace use the tools and machines on their own. In service-oriented makerspaces users are supported and advised from staff during opening hours. Moreover, service include that the makerspace staff develop and prototype the ideas of their customers in the sense of contract development. Service-orientation has

[23] Author's illustration
[24] Author's illustration

advantages in terms of working safety, reducing risk of machine damage, and injury to users. It is also possible, that professionals and experts are in the makerspace occasionally, for example, for workshops or training.

Figure 18 displays the investigated case studies based on their operation model in the new taxonomy framework. Here, it can be seen that all the makerspaces investigated have in common that they are still rather closed to internal projects and employees.

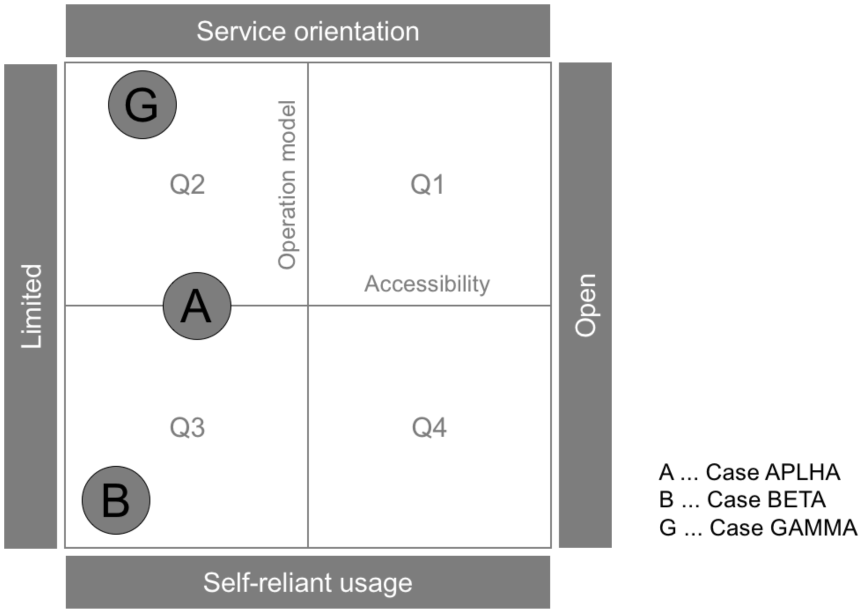

Figure 18: Operation models of investigated corporate makerspaces (qualitative)[25]

5.2.2 General perspective

From a general viewpoint, the developed taxonomy framework allows the evaluation and comparison of all kinds of makerspaces (see chapter 2.2.1) with each other. Here, the accessibility dimension of a makerspace describes whether the access to a makerspace is limited to specific groups or if anyone can enter the makerspace. Makerspaces with closed access have the advantage that only the users belonging to a certain community are present (can even be a corporation) and thus the members can work on confidential projects since all are part of the same group. It is inadmissible to enter and use the makerspace for externals that are not part of the community.

In contrast, at makerspaces with open access it is possible for all people to enter the space, use the machinery and equipment and work on projects. At public makerspaces with open

[25] Author's illustration

access, some users are worried about working on confidential projects. However, there are also makerspaces operating between open and closed concepts, for example, with time-limited or project-related access.

The aspects in terms of the different operation models discussed above (see chapter 5.1 and chapter 5.2.1 can be applied to all kinds of makerspaces.

5.2.3 Archetypical approaches

Based on the taxonomy framework, four archetypical approaches for makerspaces are possible:

- *Quadrant 1 – Open access and service orientation:* This archetype allows everyone to access the makerspace. Additionally, various services are offered for the users such as individual support, workshops or training. Examples of this archetype are professional makerspaces, which are for-profit organizations based on a membership-model. The customers pay fees to use the space, machinery and equipment as well as for workshops and training. In some cases, access is possible 24/7, even when no staff are present.
- *Quadrant 2 – Limited access and service orientation:* This archetype has restricted access to a specific group but offers services for its members. An example for this archetype is the investigated corporate makerspace of company GAMMA. Companies may also establish a makerspace in cooperation with other firms and operate the makerspace with open access (see chapter 2.7.2.2).
- *Quadrant 3 – Limited access and self-reliant usage:* This archetype limits the access to a specific group of people. This community runs the makerspace by themselves only for its own interest. Such makerspaces originate in a bottom-up approach, being started by a small group of people, working on projects alone or together. Examples for this archetype are hackerspaces (see chapter 2.2.1.1) or student-run makerspaces at universities with the goal of self-directed knowledge enhancement.
- *Quadrant 4 – Open access and self-reliant usage:* This archetype offers open access to the makerspace and is run by a group of volunteers. Examples of these are community-run makerspaces which offer open access to everyone. This archetype can be seen, e.g. in developing countries, where communities start to build up a makerspace with own-build machines.

When displaying makerspaces in the taxonomy framework, additional features such as color coding, diverse signs, or different sizes of the signs can be used to integrate further dimensions such as makerspace type, staffing, size or user base.

5.3 Additional findings from case studies

Measuring success. The starting point for the implementation of a makerspaces in a company are the fundamental considerations on the general goals that one would like to achieve with the implementation of such a facility. If the establishment is a strategic project, it is important to consider the value added for the company and how to make this value measurable. The conducted case studies reveal that for companies it is quite hard to establish metrics to measure the success of a makerspace. For example, it is very difficult to track the development of ideas and concepts that have been created in the makerspace. This is because, in many cases, the developed product has only very little connection with the very first idea on which the final concept is based.

Possible success measures are for example, the number of visitors, the number of conducted safety instructions, the number of users attending workshops, the number of prototypes built, the number of photographed and documented product concepts, or the hours of laser cutter usage per week or month. Measuring these parameters can be meaningful and necessary to maintain an overview of the use of the corporate makerspace and to control the operations. Theses metrics are helpful for finding spots, where organization and management can be improved. But to assess the success of this facility, these 'hard-coded' KPIs are not sufficient. None of the investigated makerspaces in the three companies bases success measurement on such quantitative KPIs. Also, because the fear of control among the employees is relatively high; they do not want to be tracked on how much time they spend in the makerspace. In some cases, the superiors even do not appreciate the activities of their employees in the makerspace.

This dissertation reveals that the most relevant and appropriate success measure is employee satisfaction. For example, company ALPHA determines the success of the makerspace by means of an employee satisfaction survey. Within the company, the makerspace is seen as a service platform for the creative community. For this reason, the degree of user satisfaction with the service of the corporate makerspaces has highest priority.

The degree of satisfaction with the service of the corporate makerspaces is measured with the so-called *net promoter score*. In principle, this approach is a way to measure the desire for one's own brand. The corporate makerspace uses the net promoter score as a measure for how well the users evaluate the services of the corporate makerspace. Here, the question is: How likely is it that you recommend the makerspace to a colleague? The user's response is measured on a scale from zero to ten, with ten being *most likely* (the highest value) and zero with *very unlikely* (the lowest value). The responses with nine and ten count as *promoters*. Answers with seven or eight as *undecided* and values from zero to six as *detractors*. The net promoter score is calculated by subtracting the percentage of detractors from the percentage of promotors. If the makerspace has more promotors than detractors, the net promoter score is positive (at best plus 100 percent). This score represents an important indicator for the perception of the corporate makerspace brand. The net promoter score can be measured throughout the year using employee surveys. In a slightly different way, company GAMMA measures the conversation rate, that is the rate of those who use the makerspace repeatedly.

Generally, the success of the makerspace concept is described as difficult to measure, since the quality of a prototype or service developed in the makerspace cannot be directly and objectively evaluated. In order to demonstrate the positive effects of the corporate makerspace and to make the makerspace more recognized, examples of successful projects are published internally and partially externally. To conclude, the costs for establishment and facilitation (staff, equipment etc.) is offset by the hope for a certain value added through the enthusiasm of employees and the promotion of creativity.

Agile methods. In today's fast-moving economy, it is vital to shorten the time from idea to prototype and to the market. It is important to implement new innovation processes in order to keep up with the growing global competition (Arnkil et al. 2010, p. 15). Therefore, agility during product development processes is seen as beneficial. Agile approaches are widely used in the world of makers, where the strategy is to start a project with very low cost and make the product available on the market quickly (if possible in terms of a *beta* version). Makers share the desire characteristic to publish their projects very quickly, involving the community and thereby creating a common interest. In that way, they get user feedback and learn important lessons to improve design and quality to create a better product. They also accept failure, which is valued in the sense that it creates experience. Makerspaces are areas where new working methods like Scrum can be tried out. Scrum is a framework that emphasizes teamwork, accountability and iterative progress towards a well-defined goal (Techtarget 2014). Several publications on the Scrum methodology (focusing on software development) are available (see Schwaber and Beedle 2002; Schwaber and Sutherland 2011; Pichler 2013; Gloger 2016). In makerspace ALPHA and makerspace GAMMA the application of agile working methods based on the agile manifesto (Cunningham 2001) could be observed (e.g. daily stand-up meetings, using Kanban boards).

Time and cost. When companies operate an internal prototype production facility, product development teams can hand over concepts to get them produced. If companies do not have such a facility, then everything needs to be purchased from external suppliers, which usually goes hand in hand with long delivery times and higher costs. Moreover, due to external production, learning effects are unexploited.

As an example, since the implementation of the makerspace at company GAMMA projects are carried out faster while still delivering the same quality. The main reason is a simplified purchasing process that significantly reduces delivery times for purchased parts. This process does not conform with the standard purchasing processes of the company; it must be seen a work-around, so that the short delivery times of required parts can actually be achieved.

In addition, the makerspace in all three companies is used to avoid sourcing parts externally by producing the necessary things themselves. For example, the ability to print the components needed means that concepts are tried out quickly. For example, in company BETA this approach is used to allow more iteration loops within shorter development times. Furthermore, due to the establishment of the makerspace, some engineers learned how to apply this technology. Consequently, some R&D departments integrated their own 3D printer to use it directly in their offices. Keeping the costs low is also essential. Rapid prototyping helps to make tests very fast and allows the maker to understand quickly if a concept works as intended. If the result is insufficient, the cost to start again or re-create is quite low. Thus, a corporate makerspace supports in terms of minimizing the costs of making changes.

