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How to Make (Almost) Anything -
A Concept to Enhance the Maker Movement at Graz University of Technology

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“Tell me, I'll forget.

Teach me, I may remember.

But let me ***make*** it, and I'll understand.“

based on Xun Kuang (312-230 BC)

Chinese philosopher

Affidavit

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources, and that I have explicitly marked all material which has been quoted either literally or by content from the used sources. The text document uploaded to TUGRAZonline is identical to the present master's thesis.

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Date

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Acknowledgement

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Abstract

The course „How to Make (Almost) Anything” in 1998 and the establishement of the first Fab Lab (Fabrication Laboratory) at the Massachusetts Institute of Technology (MIT) in 2002 started a global movement. Tinkerers, hobbyists, entrepreneurs and companies participate today in a global network of makers. Some of the most popular initiatives are “Fab Labs”, “Hackerspaces” and “TechShop”. All of these institutions share the goal of democratizing the manufacturing process.

In 2014, the Institute of Industrial Management and Innovation Research started the first university-based Fab Lab in Austria located at the Graz University of Technology. The aim of this thesis is to enhance the Maker Movement at TU Graz. To explore this topic and its possibilities this work is sub-divided into three main parts. First, a review of existing literature and internet sources regarding leading Makerspaces in Europe and the US is conducted to provide a general overview of the global Maker Movement. Second, market needs are investigated by interviewing industrial partners and actual makers. Third, a concept for a course using resources provided at the Fab Lab Graz is developed.

The literature review highlights the impact of the Maker Movement on the traditional business landscape and how this is increasing. The influence of Makerspaces on established enterprises expresses itself in two innovation theories: open innovation and user innovation. From the internet search results on leading Makerspaces in the US and Europe a typical list of available equipment and information regarding accessibility and usability-concepts of Makerspaces was acquired.

The second segment of this thesis, “Market Needs”, postulates that a living community of makers is the most valuable aspect of the Maker Movement for traditional enterprises. Further, information about possible synergies with the Fab Lab Graz and expectations of enterprises on digital fabrication laboratories are evaluated.

The third part of this thesis focuses on education at Makerspaces and the development of a course concept for the Graz University of Technology. According to literature, the strength of Makerspaces in education lies in hands-on learning and project centered classes. In conclusion, the course at Fab Lab Graz is to be held as a laboratory exercise where students will design and actually build a radio-controlled car.

During the of six month period of this research, the number of active Fab Labs worldwide has increased from 442 to 562. This fact shows the impressive development of the Maker Movement. In conclusion it can be stated that the potential of Makerspaces and their creative environment has not yet reached its zenith.

Zusammenfassung

Die Gründung des ersten Fab Labs (Fabrication Laboratory) sowie die Entwicklung der Lehrveranstaltung „How to Make (Almost) Anything“ am Massachusetts Institute of Technology (MIT) sind der Ausganspunkt einer globalen Bewegung, die unter dem Begriff „Maker Movement“ weltweit Bekanntheit erlangt. Tüftler, Bastler, Entrepreneure und Unternehmer, sogenannte „Maker“, nützen heute als Makerspaces bezeichnete Werkstätten und bewegen sich im globalen Maker-Netzwerk. Zu den populärsten Initiativen gehören „Fab Labs“, „Hackerspaces“ und „TechShop’s“. All diese Einrichtungen teilen das gemeinsame Ziel, Produktionsprozesse zu demokratisieren.

Im Jahr 2014 gründete das Institut für Industriebetriebslehre und Innovationsforschung der Technischen Universität Graz das erste universitäre Fab Lab in Österreich. Das Ziel dieser Arbeit ist es, den Trend „Maker Movement“ an der TU Graz zu unterstützen. In dieser Arbeit wird eine Übersicht bestehender Literatur erstellt und führender Makerspaces in den USA und Europa werden im Rahmen einer Internetrecherche analysiert. Weiters werden die Marktbedürfnisse durch Experteninterviews mit Industriepartnern und tatsächlichen Nutzern („Makers“) erhoben. Abschließend wird ein Konzept für eine Lehrveranstaltung im Rahmen des Fab Labs und der bestehenden Lehrveranstaltungen des Intsitutes für Industriebetriebslehre und Innovationsforschung entwickelt.

Die bestehende Literatur unterstreicht die positiven Auswirkungen der Maker-Bewegung auf die traditionelle Unternehmenslandschaft. und äußert sich in den zwei Innovationstheorien: „Open Innovation“ und „User Innovation“. Aus der Internetrecherche bezüglich führender Makerspaces resultiert eine Liste über verfügbare Produktionstechnologien in solchen Einrichtungen sowie Informationen zu Geschäftsmodellen und Nutzungskonzepte. Die Analyse der Marktbedürfnisse macht deutlich, wie wertvoll für traditionelle Unternehmen eine aktive Community der Maker-Bewegung ist.

Der letzte Abschnitt dieser Arbeit konzentriert sich auf Makerspaces in der universitären Ausbildung mit der Entwicklung eines konkreten Konzeptes für eine Lehrveranstaltung an der TU Graz. Laut vorliegender Literatur ist die Stärke von Makerspaces in der Ausbildung das „Hands-on-learning“ in projektzentrierten Kleingruppen. Daraus abgeleitet wird die Lehrveranstaltung als Laborübung abgehalten, in welcher die Studenten auch ein ferngesteuertes Auto konstruieren und fertigen.