Promoting sustainability. One goal of company ALPHA is to raise awareness of the usage of sustainable materials within the workforce. Therefore, harmful materials to the environment will be excluded in the future. The designers should comprehend that they can influence environment sustainability with their choice of materials. PVC (polyvinyl chloride) free textiles should be used more frequently, and so the material library offers these kinds of fabrics. The makerspace team pushes the sustainability topic by encouraging designers to feel responsible for the environment, for example, by using fabric residues instead of new materials when making samples. The makerspace team supports a lot of people from different departments and thus is able to influence which materials are used (e.g. environmentally friendly textiles).

Cultural change. The overarching aim recognized from the case studies is that the establishment of a corporate makerspace should initiate and lead to cultural change. The employees should be motivated to try out new things, to quickly convert ideas into physical concepts and learn from the mistakes made in terms of learning by doing – according to the motto *'fail early to succeed sooner'.* The creative atmosphere and interpersonal exchange in makerspaces are important aspects that support the cultural change efforts of a company. However, a corporate makerspace can only be one element of the corporate strategy in terms of cultural change. A makerspace may change the culture in a company by removing existing barriers to contributing to projects or starting projects from scratch.

Future directions. At company ALPHA, there are plans to develop a kind of makerspace van, with which employees can participate in various maker events. The idea is to make the topic of open source more accessible to a broader audience. Another direction is support independent learning of the users. Employees should acquire new skills by means of online tutorials. As observed, some people only want to know the basics in certain topics, but others want to become real experts in specific areas. This allows employees to acquire knowledge in their desired directions, depending on their personal interests.

At company BETA, topics such as design thinking, digitization, Internet-of-Things (IoT), and in particular virtual reality will have a strong influence on the makerspace. Moreover, one goal is to open up in the future. This could be done externally through cooperation with universities, startups and other companies. For that to achieve, company regulations need to be adapted and aligned. Alternatively, there could be internal opening in the sense of an open doors policy. This means that all users will get their own entry card to simplify and facilitate access. In addition, the makerspace will be expanded spatially and relocated to a more central place. The makerspace concept will be specified to make it easier to transfer to new locations. Further locations are being planned.

At company GAMMA, further makerspaces are intended to be implemented worldwide based on a franchising concept. Therefore, a playbook providing makerspace guidelines (infrastructure, facilitation, processes etc.) is planned. Staff members at already existing makerspaces will be involved in this expansion process. Work is in progress on how to make it possible for employees to use the machinery and equipment independently and how they can improve co-operation with external persons and institutions.

To conclude, opening up the corporate makerspace for externals is a future direction in all investigated case studies (see Figure 19).

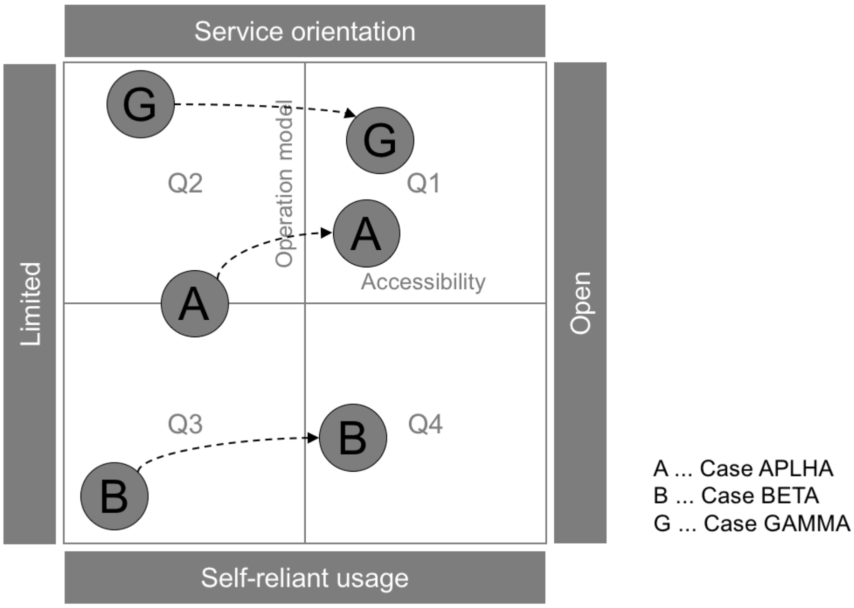

Figure 19: Future directions of investigated corporate makerspaces (qualitative)[26]

As a general point of view, many of the persons interviewed from all three companies assume that there will be more makerspaces in companies as well as more makerspaces publicly accessible in the cities. The comprehensive access to such facilities can lead to a widening of the worldwide maker community. In the future, the themes of design thinking, digitalization, Internet of Things and Virtual Reality will play an important role and will lead to new innovations in these areas.

5.4 Requirements for a corporate makerspace

The investigated case studies reveal several factors favorable for corporate makerspaces as explained in the following sections. Some of these factors are of general nature and are relevant for all kind of makerspaces. But some factors are corporate-specific and thus must be considered especially for makerspaces within the corporate context. All identified factors are structured under four themes: *management buy-in, inspiring environment, entrepreneurial culture* and *user support.*

5.4.1 Management buy-in

The mindset and behavior of the top management has great influence on the corporate culture, therefore it is necessary that top managers support the corporate makerspace and

[26] Author's illustration

its existence. The CEO of company ALPHA is a good example, who mentioned that *"[…] they can do everything they want, that's their playground."* Four main aspects are related to top management support:

- *Ensure financial grounding:* Decision-makers need to be convinced that the makerspace initiative is something worth supporting. This is because the management must provide the budget for the makerspace to ensure its implementation and operation. Notably, it is necessary to support the managers and operators of the makerspace in their initiatives and activities to grow and further develop the corporate makerspace.
- *Frame guiding principle:* Management considers return on investment, therefore what the mission is needs to be clarified, what the goals of the establishment of such a facility are and how the is success measured.
- *Take measures:* It is necessary to set up specific key performance indicators to track the success of the makerspace. As the case studies reveal, it is difficult to measure the success of such a facility, but, e.g. employee satisfaction surveys for getting feedback on services and offers of the makerspace is an appropriate tool (see chapter 5.3).
- *Adapt processes:* In large established companies, there are internal policies and processes that must be adhered to. If one wants to work differently, then usually one quickly reaches limits. It is hard to adapt traditional corporate regulations and processes according to the new ways of working in a corporate makerspace. Thus, it must be allowed to execute non-conform actions.

5.4.2 Inspiring environment

A makerspace needs to go beyond space, it needs to be an open and inspiring environment that stimulates creativity and innovation. Environment comprises the physical space and the practices and experiences within it. A makerspace provides the opportunity to play around with new things. People should like to spend time in the makerspace, so they should also have fun doing their work there. In that way, an active and lively community may emerge. Basically, the corporate makerspace is a tool that can be used but does not need to be. Thus, it is important to create conditions that make the makerspace attractive for the employees. The following aspects need to be considered regarding space and infrastructure:

- *Convenient location:* The nearness of the makerspace to employees' workplaces is crucial. The location of the corporate makerspaces needs to be as central as possible. This allows easy access, facilitates dropping-in traffic and hence ensures a high number of visitors. Because creativity is often impulsive, the nearness to the design and development units is fundamental to keep the barrier to usage low.

- *Open accessibility:* The makerspace must be open to all employees. Additionally, working time models that allow employees to spend dedicated time on new projects and to push further innovative ideas is beneficial (see chapter 2.6.4.2). Keep bureaucratic effort for access and usage as little as possible. Creativity is often spontaneous thus employees should be able to use the makerspace whenever they want.
- *Flexible use:* When designing the makerspaces, it is essential to consider all possible use cases for the makerspace (meetings, workshops, events, coffee breaks etc.). It must be possible to switch between each setting very easily and fast. Consider sufficient storage capacities for materials and prototypes within the space.
- *Relevant tools:* Depending on the industry sector, the company's product portfolio, the focus of the makerspace and the users' needs, each makerspace needs to select the appropriate tools. This means that during implementation, future users should be asked about their requirements and wishes. The case studies show, that it is not easy to predict which machinery and equipment is really needed and how it is used, because one does not exactly know on which projects the users are going to work (especially in the case of private projects). It should be possible to set up and arrange new machinery and equipment in the makerspace easily.

5.4.3 Entrepreneurial culture

One goal of corporate makerspaces is to foster entrepreneurial thinking and acting, which means that people take ownership of their ideas and push them further. This should go along with fun and playfulness. The following aspects need to be considered relating to culture:

- *Promote trial-and-error attitude:* Establishing a culture where people are not mistreated when they are wrong – allowing the possibility to fail – is one of the most challenging things within a company (see chapter 2.6.4.1). Therefore, the employees should be offered more freedom and let to experiment in the makerspace. It is important to set up a culture with an open-minded spirit, where people can test unorthodox ideas in an exploratory way. Multiple iterations should be allowed and when wrong, people must be supported and engaged to start again.
- *Screen ideas:* The makerspace functions as the focal point for new ideas across the company. This means that good ideas must be detected and separated (see chapter

2.5.7); the support of fruitful projects is central. However, pursued projects should be aligned with the overall innovation strategy of the company.

- *Establish open ecosystem:* At the individual level, a main factor is that employees become more open towards new things. Thus, a makerspace needs to offer the possibility that employees start their own projects. At the institutional level, first open the makerspace internally. Later, it is suggested to open to a broader ecosystem in the context of open innovation strategies to fully tap the potential of the maker community. Obviously, opening the makerspace comes with challenges such as the balancing of confidential and open projects. The makerspaces investigated started with building bridges to other corporate makerspaces, but also to academic institutions.

5.4.4 User support

Helping users to transform their ideas and desires into projects and support during the phase of building the physical representations is vital to make the users satisfied with the services of the makerspace. On the other hand, users must get sufficiently trained on operating the machines, so that they can work independently. This is recommended so that the makerspace staff do not get overloaded by requests from the users. The following aspects need to be considered when setting up the makerspace team and when working with the users of the makerspace:

- *Team spirit:* The most important factor identified from the case studies is the team spirit. If, as in the case of company ALPHA and GAMMA, a dedicated team is responsible for the corporate makerspace, the staff team composition and how they work with each other is essential. The composition as an interdisciplinary team should integrate employees with different specializations, for example, from various fields such as engineering, social science or design. It needs to have a lot of understanding for the colleagues, a good atmosphere as well as trust and cohesion within the team. This allows the staff members to speak openly about all things that concern or burden them. In addition, the staff members must be flexible, service-oriented and like to work with other people and have a pleasure to teach and support others. The human aspect definitely outweighs space, machines and equipment. Good teamwork leads to good solutions in most cases. Empathy – the ability to listen and slip into someone else's shoes – is an essential competence for the staff members of the makerspace team. If a team member is overloaded, it is important that the colleagues support the person and take over work packages. To keep staff members highly motivated, it is recommended to organize teambuilding and social activities for the whole makerspace team.

- *Visibility:* Marketing the makerspace is a necessary task so that all employees in the company know its existence and its opportunities. But in many cases, employees are not aware of the opportunity to use a makerspace for their projects due to too few marketing activities.
- *Exchange:* Although many users have a technical or design background, various disciplines are present in a makerspace. It is likely that these people come with different nationalities and cultural background. The makerspace staff need to promote communication and exchange between the community members to pave the way for transdisciplinary collaborative projects. In addition, it is important to foster mutual support, where employees with experience in the usage of machines, programming, or other special skills are invited to share their knowledge with other members.
- *Incentives:* Setting up reward systems to engage employees in pursuing new ideas (e.g. employee patent incentive program at Ford Motor company) are beneficial. In company ALPHA, some departments even force their employees to complete projects in the makerspace as part of their individual annual performance objectives.
- *Occupation and availability:* Ensure that employees can use the space whenever they need it. If many employees want to use the makerspace at the same time, capacity problems occur. These shortages are dependent on the number of machines and workplaces provided, which is related to the size of the space. The implementation of a booking and machine reservation system can make transparent, when the space and the machines are free to use. When machines are booked all the time, additional items can reduce the bottlenecks.
- *Focus on community.* The challenge is to maintain the initial hype, which may occur with the opening of the corporate makerspace. Actions which can be taken to cope with this challenge range from actively searching for people who offer interesting topics within the framework of workshops to making new material or equipment available.

To conclude, many of the identified factors are applicable for makerspace in general (see also chapter 2.2.1.5). Corporate-specific factors are especially the support of the management, the allowance to adapt existing processes (e.g. purchasing), and the challenge of dealing with confidential projects when opening up the makerspace to externals.

6 Contributions to organizational learning

In this chapter, the findings of the empirical case studies are synthesized and discussed as they relate to the three organizational learning processes: creation, retention and transfer of knowledge. Additionally, the findings are related to prior research.

6.1 Knowledge creation

Prototyping and experimentation. One of the most essential characteristics of a corporate makerspace is the making of prototypes during the creative process, which can result in physical prototypes, functional demonstrators, mock-ups etc. Employees can transform their designs into reality and thus achieve tangible results. The problem is, that today many employees only work digitally in the corporations. By offering a corporate makerspace to its employees, the companies strive for more innovation as the people can use their own hands in the production of prototypes. Although individual components are manufactured by the digital manufacturing machines, the prototypes must be assembled. Through the manual work, the people get immediate feedback and notice directly, what works and what does not. They can learn from the mistakes they make and these reflections after making can bring valuable contributions to the process. This is in line with Holm (2015b, p. 29), who argues that prototyping allows for rapid feedback and thus design improvement.

> *"It's getting people back into using their hands and I think a lot of innovation can come off when you are making, because mistakes happen. You find, oh when you thought that, actually that happened, so you didn't realize that was going to happen and you can't find that from using a computer."* (A6)
>
> *"I think this is a totally new way of working."* (A8)

There are often no possibilities on factory floors to use machines to make prototypes. For example, in company ALPHA designers usually create drawings and sketches of new designs on paper and/ or digitally on computers. Before the makerspace network was implemented at company ALPHA, the designers had to hand over their designs to the sample room if they needed a physical prototype. It was not possible for the designers to produce the samples by themselves, because only the trained staff of the sample room are allowed to use the professional machines. This gap in independent physical prototyping as a possibility for designers to realize their ideas in physical shapes by themselves was closed by the establishment of the makerspace.

In many cases, a good prototype results in a budget being provided for further development of the idea. The implementation of small projects in the makerspace is easy for the departments, since there are no costs for the commissioning department, the costs are covered by the corporate makerspaces. Furthermore, people who work on private projects in their free time have new ideas which can also be useful for companies.

> *"When people do something for private purpose, then they tend to be more passionate about it than if it is in a professional context."* (A5, translated by the author)

> *"For me it has immense impact on the whole work here. If they are allowed to work with the machines for private purposes, then they also learn in addition. And also give more and deal more intensively with the matter if it is for something private. And all the know-how they can then apply here for prototyping for internal projects."* (G1, translated by the author)

> *"For personal projects, the motivation is often very high and the acquired knowledge and experience gained in the implementation of private projects, the employees can also use in the professional context. Working on personal projects spark new ideas, which one can bring back into the company."* (B1, translated by the author)

According to Forest et al. (2016, p. 6), high quality design concepts require the building and testing of different designs. That assists the detection of design errors in the product early, crucially before production starts. Prototyping enables a faster visualization and conception and therefore an improvement in the continuous development process of products (Katterfeldt et al. 2014, pp. 124–125). Basically, the acceptance of prototypes can be tested directly on the customer, this way the customer satisfaction is measured beforehand and predictions are made about how the final product will be received on the market (Arnkil et al. 2010, p. 28). For the companies investigated, testing with end-users plays a minor role. Prototypes are more used for internal product development teams.

Doing becomes the essential part during the process of rapid materialization and leads to learning in a more active way (learning by doing). Eisenhardt and Tabrizi (1995) found that learning by doing accelerates the pace when developing new products. The researchers argue that approaches of improvisation combining real-time learning and testing lead to more effectiveness than planning, particularly in uncertain environments.

Similarly, Argote (2013b, p. 197) concludes that learning by doing should be preferred when knowledge is uncertain, not understood well, and highly dependent on the context of the organization. This is especially of concern when working on radical innovations. As the case studies show, corporate makerspaces are used for both working on incremental innovations as well as projects on radical innovations and used for product and service innovations as well as new business models.

> *"It's about incremental as well as disruptive innovations, that's right, in some cases, theoretically market-breaking innovations."* (G2, translated by the author)

Creativity. Furthermore, experimentation increase the number of random innovations. Especially in company ALPHA, at the beginning of the standard design process, many ideas are fabricated in the makerspace. At this stage of the process, many employees are present in the makerspace and can use the opportunities afforded by the makerspace spontaneously. Employees should not be forced to work only in their workplaces, because this hinders creativity. In the early stages of the design process, new solutions are implemented very quickly during the idea-finding process.

> *"I see an immense amount of benefit which I didn't think before. [...] Being creative doesn't only mean to do nice sketches or nice products creatively, it means challenge yourself and think out of the box, put yourself out of the comfort zone more often and then you will become more creative. [...] When they enter here, they say 'ah we are not creative', I say, wait, wait, wait, you are creative, the thing is that you don't know it."* (A1)

Essentially, creative employees get the opportunity to start an innovation project with a physical prototype. Bill Coughlin, CEO at Ford Global Technologies, states (Flaherty 2012): *"An idea on paper is easy to kill, but when you create a prototype of it and a supervisor can see it and experience it, it's harder to say no. Once someone starts thinking creatively it's hard to turn that off. People stop seeing problems and start seeing opportunities."* From experimentation, employees are more likely to get new ideas and to spontaneously discover new possibilities or processes on how a new product can be created.

Especially, idea workshops with employees from different functional units can discover and initiate the development of new products and processes (Schirmer et al. 2012, p. 54). This is related to the topic of co-creation, which is the term used for any act of collective creativity (Sanders and Stappers 2008, p. 6). Meeting others in the makerspace helps with increasing individual creativity. The employees become more creative by participating in the workshops offered at the corporate makerspace. Especially in company ALPHA, many workshops are run, where the users get introduced to new design methods and are supported when making their prototypes. Additionally, Weinmann (2014, p. 17) claims that prototyping enhances the creativity of the participants in a makerspace.

> *"People are coming here and are much more relaxed and then they might accomplish much more even in a shorter time like we saw this morning in two hours. They have reached a number of sketches that they wouldn't have reached in seeking their own desks for one week. So, these are the things that you realize, when given the right ingredients and the right space you might get much more out of it."* (A1)

Entrepreneurial thinking. The entrepreneurial spirit within a company can be improved, because the employees get the opportunity to experiment with new technologies and start new projects. Employees are more likely to take on risks and the chance to discover *accidental entrepreneurs* within the company is raised (Holm 2015a, p. 28). Here, it is essential to support entrepreneurial employees with a commercialization process which supports the idea generator to develop the idea further. In that way, corporate makerspaces can serve as incubators for the development of new innovative products, services and processes (Weinmann 2014, p. 7).

Existing research suggests that self-efficacy, persistence and activity of individuals is supported through a makerspace, which makes it easier for employees to solve emerging problems (University of Southern Carolina 2017). The usage of digital machinery allows the users to prototype, to work hands-on and to more easily make ideas tangible. The faster ideas are made tangible, the sooner they are evaluated, refined and the best solution found (Seravalli 2013, p. 7). By accepting failure as an possible part of innovation, employees are reminded that the makerspace is not about the end product, but the process instead (Nebraska Libraries 2016, p. 9). That means, the company may develop a kind of failing culture, where trying out new things is allowed and even encouraged.

Inspiration. An important aspect in corporate makerspaces is the inspiration of employees. Therefore, it is important that samples developed and produced in the makerspace are made visible to everyone, for example, by presenting the prototypes in showcases. The presentation of these items supports the understanding of new concepts and product ideas. Additionally, posters with results of finished projects should be placed inside and outside the makerspace. This is intended to inspire employees from different departments and spark conversations between them. Moreover, that demonstrates the potential of the makerspace to the management.

> *"I think people come here with preconceived ideas but then also come in and see maybe something else someone else is working on or something that we have produced. [...] People are looking out and they are keen to be inspired within the space, not just bringing their ideas, so that's nice."* (A6)

Since the makerspaces are available to all employees, some business units use the makerspace for internal workshops and meetings as well as for creative work (e.g. company ALPHA and GAMMA). The main reason here is the appealing design and atmosphere. Conventional meeting rooms differ little from the usual workplaces of the employees. At company ALPHA, there is a very relaxed atmosphere in the corporate makerspace (nice space design, background music etc.). Remarkably, some employees use the corporate makerspace during their breaks, just to get inspired:

> *"Another use case is that people come in with a coffee and get inspired, listen to music and just watch what the others do."* (A5, translated by the author)

Employee motivation. The case studies show, when employees can fabricate their ideas themselves, they have a learning experience which increases their motivation. Basically, researchers have identified several forms of motivation, each with certain consequences for learning, performance, personal experience, and well-being. The motivation and performance of employees is increased by an optimized work environment (Davis et al. 2011) such as a corporate makerspace. On the other hand, literature shows how resource conflicts, risk and high uncertainty make knowledge and research work very complex (Trott 2008; Karlsson et al. 2004; Hansen 2002) or how deadlines, directives, pressured evaluations, and imposed goals diminish intrinsic motivation (Ryan and Deci 2000, pp. 68-70). Intrinsic motivation is the *"[...] inherent tendency to seek out novelty and challenges, to extend and exercise one's capacities, to explore, and to learn."* (Ryan and Deci 2000, p. 70). The case studies illustrate that corporate makerspaces can provide the supportive context so that people exploit all the positive potential of human nature as much as intrinsic motivation.

> *"People are suddenly utilizing their strengths in such a different way."* (A2)

Likewise, Weinmann (2014, p. 17) states that makerspaces at universities increase student's motivation. They come voluntarily to the makerspace and share their interest of building things with an interdisciplinary community, which all is quite motivating and satisfying for them (Weinmann 2014, p. 39). In the same way, the usage of makerspaces within a company increases the motivation of its employees, when they get an opportunity to work in the makerspace on professional as well as private projects.

Skill enhancement. Having access to machines and meeting skilled people in a new way, contributes to the development of human capital in the area of individual knowledge, competence and skills of each participant in the makerspace (Seravalli 2014, p. 115). The offers of corporate makerspaces can be appreciated as competence development measures for all employees. Training on different topics promote the development of new skills. Workshops are essential for knowledge generation, sharing and storing (Schirmer et al. 2012, p. 166). As already argued, workshops based on a hands-on approach with prototyping and making experiments in the makerspace, can encourage learning by doing and thus raise the learning effect (see also Weinmann 2014, p. 2). Such workshop formats can provoke and stimulate action through actual experience (Mogensen 1992, p. 11).

Company BETA sees importance especially in learning and trying out new technologies. This means that the makerspace offers possibilities where employees are trained on trending topics. By attending workshops, the skills and competences of the participants get improved (e.g. problem solving, methodical competence).

> *"It's also quite important to have that for competency building of the employees."* (A7)

6.2 Knowledge retention

Repositories. Knowledge can be embedded in various repositories: individuals, routines (formal and informal), organizational structures, technologies or culture (see chapter 2.5.5.2). For knowledge retention, it is important to transform tacit knowledge into explicit knowledge (e.g. physical prototypes). Corporate makerspaces with staff being present function as a tool for storing knowledge. Particularly, the makerspace staff foster the transactive memory system of an organization, because the staff members meet people from different departments and thus they know quite well who knows what in the company. The makerspace staff can forge the links between the people from different business units, who face the same problems.

> *"I know someone, let's call him! He'll come by, too. Wow, this is possible? I never would have thought that. Yes, we do that! And yes, that improves knowledge management."* (G2, translated by the author)

Regain knowledge. In the context of knowledge retention, organizational forgetting plays an important role. Case study ALPHA displays how the company lost valuable knowledge, because it shifted manufacturing abroad. Today, one use case of the corporate makerspace in company ALPHA is to rebuild lost skills and knowledge about the production of products among the employees. This knowledge can be re-learned by the designers with the activities done in the corporate makerspaces.

> *"There was an incredible amount of knowledge lost – manufacturing knowledge – that was quite a thought at the beginning to create a way once again, that employees can work with the product actually, which used to be completely commonplace. Building this knowledge of what it means to make a product, if only rudimentary, was a use case that existed in the beginning."* (A5, translated by the author)

Documentation. It is common practice that the staff members store project documentations and experiences gained during operations in online storage systems. In that way, lessons learned are made available for the other spaces. This information exchange provides transparency, creates a sharing attitude and makes it possible to profit from each other.

> *"We have a shared cloud system. We are really open, so everything what we put in the cloud they can enter. Same for us, we can enter the all the stuff that they make. After every workshop, we make pictures and videos, then we put that in the cloud system and then the others can see, these guys did this and we can see what they are working on."* (A8)

This is in line with the existing literature, which suggest that insights, ideas, and best practices need to be shared from one makerspace to another (Maker Media 2013, pp. 1-2).

Idea collection. The corporate makerspace functions as a focal point where it is possible for a product independent unit (such as human resources) to suggest ideas for products. For example, if an employee of a product-independent unit had an idea on how to improve a product, there was previously no contact point where it was possible to raise the idea for further development (case ALPHA). Now, the corporate makerspace serves as a starting point for ideas from all areas of the company, this is related to the concept of collective intelligence (see chapter 2.5.7). A corporate makerspace is supportive, because independent of where the good ideas come from, one must be able to detect them to take advantage of them.

6.3 Knowledge transfer

Communication. One major goal of corporate makerspaces is to increase the likelihood that people meet colleagues from other departments and to increase the willingness of employees to communicate with each other. Especially in company ALPHA, the communication between the employees has significantly improved since the opening of the corporate makerspace and the maker community has become much bigger. People have become more open, and as mentioned above are more likely to speak to colleagues from other departments they do not yet know.

> *"So, people really like the fact that you can exchange ideas with people from other departments and also talk about the same problems. Usually, that does not happen often, because the departments themselves are rather closed."* (A3, translated by the author)

Noticeably, the makerspace design plays an important role in terms of fostering communication. According to Waber (2014), only few companies measure whether the design of their workspaces helps or hurts performance. Face-to-face interactions are by far the most important activity in an office and thus creating chance encounters between knowledge workers improves performance (Waber et al. 2014). Allen and Henn (2007) created a holistic concept for R&D working environments where they focus on the product development process (PDP) and make it visible in the architecture. Thus, management tools, organizational structure and physical environment are connected. The architecture must fulfill the task of bringing employees together and increase communication between them. Allen and Henn's concept put the prototypes of current projects into the center of the building. This area is also the central location for communication between the different project and development teams. A holistic view of processes, information and communication technology and the physical environment is particularly important in the context of increasing exchange as well as cooperation in and between research activities (Heerwagen et al. 2004; Nonaka and Konno 1998; Becker and Steele 1995).

In certain contexts, openness is extremely powerful and valuable for innovation processes. But appreciating more openness can also be quite a painful process for some employees. However, some users are eager to share their knowledge with others and offer, e.g. workshops and training on topics they are good at. Conversely, if there is demand for acquiring new knowledge, e.g. workshops are organized.

> *"And that's the way how we get new people in for workshops and they write down what they want to learn. So, from that we know, there are a lot of people who want to do something."* (A8)

Today, massive knowledge is accessible through the Internet at any time and from anywhere. People can inform themselves by Massive Online Open Courses (MOOC). In contrast, the hands-on experience-based approach in makerspaces cannot be transferred via web courses.

Inbound knowledge transfer is a mode of inbound open innovation (Chesbrough 2006). When opening a corporate makerspace to company-externals, new ideas and approaches find their way into the company. However, companies often lack openness to the outside world. The case studies support this by the fact that all examined makerspaces are not yet ready to open up to company-externals. Surely, this is attributed to the existing processes that make it difficult. Moreover, there is a general reluctance and uncertainty regarding the use of the global maker community. Here, the issue is to prevent the unwanted transfer of knowledge to the outside. The cases show slightly inbound knowledge transfer but no intentional outbound transfer.

Communities. Corporate makerspaces create new communities and networks, which strengthen internal networks and support interdisciplinary work (see also Weinmann 2014, p. 24). Generally, communities provide the opportunity for people to experience social exchanges, ranging from casual conversation to shared purpose (Barron and Barron 2016), In a makerspace, people are working on different projects. Because of the diversity of users and the given structures in the makerspace, a range of skills is applied to different projects (see Wilczynski and Adrezin 2016, p. 3). The diversity of people and projects lead to more passion for one's work and new ways of working (Maker Media 2013, p. 35). Within makerspace communities, users with various degrees of knowledge and skills learn from each other by sharing knowledge (see Weinmann 2014, p. 62). For example, the knowledge of how to operate machines properly can help to reduce the number of accidents and damage when working with machinery and equipment (Weinmann 2014, p. 62).

Collaboration. The establishment of a corporate makerspace is intended to promote the collaboration between the individual business units, which should lead to breaking departmental silos and fostering networking. Through collaboration of the various project groups in the makerspace they profit from each other mutually. For example, company ALPHA faces the issue that individual business units are very closed, little communication and exchange happens. The cooperation between the business units is missing. Now, the corporate makerspace acts as a collaboration platform and offers employees from the various areas the opportunity to get in touch with each other, to exchange ideas about designs, and to work on joint developments. For example, employees who had not previously known each other met in the corporate makerspace and recognized in the conversation that they both face the same problems. In some cases, it has even led to the launch of a new cooperation.

> *"It's about collaboration, it's about share your knowledge. That sometimes you give something away which also gives you satisfaction. Learning from others makes you happy."* (B1, translated by the author*)*

For example, when a new project is started in the makerspace of company GAMMA, it is an option to involve specialists from other companies, or even try to attract them as customers. Customer co-creation describes the active integration of customers into corporate business activities, with the purpose of including external sources (Ihl and Piller 2010). Including the customer into the development process leads to more suitable co-constructing, joint problem solving, and personalized customer experience. But, co-creation requires adjustments and risk-taking for both managers and consumers (Prahalad and Ramaswamy 2004, pp. 13-14). Established organizations can tackle complex challenges and develop new ideas and initiatives by collaborating with each other. (Baek et al. 2008, p. 2; Baek et al. 2010). It is worth noting that, collaborating across various sites, countries and continents, can lead to problems due to technological, cultural and linguistic differences in the locations around the world.

Visual aid. The ability to use physical prototypes as a visual aid for conversations makes it easier to explain one's own idea and allows to better understand other people. Thus, using prototypes can lead to reduction of language barriers between employees. If one has difficulties with explaining concepts intelligibly to other people, one can instead use prototypes and patterns to pass on the ideas. The touch and feel aspect brings an additional sense in the discussion process. In company ALPHA, employees are now able to present their ideas by viewing real objects in addition to the sketches and digital drawings during the meetings within their business units. As one employee stated:

> *"Project meetings have a completely different quality since the introduction of the corporate makerspaces, because for the employees it is easier to visualize their visions and ideas and really show what they mean."* (A3, translated by the author)

Employer branding. Corporate makerspaces are used to market the company externally as well as internally as innovative and employee-oriented. This is important for the companies to position themselves as an attractive employer and to interest talent. In the case of company ALPHA, the new photos of the management board were made in the corporate makerspace. At company BETA, the corporate makerspace is very prominently represented in the annual report. Company GAMMA already operates seven locations worldwide and in the investigated makerspace a group of students are working, who may become regular employees in the future. These examples show the high recognition of the makerspace facilities in all three companies. The goal is to attract talent and thus to enable a transfer of knowledge, skills and competences into the company via hiring new employees.

Intellectual property. Important questions are, how are ideas protected and who is the owner of the ideas? For example, at Company ALPHA, all industry-specific ideas of employees (including also those ideas during free time) are intellectual property of the company. Employees are not allowed to develop their own business, which could conflict with the company's products. All three companies have well-established processes for what happens with new ideas and developments. In principle, inventions that arise in the makerspace are property of the company. In any case, the company must align procedures for patent application and idea commercialization. It must be clarified beforehand what happens with a new idea which results in a patent and who is the owner of the rights of that patent (see also Arnkil et al. 2010, p. 35).

7 Implementation procedure

This chapter introduces a five-step procedure model on how to set up a makerspace within an established company. Beforehand, two different possible approaches – top-down and bottom-up – are clarified. Then, a detailed explanation of each step within the five phases is provided. Finally, central aspects to consider during implementation and possible challenges are summarized.

7.1 Top-down versus bottom-up

Two approaches of how a makerspace can be set up within a company are possible: *top-down* or *bottom-up*. In two of the three studied companies, the impulse for the implementation of the corporate makerspace came from employees, who were already makers and liked to build stuff – in private life as well as professional settings. In company ALPHA, senior managers had tried to implement a makerspace but this had never been realized. When the company undertook a strategic realignment, the implementation of a corporate makerspace was recognized as an important element to support the new company strategy. The implementation of a makerspace was considered as a way to make key strategic topics more 'tangible' for the employees.

At company GAMMA, the impetus to establish a makerspace came directly from top level management. The CEO of the company gave the order to develop a space to support faster developments. In contrast to this top-down approach, the corporate makerspace in company BETA was implemented in the sense of a bottom-up approach. There, it was an idea and initiative that emerged from a group of young professionals. The group got support and a small budget from one department to set up a makerspace by themselves. In line with the basic idea 'think big, start small', a space was set up. The big difference in the approach of the two companies is the support of the top management level from the beginning. While company ALPHA and GAMMA provided a dedicated budget to implement because of the strategic aspect, the establishment of the corporate makerspace at company BETA was a small pilot project with little effort. In general, many makerspaces emerge in a bottom-up manner, when like-minded people come together to make, create and hack (Litts et al. 2014, p. 5).

Procedure model. Whether top-down or bottom-up, the implementation of a corporate makerspace comprises the following five main steps (see Figure 20): (1) *prepare budget ask,* (2) *develop project plan,* (3) *design corporate makerspace,* (4) *execute realization,* and (5) *launch, operate, monitor.* Importantly, the process is of iterative logic, where steps are repeated if necessary. The procedure model and the activities are based on ISO 21500 guidance on project management (ISO 2012).

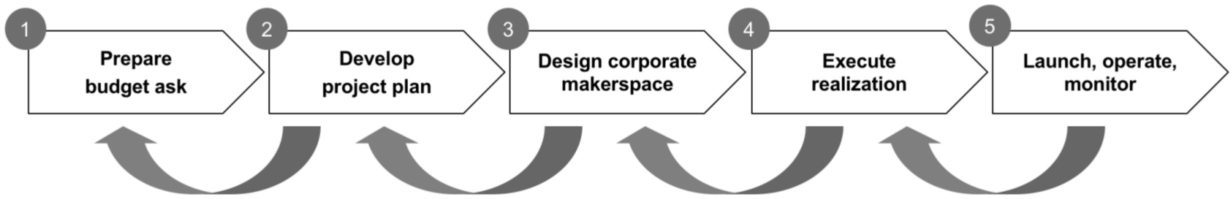

Figure 20: Five-step implementation procedure[27]

7.2 Phase one: Prepare budget ask

The main question to be answered is: how can internal buy-in from executives and managers be ensured? Phase one consists of the following tasks, which are necessary to convince decision-makers to support the corporate makerspace initiative:

- *Describe need:* It is recommended to describe real problem situations of employees, where the implementation of a makerspace can provide the solution.
- *Frame objectives:* It is necessary to think about the main objectives, which should be addressed with the corporate makerspaces. What is the value added for the company? The makerspaces initiative should be recognized as part of the company's overall strategy. The question to answer is, to which strategic goals may the makerspaces contribute? Furthermore, it is beneficial to outline certain use cases for the usage of the makerspace.
- *Define success measures:* Based on the objectives, it is possible to elaborated success measures in terms of key performance indicators (KPI). This is necessary to monitor the ongoing accomplishments of the pre-defined goals. KPI's such as users per month, employees attending workshops, people visiting the space, number of printed prototypes, hours of laser cutter usage etc. are necessary to maintain control of operations. However, the cases reveal that the most appropriate success measure is the degree of employee satisfaction, which is measured with the net promoter score throughout the year using employee surveys (see chapter 5.3).
- *Estimate budget:* An indispensable premise during phase one is the estimation of the necessary budget, which is needed for the implementation as well as to ensure the ongoing operations of the makerspaces. One option is that a fixed amount of budget is provided. Another option is that a concept for the makerspace is developed, which

[27] Author's illustration

then is the basis for the calculation of how much money is needed to implement the desired concept.

The results of phase one are portrayed needs as well as proposed objectives, use cases and budget. The first milestone is the decision to implement including budget approval.

7.3 Phase two: Develop project plan

The following tasks need to be considered during phase two:

- *Implement project organization:* The first step within phase two is to set up a proper project organization aligned with project management processes. Relevant aspects such as limitations, milestones, deliverables, or risks as well as the responsible project team for the implementation are specified in greater detail.
- *Analyze as-is situation:* The project team starts with a detailed analysis of the as-is situation in the company to understand the boundary conditions and how they will influence the future shape of the makerspace.
- *Evaluate available resources:* It is vital to get an overview of available internal and external resources such as possible locations, support from employees with experience on makerspaces etc.
- *Get budget clarity:* Define who is in charge in terms of financial aspects, create budget processes and create a detailed cost estimate based on current assumptions and further milestones. The budget includes at least the following categories: construction, planning, machinery and equipment, furniture, IT and contingency.
- *Set up timeline:* The proposed timeline gives an overview on the work packages, milestones and deliverables. The time needed for the implementation of a corporate makerspace depends on various factors and can range from a few weeks up to several months from the beginning of the project until the opening event.

At the end of phase two, project organization is implemented, the as-is situation is analyzed and an overview of relevant resources is available. In addition, accompanying support processes such as change management should be considered.

7.4 Phase three: Design corporate makerspace

Within this phase, the shaping of the future makerspace takes place. Fortunately, designers and architects of makerspaces tend to have a mentality of putting people first rather than tools when implementing and growing a makerspace (Litts 2014, p. 6). The design phase of the makerspace consists of the following main tasks:

- *Consider five design dimensions:* The design of the corporate makerspace splits up into five work streams: *proposition, place, process, people,* and *promotion.* These five design dimensions are elaborated on in more detail in the subsequent sections. It is recommended to establish small project teams with main responsibilities in all five work streams. Setting up project milestones must be done together with all work stream leaders.
- *Do benchmarking:* Visiting already implemented makerspaces at other companies is suggested to get a sense of how a makerspace could work within a corporate setting. It is also recommended to visit best practices of privately-owned or academic makerspaces to get different perspectives on the topic. The aim of benchmarking is to quickly find out what works and what does not work when talking with the responsible people in the various spaces. The lessons learned help to get a better understanding of relevant issues during implementation and operation of the makerspace.
- *Integrate user feedback:* During the implementation process it is essential to get in contact and talk with future users of the makerspace. This is necessary to capture the needs, wishes and expectations of the employees who will use the space afterwards. Based on the user needs, the makerspace can be designed in a way that the employees are attracted.
- *Evaluate options:* The elaboration of various design options allows comparison with each other to find the solution which best fits to the local conditions.
- *Initiate realization:* When the main planning steps are completed, the construction work and the realization of the elaborated processes can start. Theoretically, this is be done when all decisions for the most appropriate design of the makerspaces have already been made. Realistically, planning and execution go hand in hand. Therefore, proper coordination of all tasks within the five work streams becomes crucial.

7.4.1 Proposition

This design dimension addresses the proposition, which defines the relationship between corporation, makerspace and employees. It is recommended to define specific makerspace principles on the normative level. What is the mission and vision? Who is the target audience? What is the purpose? What are the roles and responsibilities?

Additionally, answers to the following questions can be used as guidelines when defining the proposition: What is the focus of the space and what should be accomplished? Which projects should be in the space? Are incremental innovation projects, radical innovation projects or both types favored? How do we frame certain innovation challenges? How much diversity of ideas do we want? Do we focus on narrow problems, or do we explore broader innovation opportunities? Do we want to organize collaborative projects with external partners and how do we do that?

7.4.2 Place

Within the design dimension *place,* the first step is to define the location of the makerspace. As already mentioned above, centrality and nearness of the makerspace location to the workplaces of the employees is crucial to facilitate drop-in traffic and ensure a high rate of visitors and utilization. Furthermore, this dimension includes the topic of machinery and equipment.

Create design language. Makerspaces are places for creativity and innovation. Therefore, the space must be designed in a way that it provides a stimulating atmosphere. A common theme on how the makerspace is perceived by its users must be created. This theme acts as a guideline for the design of related aspects such as online presence and communication strategy. The support of professional architects and designers is helpful to find the appropriate interior design.

Outline layout. Elaborating the layout plan goes hand in hand with creating the design language. It makes sense to create 3D sketches and fill the space with machinery, equipment and furniture. For the floor layout, it is necessary to decide on relevant aspects that influence the layout plan such as registration process or safety regulations. Room sizes should be carefully considered according to their initial function and on how they might be used in the future. For example, are separated rooms needed for closed projects? Simultaneously, the relevant machinery and equipment needs to be selected, because the amount and specifications affect the layout plan. Following the accepted investment plan, a procurement plan needs to be developed. The procurement plan includes all purchases that are necessary to realize the makerspace. For example, which machinery will be purchased from which company. Delivery times play an important role and need to be considered properly in the planning process. After the elaboration of a detailed construction plan and the definition of construction requirements, a vendor bidding and selection process is necessary to determine the suppliers for the various parts of the construction work.

Start construction work. When all relevant partners have been selected, the construction work can start. The orders for machinery, equipment, tools, furniture etc. can take place in parallel. When the construction work is finalized, all machinery and equipment can be installed and implemented, furniture and fixtures can be placed.

7.4.3 Process

The *process* design dimension focuses on the operation and management of the makerspace. This ranges from offering basic machinery training up to the possibility of self-directed usage of the makerspace for the employees. Important questions to answer here are as follows: How long can employees use the makerspace? How do we structure and organize the makerspace to best support employees and innovations? Which programs should we offer? How can we make it easy for employees to work and use the makerspace? How can we identify the good ideas to work on?

Two key aspects need to be considered within this work stream. First, create a makerspace user journey and second, define the internal processes. The makerspace user journey is necessary to develop proper offers for the users as well as define the internal processes. Here again, it is essential to get the feedback of the future users to get insights on customer needs. It is useful to organize a user experience workshop to develop the user journey for the makerspace.

When developing the internal processes, these questions are to be reflected on: How should the makerspace work? What is the operation model? How are the responsibilities spread? How should the customers use the makerspace? The following aspects need to be considered in terms of makerspace operations:

- *Entering the makerspace:* What happens when a person enters the makerspace needs to be clarified. On a general level, the individuals can be split up in two groups: first, persons who visit the makerspaces for the first time and second, users who have been already at the makerspace. For the second group, no immediate actions are required. For the first group, it is essential for the staff members to recognize first time visitors. In most cases, people let the staff know that they are visiting for the first time. The next step is to show the people around, explain the house rules and inform them about onboarding procedures and machine training. This ends with the person signing the waiver that they have attended the introduction tour. For example, in company ALPHA the people get a sticker on their badges. Finally, the user information is entered in a database.
- *Onboarding:* Here, the purpose of the onboarding training needs to be defined. What information is essential for the users to know? It is recommended to make the onboarding training mandatory for all new users.
- *Using of machines:* The machinery can be categorized in two types: *hazardous* and *non-hazardous.* In the case of hazardous machinery, users always have to talk to the staff before they start working. Because of health and safety aspects, it is recommended that the staff members support the users in operating this type of

machinery. Non-hazardous machinery are operated by the users themselves, but staff members support if needed. After usage, the machinery must be cleaned. Additional questions to be considered are: What machines are bookable? Can users book and use machines post opening hours? Which machines have limited access post opening hours? How does the booking system work? In terms of tools, it needs to be defined how the makerspace staff wants to manage the tools, e.g. signing for and giving out a set of tools by the makerspace team.

- *Material management:* It is assumed that certain amounts of basic materials are available for the users all the time. Depending on the makerspace purpose and the industry of the company, the types of basic materials can vary. A procurement process including material ordering and payment needs to be established. In some cases, it is easier to bypass the standard purchasing processes of the established organization, because they would take too long. Moreover, it should be possible for users to bring their own materials as well, especially, when employees want to work on private projects in the corporate makerspace (if that is allowed).
- *Workshops and training:* First, relevant topics for workshops and trainings must be identified, e.g. 3D printing or a laser cutting. Based on the number of requests, the needs of the users and a conducted traffic analysis, the dates and frequency for workshops and trainings can be scheduled. Health protection and safety regulations are indispensable aspects. House rules must be followed strictly and accidents must be avoided.
- *IT-infrastructure:* In collaboration with the IT department, the requirements for the IT system needs to be identified (registration process, booking systems for machinery and training, collaboration platform etc.) and translated into technical specifications. For example, how should the website and user interface look? User acceptance tests for website design, layout and content should be undertaken (for the beta version as well as the full version).
- *Idea commercialization:* What happens with great ideas generated by people working in the makerspace? Who owns the rights? These and all related questions need to be tackled. Here, it is necessary to establish a clear process for idea commercialization. Advisors from the legal department provide support when setting up the legal framework including intellectual property regulations.

7.4.4 People

By involving the right people from both inside and outside the company, a corporate makerspace team can combine intimate business knowledge with fresh perspectives. Some questions to be answered during this design dimension are for example: how can we find the right people to work in the makerspace? Which internal and external mentors should we bring on board? The following tasks need to be undertaken:

- *Set up recruiting process*: Finding the right people to lead and operate the corporate makerspace is essential. Here, it is helpful to align with the company's human resources department to choose the proper talent acquisition strategy. Aligning with works councils may be required.
- *Develop job descriptions:* The tasks and responsibilities of the open jobs must be outlined. The process should allow internal as well as external applications. It is recommended to use existing networks. The preparation of a staffing plan is valuable in terms of displaying the organizational structure and prioritizing critical positions.
- *Drive recruitment:* This can be done with steady communication of the makerspace concept within the organization. Furthermore, offering the opportunities for employees and external people by posting all open positions both, internally and externally is obligatory. Tasks to evaluate possible candidates need to be developed, e.g. integrate a case study during the job interview sessions. For example, company ALPHA started with an initial round of video interviews where a couple of promising candidates emerged. The second round consisted of in-person interviews with a presentation of a prepared case study as well as a technical assessment for the usage of machinery and equipment. A proper training plan for the onboarding of the new staff members is necessary.

7.4.5 Promotion

This design dimension deals mainly with the question of how to properly communicate and market the makerspace offers and opportunities. Therefore, a communication strategy needs to be defined. It is suggested to hold a workshop with the project team to develop the communication plan by using creativity techniques such as brainstorming. The communication strategy includes the following aspects:

- *Communicate makerspace concept:* It is important to start the internal communication of the makerspace concept quite early, so that all employees are informed about the new space in advance. Open positions in the makerspace are potential opportunities for current employees. When the first article is published, it needs to be considered that reactions and questions will follow as one example from company ALPHA expresses: *"This is awesome. Please keep me on your mailing list and let me know what is going on and when."*. But keep in mind that it takes time to give answers to user questions.

- *Design makerspace identity:* To transport the message of the makerspace and distinguish the makerspace initiative from others, it is necessary to develop a makerspace identity as a guideline for digital and printed makerspace content (logos, photos, videos etc.). This is central to generating visibility and attention.
- *Develop launch plan:* It is recommended to develop a timeline for all publishing actions, e.g. when which articles are published in the internal social network. Moreover, the opening event activities need to be defined. When defining the opening event, consider three dimensions: *who, when,* and *what. Who* describes the target audience. Put the focus on the target group, but also think about how to involve all others. Estimate the number of individuals attending. *When* defines the official opening date. Maybe there is an opportunity to combine the opening event with another happening at the company, but consider a 'beta' testing prior to official launch (the required time span depends on the local conditions, but at least two to three weeks). *What* describes the format of the opening event. Possible activities are information tours with showcasing capabilities, photo booth, virtual reality booth, exhibitions, awards, feedback mailbox, inspiring speakers, short trial workshops or challenges to engage guests. Here, think of how to present the makerspace concept in the best way.

7.5 Phase four: Execute realization

The fourth phase of the procedure model comprises all necessary tasks that need to be done to execute the developed concept. It is important to ensure the responsibilities for construction work, ordering, purchasing, installation of machinery and equipment, setting up of IT-infrastructure, recruiting process, communication and marketing etc. However, implementation and planning are contiguous activities and follow an iterative logic. One main aspect is integrating test users during the realization process.

7.6 Phase five: Launch, operate, monitor

When all the preceding steps have been completed, the makerspace can be launched with the official opening event. Tasks associated with ongoing operations are to implement a monitoring system (e.g. measurement of usage frequency of machinery and equipment); ask for, evaluate and integrate user feedback; and identify possible barriers for employees with the goal of minimizing them. Internal processes should be refined and improved continuously. In addition, it is also necessary to think about how to further develop the makerspace and what new offers (technologies, workshops, events etc.) should be implemented and proposed to the users. Finally, a roadmap which displays the outlook and evolution of the corporate makerspace concept post opening should be developed.

One of the main assignments during this phase is building the community. It is necessary to think about mechanisms that facilitate interactions between employees from different business units. Other questions to be answered are: how do we foster networking to support employees and innovations? How can we tap into already existing communities and add value to the organizational system?

7.7 Considerations and challenges

The investigated case studies reveal some aspects that need to be considered during the implementation process. These aspects are described shortly in the following sections.

Meetings. To ensure the exchange of information between the five different work stream teams it is necessary to set up *lead calls*. These meetings provide the possibility to review open action items from the to-do list, review project timelines, give updates on progress of the different work streams, discuss important and urgent issues, introduce new aspect and define further action items, priorities and next steps. Additionally, the identification and common agreement of all involved parties (facility management, architects, vendor companies etc.) on key milestones and achievements is indispensable. Clear responsibilities, action items, milestones and deliverables ensure the ownership of tasks. Furthermore, s*teering committees* are necessary to communicate with top-management. Individual work stream meetings and workshops with the responsible people during the implementation process are necessary to ensure progress. Team workshops are recommended for idea generation and critical questioning to get the best solutions out of the process.

Communication. A cross-functional communication plan is vital to optimize the interaction and collaboration within the implementation team and between the departments involved. Regular exchange between the individual members of the project team is important to ensure a common knowledge base during the ongoing implementation process. Insufficient internal communication leads non-transparency during the progress of the implementation. Here, the establishment of a database with the ability to share information, update contents and timings is helpful.

Iterations. For the accomplishment of all work streams an iterative process is obligatory, because in many cases, e.g. the space design changes over time. Here, flexibility is the key due to demand changes or the development of new technologies in terms of machinery and equipment during the planning phase.

User integration. Importantly, the users' needs and wishes for such a facility must be considered when establishing a makerspace. As mentioned above, the insights gained from customer feedback need to be integrated in the design and operation of the corporate makerspace. Moreover, after the opening of the space ask the users randomly about their opinions of the makerspace. The goal is to find out what could be improved and what already works well.

Benchmarking. Do market research and visit other makerspaces. Talking to people who are already operating a makerspace can help to identified priority actions to tackle. One option is to create a makerspace testing team and provide it with a budget and the freedom to create something at a makerspace for a few days. After the testing phase the team needs to give feedback and present the lessons learned from the other makerspace to the project team responsible for the implementation. In addition, the same test team can evaluate the new corporate makerspace during the pre-launch phase.

Schedule. Possible delays can arise easily because of different issues. For example, the opening of the makerspace in company BETA had to be postponed significantly due to issues arising related to internal regulations and processes. Another example concerns the recruitment process, which is time-consuming (up to several months in one of the cases). Getting enough relevant job applications and finding the right people seems to be an arduous task. Another aspect in terms of delays are long decision-making processes. Furthermore, when implementing more makerspaces at different sites in parallel, the coordination between the individual sites is time-consuming, which may lead to a time shift in implementation (as the example of company ALPHA revealed). Aligning the different locations and ensuring that the vision and the concept are implemented in all locations is challenging, because for each site different teams are in charge for the implementation. It is suggested to introduce first a makerspace at one corporate location and then to transfer the concept together with the insights gained directly to the implementation at other locations.

In general, the implementation of a corporate makerspace is based on the same logic as that of public or academic makerspaces.

8 Conclusion, contributions and implications

This chapter provides the conclusion, which focuses on the answers to the three research questions. Additionally, the study's contribution to theory are discussed and managerial implications are specified. Finally, the study's limitations and suggestions for further research and investigations are presented.

8.1 Conclusion

This dissertation investigated corporate makerspaces in established enterprises based on three research-leading questions. The following sections summarize the answers to these questions.

RQ1: How are corporate makerspaces designed and operated in practice?

Data comparison of the three investigated cases shows differences in infrastructure (e.g. location, layout, design, interior), facilitation (e.g. staff responsible for user support, access to machines) and community (e.g. diversity, user base). On the other hand, commonalities are found in the areas of fabrication machinery and equipment, material usage, safety standards, content of trainings and workshops. Basically, a corporate makerspace should offer an environment for a company's employees for exchange, handling tools, co-construction and usability that allows different people to work in a common space, oriented to design, prototyping and exploration of ideas.

The three investigated corporate makerspaces apply dissimilar operation models. The most important difference between the operation models is the area of facilitation. The three different approaches are *service orientation, self-reliant usage,* and a *combined model* of service orientation and self-reliant usage.

The *service orientation* operation model focuses on further development and realization of ideas and supporting users with methodical and technical expertise. The *self-reliant usage* operation model focuses on self-responsibility and independent learning of the users by offering the infrastructure (space, machines, technologies etc.) The users support each other, work together on projects, and organize different trainings and workshops according to their own interests. In-between these two operation models, a *combined model* is possible.

Besides the different operation models, the dimension of accessibility is set out as central. These two factors (operation model and accessibility) are used to build a new taxonomy framework, which allows to compare and display the different approaches of makerspaces (not only applicable to corporate makerspaces). Based on the taxonomy framework, four archetypical approaches for makerspaces are possible: (1) *open access and service orientation,* (2) *limited access and service orientation,* (3) *limited access and self-reliant usage,* and (4) *open access and self-reliant usage.* Independent from the applied operation model, all three investigated corporate makerspaces limit the access to its own employees, but want to open up to externals in the future.

Several factors are identified that are favorable for corporate makerspaces. The factors are clustered under the following four themes:

- *Management buy-in:* It is necessary that top managers support the corporate makerspace and its existence with financial grounding and allowing the makerspace team to grow the initiative. Framing guiding principles supports in communicating the mission of the corporate makerspace. Employees satisfaction surveys are an appropriate tool to measure the success of the facility but also to get feedback on services and offers.
- *Inspiring environment:* The environment comprises the physical space and the practices within it. In terms of space and infrastructure, a convenient location, open accessibility, flexible use cases, and the provision of relevant machinery and tools are required so that the users can play around and try out new things.
- *Entrepreneurial culture:* An active and lively community may emerge when people want to spend their time in the makerspace, because of the creative and stimulating atmosphere. Here, promoting a trial-and-error attitude is crucial, but also very challenging. Furthermore, some makerspaces have established work arounds, because sticking to the traditional organization rules inhibits agile working methods. Entrepreneurial thinking and acting may also be fostered through the establishment of open ecosystems with partners outside of the corporation, e.g. academic institutions.
- *User support:* The most important aspect is the team spirit of the makerspace staff, which needs to build on trust and mutual support. Diversity and interdisciplinary skills are beneficial to provide the best user support possible. Marketing is necessary so that all employees in the company get to know the opportunities provided by the makerspace. The challenge, however, is to maintain the initial hype after the opening of the corporate makerspace.

To summarize, a company needs to align the design and operation of its corporate makerspace to its product and service portfolio, internal processes and employees' expectations. Top management support and internal marketing is essential to build an active community of collaboration, openness and cross-functionality around the corporate makerspace. Additionally, the corporate makerspace must constantly change and adapt to challenges and new opportunities. Furthermore, it is necessary to frequently investigate the needs of the users to sustain momentum.

RQ2: How can a corporate makerspace support organizational learning in an established enterprise?

The answer to this research question is structured according to the three organizational learning processes: creation, retention and transfer of knowledge.

Knowledge creation. The most important role of corporate makerspaces is prototyping and experimentation. Depending on the operation model, employees can independently transform their designs and ideas into physical prototypes and functional demonstrators, which they were not able to make in the past. Prototyping and experimentation enhances the creativity of the users due to the ability to learn in fast iterations what works and what doesn't work. It is more likely that the employees come up with new ideas spontaneously, if the employees are allowed to work on personal projects. This is beneficial for the companies, because the knowledge and experience gained by the employees when working on personal project, can then be applied in professional contexts as well.

A corporate makerspace allows employees to unplug from their traditional working routine. The case studies show, when employees can fabricate their ideas themselves, they have a learning experience which increases their motivation and the ownership of their idea. The produced items support better understanding of new concepts and ideas. Showcasing these physical representations inspire and spark conversations between users. As the cases show, some employees visit the makerspace regularly just to be inspired by the creative environment.

Another aspect concerns the knowledge creation and skill enhancement of employees during training and workshops offered in the makerspace. Workshops based on a hands-on approach with prototyping and making experiments in the makerspace encourages learning by doing and thus raises the learning effect.

Knowledge retention. Knowledge can be stored in various repositories (e.g. individuals). It is important to transform tacit knowledge into explicit knowledge. One way to support this transformation is the making of ideas and thoughts physical in terms of artifacts in the corporate makerspace.

Furthermore, corporate makerspaces foster transactive memory systems in an organization. After some time of operation, the maker community (makerspace staff members and users) know quite well who knows what in the company. This enables to initiate connections between the expert knowledge stored in employees from different business to find new solutions to existing problems.

One important role of a corporate makerspace is the function of being a focal point, where it is possible for product-independent departments to pass ideas on to. Based on the ideas collected, the makerspace team starts new projects by themselves or searches for people who are interested in further developing an idea. Concerning collective intelligence, the makerspace is supportive because independent of where the good ideas come from, the makerspace team serves as a starting point for ideas across all areas of the company.

Knowledge transfer. One major goal of corporate makerspaces is to increase the likelihood that people meet colleagues from other departments and to increase the willingness of employees to communicate with each other. The case studies show that employees become more open and are more likely to speak to colleagues they do not yet know.

From the perspective of knowledge sharing, users are eager to share their knowledge with others and offer, e.g. workshops and training on topics they are good at. The community in the makerspace provides the opportunity for the people to experience social exchanges, ranging from casual conversation to shared purpose. Thus, a corporate makerspace is a place where knowledge is passed on from employee to another. Moreover, the ability to use physical prototypes as a visual aid for conversations makes it easier to explain and share one's own idea. Thus, using prototypes leads to reduction in language barriers between employees.

The establishment of a corporate makerspace is intended to promote collaboration between the individual business units, which should lead to breaking down silos and fostering of networking. Through collaboration of the various project groups in the makerspace they can profit from each other mutually.

Literature suggests that corporate makerspaces are used to open up to the outside world so that new ideas and approaches find their way into the company. But the conducted case studies show different results. The investigated makerspaces lack openness to the external world. This is illustrated by the fact that all makerspaces examined are limited to the own employees of the company. The problem is mainly that the existing regulations make it difficult to open up the makerspace to externals. Another issue is to prevent the unwanted transfer of knowledge to the outside. All three makerspaces want to open up and allow access to externals in the future.

Another role of a corporate makerspaces is to function as marketing tool to promote the company externally as well as internally as innovative and employee-oriented. This is important for the companies to position themselves as an attractive employer. In this way, the company attract talent and thus enable a transfer of knowledge, skills and competences into the company via hiring new employees.

RQ3: How can a corporate makerspace be implemented in an established enterprise?

Two approaches of how a makerspace can be set up within a company are possible: *top-down* or *bottom-up*. On the one side, the top management of a company recognizes the implementation of a corporate makerspace as an important part to support strategic topics (e.g. during a strategic realignment of the company). On the other side, it is an initiative that emerges from a group of employees that get support and are provided with budget from one department to set up a makerspace in the company by themselves.

Whether top-down or bottom-up, the implementation of a corporate makerspace comprises the following five main steps: (1) *prepare budget ask,* (2) *develop project plan,* (3) *design corporate makerspace,* (4) *execute realization,* and (5) *launch, operate, monitor.* Importantly, the process is of iterative logic, where steps are repeated if necessary.

Phase one focuses on describing the need, framing the objectives, defining success measures and estimating the budget to get approval from the executives. During phase two the project organization is implemented, the as-is situation is analyzed in detail, available resources are evaluated, clarity over budget allocation is achieved and the time schedule is set up. The main phase of the procedure model is the design phase, where it is necessary to consider five design dimensions (proposition, place, process, people, promotion). Additionally, benchmarking results and user feedback needs to be integrated. After the evaluation of the various options the execution of the realization can take place. When all preceding steps have been completed the makerspace can be launched with the official opening event.

During the implementation process it is important to ensure that clear responsibilities, action items, milestones and deliverables are agreed on at the end of meetings. Regular exchange between the members of the project management team is important to ensure a common knowledge base during the ongoing implementation process. Iterations are necessary; thus, being flexible is key. Importantly, the user's needs and wishes for such a facility must be considered. The challenge is sticking to timeline (delays arise easily because of manifold issues). When implementing more sites in parallel, coordination between the individual sites is challenging and time-consuming. Furthermore, lack of internal communication results in difficulties to keep transparency during the progress of the implementation.

8.2 Theoretical contributions

The results of this thesis contribute to existing knowledge in various ways. Firstly, this thesis is the first study based on a multiple case study approach and provides detailed insights in the design and operation of corporate makerspaces from distinct industries.

Secondly, the cross-case evaluation revealed that the investigated corporate makerspaces are operated according to three different operation models: *service orientation, self-reliant usage,* and a *combined model* of service orientation and self-reliant usage. The operation model and the accessibility to a makerspace are used as the two dimensions to establish a new taxonomy framework which offers a tool to compare and display different approaches of makerspaces. Based on the taxonomy framework, four archetypical approaches for makerspaces are possible: *open access and service orientation, limited access and service orientation, limited access and self-reliant usage,* and *open access and self-reliant usage.*

Thirdly, this thesis discusses the concept of corporate makerspaces in the light of knowledge creation, retention, and transfer. Relevant aspects of corporate makerspaces are linked to the theory of organizational learning. The findings show that a corporate makerspace supports the organizational learning capabilities in various ways (depending on the operation model applied).

Fourthly, the proposed implementation procedure provides the first detailed step-by-step guideline for setting up a makerspace within the corporate context and thus adds knowledge to the existing playbooks in makerspace literature. Furthermore, relevant considerations and challenges during implementation are addressed.

Finally, the insights and findings of the case studies on corporate makerspaces are valuable for makerspaces in general, because many aspects discussed in this thesis can be transferred to other institutions when considering the institution as an organization providing a certain context.

8.3 Managerial implications

Which makerspace model is beneficial for which companies and why? Most influential seems to be the question, what should be achieved with the implementation of a corporate makerspace. To realize the full potential of a corporate makerspace, the combined model of service orientation and self-reliant usage of the employees emerges as the most promising model. Because this model allows that employees can work on their own ideas independently while on the same time dedicated staff is pushing forward innovative projects. When comparing the investigated makerspaces, the one case having applied this model has reached the highest number of employees and with a broad user community and thus fosters many opportunities for exchange between the employees.

The case studies show that the implementation of a makerspace is beneficial in terms of development times, the quality of product designs, solution concepts and team meetings. Furthermore, the makerspace fosters the motivation of the employees, enhance their entrepreneurial spirit, and nurture their creative potential. Additionally, the corporate makerspace is used to attract talent in terms of positioning the company as innovative and employee-supportive.

The insights of this thesis provide advice for managers in improving their own corporate makerspaces. The step-by-step implementation procedure offers a guideline for practitioners to set up a corporate makerspace. Furthermore, the requirements, considerations and challenges identified support the managers to adopt the most appropriate operation model for their company-specific context.

8.4 Limitations and further research

Firstly, the scope of the empirical study is limited to large-scale established enterprises with headquarters located in Europe. Thus, it would be interesting to investigate makerspaces in SMEs to identify differences and commonalities based on the size of a company. In addition, the corporate makerspaces investigated are all situated in Germany. Further studies could elaborate on the influence of the region and the respective culture on the adoption of the makerspace in companies (differences between Europe, U.S., Asia etc.) In the same way, it would be stimulating to set up and investigate difference hypotheses (e.g. large companies use makerspaces more frequently than SMEs).

Secondly, the corporate makerspaces concept as an organizational tool to foster creativity and innovation in companies is quite new and the number of companies having adopted this tool is still low. It would be interesting to evaluate distribution hypotheses (how many companies have heard of this concept, want to implement it in the future, are currently working on it) in terms of quantitative research design to get a better overview of the actual situation and demand. It would be very exciting to find cases, where companies have implemented such a facility, but closed it again. To find the reasons for that would greatly improve the understanding of corporate makerspaces and their operation models.

This dissertation focuses on the company-internal concept of makerspaces. Therefore, it would be interesting to find out differences between the 'corporate makerspace' model, the ‘cooperative model’ and the ‘cooperation with external makerspaces’ model (as described in chapter 2.7.2). Moreover, the findings of this study are transferable to other contexts. Further studies could deepen the knowledge in terms of differences and commonalities between corporate makerspaces and academic makerspaces.

Thirdly, this research study is the first multiple case study approach (investigation of makerspaces in three companies). The findings in this thesis are based only on the companies investigated. Further studies of makerspaces in other companies are important to generate more knowledge on the effects and success factors corporate makerspaces Furthermore, studies are needed to explore the effects of makerspaces in more detail. Additionally, the evaluation of correlation hypotheses such as what features (e.g. dedicated open innovation strategy) companies that implement makerspaces have in common. One specific research task would be to explore if a makerspace is conducive to overcome the not-invented-here (NIH) syndrome – attitude against adopting external ideas – in companies. That would be very valuable because the NIH is the most mentioned barrier across the open innovation literature.

Fourthly, further studies could investigate other industries (e.g. process industry) to better understand which model is more appropriate for which setting and industry branches. Examples from banks show already that non-physical product industries are applying the makerspace concept. For which industries are makerspaces rather not suitable and why? How do the barriers for a makerspace differ due to the different industries?

As a fifth point, this study elaborates how makerspaces support knowledge creation, retention and transfer. Argote (2013b, p. 204) proposes that it is important to better understand why some organizations are better in learning than others. It would be very exciting to investigate differences in learning rates between companies with and without a corporate makerspace. Are companies operating corporate makerspaces better at learning than companies without offering that service to its employees? What are the differences between sites with and without makerspaces within one and the same company?

In addition, it would be desirable to apply and scientifically accompany the introduction of a makerspace based on the procedure model described in other companies. And in the sense of a longitudinal study, to make a comparison of relevant aspects before and after the introduction of the makerspaces and to repeat it at regular intervals after the opening.

To conclude, when looking at the lifecycle of corporate makerspaces, we are still at the beginning. Most of the companies have only recently started to use this tool. In the following years, we need to learn more about how to use makerspaces to their full potential in various contexts.

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Appendix A

Table 8: Interview guideline – page one

Category	Question
General	▪ Launch of makerspace, size (sqm), room separation ▪ Date, duration, interview
Individual	▪ Name of interviewee, position, personal background ▪ What are your responsibilities and tasks? ▪ What do you like on your job? ▪ How do you work with your team members? ▪ How do you organize your work?
Infrastructure	▪ Which areas/ machines/ tools/ equipment/ technologies/ Software/ materials are available? ▪ Which areas/ machines/ tools/ equipment/ technologies/ Software/ materials are used how frequently? ▪ How is maintenance organized?
Facilitation	▪ What are the opening hours? ▪ What workshops, trainings and events do you offer? How many participants? ▪ How much budget is available for the different projects? ▪ How many employees are working in the space? ▪ What is their expertise? What are their tasks? ▪ How do you organize and monitor operation? ▪ How and from where do you get the materials? ▪ What materials can the employees use? ▪ What kind of reservation system do you use? ▪ What are the greatest challenges during operation? ▪ What are conditions for smooth operation? ▪ Is IPR an issue? ▪ How is the makerspace connected with the traditional innovation process?
Community	▪ Which employees have access? ▪ Who are the actual users, from which departments do they come from? ▪ How many users do you have on average? Growth since launch? ▪ What is the feedback of the users? ▪ What changes have been made by the users' feedback? ▪ How do you collaborate/ cooperate with customers, competitors, suppliers? ▪ What are the topics the employees are working on in the makerspace? ▪ How many projects have been implemented? ▪ Is it possible to work on private projects? ▪ How would you describe the atmosphere in the space? ▪ How do the users behave, interact and work with each other? What is different compared to usual work and daily business? ▪ Can you describe an idea that was generated in the makerspace?

Table 9: Interview guideline – page two

Category	Question
Objectives	▪ Where did the idea come from? When? Who? ▪ What were the reasons for the implementation? ▪ What use cases were considered?
Implementation	▪ What steps were necessary for implementation? ▪ Which activities were done in the individual steps? ▪ How long did each step take? ▪ Which activities were particularly difficult? ▪ What were the problems during implementation? ▪ How did you overcome the obstacles? ▪ Who was responsible for what? ▪ How much was the implementation cost? ▪ In your opinion, what was good during implementation?
Effects	▪ What are the opportunities and benefits of the makerspace? ▪ What effects could you observe? ▪ How do you measure and monitor success? ▪ What kind of KPIs do you use? ▪ Which of the initial goals have already been achieved? ▪ Are there any drawbacks?
Future	▪ What are your next steps? ▪ What are the plans for your makerspace for the next years? ▪ How do you see the future of makerspaces in general and at companies in particular?