Die Anzahl der aktiven Fab Labs hat sich in den vergangenen sechs Monaten weltweit von 442 auf 562 erhöht. Die beeindruckende Entwicklung der Maker-Bewegung über die letzten Jahre zeigt, dass das Potential von Makerspaces und ihrem kreativen Umfeld noch nicht ausgeschöpft ist.

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1 Introduction

With the course "How to Make (Almost) Anything" in 1998 and the foundation of the first Fab Lab (Fabrication Laboratory) in 2002, both initiated by Prof. Neil Gershenfeld, currently head of MIT's Center of Bits and Atoms, a global movement later on referred to as the "Maker Movement" was born.[1]

Today, the Maker Movement is spreading rapidly across the world. In all regions, new Makerspaces, Hackerspaces and Fab Labs appear monthly. Currently there are 562 Fab Labs registered.[2]

The basic idea behind the Maker Movement is to offer the possibility to produce things by providing individuals access to digital manufacturing tools. Commercial activities of users are tolerated as long as they do not interfere with the access of others.[3]

In 2014, the Institute of Industrial Management and Innovation Research at the Graz University of Technology started the first university-based Fab Lab in Austria. Four main criteria are considered as important to contribute to the global Maker Movement trend. First, the lab must provide open access free of charge for all once a week. Second, the Fab Charter is published onsite and on the web page. Third, the equipment is chosen according to the MIT's guidelines to ensure exchangeability of designs, knowledge and reproducibility across borders: a computer-controlled laser cutter, a vinyl cutter, a precision milling machine, a numerically-controlled milling machine, 3D-printer and several programming tools.[4] Fourth, Fab Lab Graz supports other labs and contributes to the worldwide Fab Lab community. The worldwide Fab Lab community has numerous commonalities, but there exist also slight differences regarding services and tools provided for different user groups, which makes every lab unique and possessing of its own identity.

1.1 Motivation

Since the opening of Fab Lab Graz many students have made use of the tools and equipment provided to test their ideas, fabricate products for courses or simply to experiment for leisure. Due to the significant rise in demand within a short period of time it became necessary to consider increasing the available space, which until then was only 40 square meters. It was realized rather quickly that to only expand the floor space

[1] Cf. Gershenfeld (2012), pp.5-6
[2] Cf. https://www.fablabs.io/labs
[3] Cf. http://fab.cba.mit.edu/about/charter/
[4] Cf. http://fab.cba.mit.edu/about/faq/

and isolate the Fab Lab from its environment would not be ideal. To foster the innovation strength of such a space it is essential to connect the capabilities of the Fab Lab with other relevant institutions, which are necessary to support entrepreneurs as much as possible during the whole process, culminating in a new start-up.

It is intended by the Graz University of Technology to enlarge the present Fab Lab in the near future. The general objective of this work is to support the Institute of Industrial Management and Innovation Research to render the best possible conditions for the Maker Movement trend at the Graz University of Technology.

1.2 Objectives

The overall objective of this thesis is to enhance the Maker Movement at the Graz University of Technology. To reach this objective, this thesis is sub-divided into three main sections.

A) **The Maker Movement, the Fab Lab Graz and similar institutions as benchmark(s)**
This part of the thesis aims to impart a general overview of the topic and the "Maker Movement". Further, an assessment of similar institutions in the vicinity of Graz as well as accumulated information from internet research regarding leading Makerspaces in the US and Europe is included.

B) **Inputs, thoughts and recommendations of actual makers and industrial partners of the Graz University of Technology**
The Maker Movement trend now reaches the traditional business landscape. Interviewing industrial partners (start-ups, SMEs and large-scale enterprises) will help to gain an understanding of how these companies react to the now available and easily accessible technologies at different Makerspaces. Identifying shared interests between the University as hosting facility of the Fab Lab and businesses is critical and will have an impact on the further development of Fab Lab Graz.

C) **Concept development for a "How to Make (Almost) Anything" course at TU Graz**
In cooperation with the Institute of Machine Components and Methods of Development and the Institute of Industrial Management and Innovation Research a concept for a course considering information and results obtained from the other sub-sections will be developed. The concept for the course includes theoretical and practical components as well as a curriculum for the course.

The results of the three different sections will lead to recommendations for implementation to reach the mentioned overall objective. The final outcome of this thesis will help the Graz University of Technology to become a valuable part of the global Maker Movement. Further, this thesis aims to realize the potential of the Maker Movement, on the one hand in education with the development of a teaching concept and on the other hand to find and use synergies with industrial partners of the Graz University of Technology.

1.3 Approach

To reach the described objectives Figure 1 shows the overall approach of this thesis. This work is sub-divided into three main blocks.

Block A describes the Maker Movement and its impact as it relates to literature (section 2). Further, different practical applications as the benchmark for Fab Lab Graz (section 3) are part of this block.

Block B engages in market needs regarding traditional businesses and makers. The focus is on collaboration with the traditional business world – requirements, synergies and expectations of industrial partners and start-ups or so-called lead users (section 4).

Block C continues with the development of a course (section 5). This block is based on information acquired in the first two blocks.

In section 6 “Conclusion” the results of the present work are discussed. Further, each section is concluded with a short summary of the identified results.

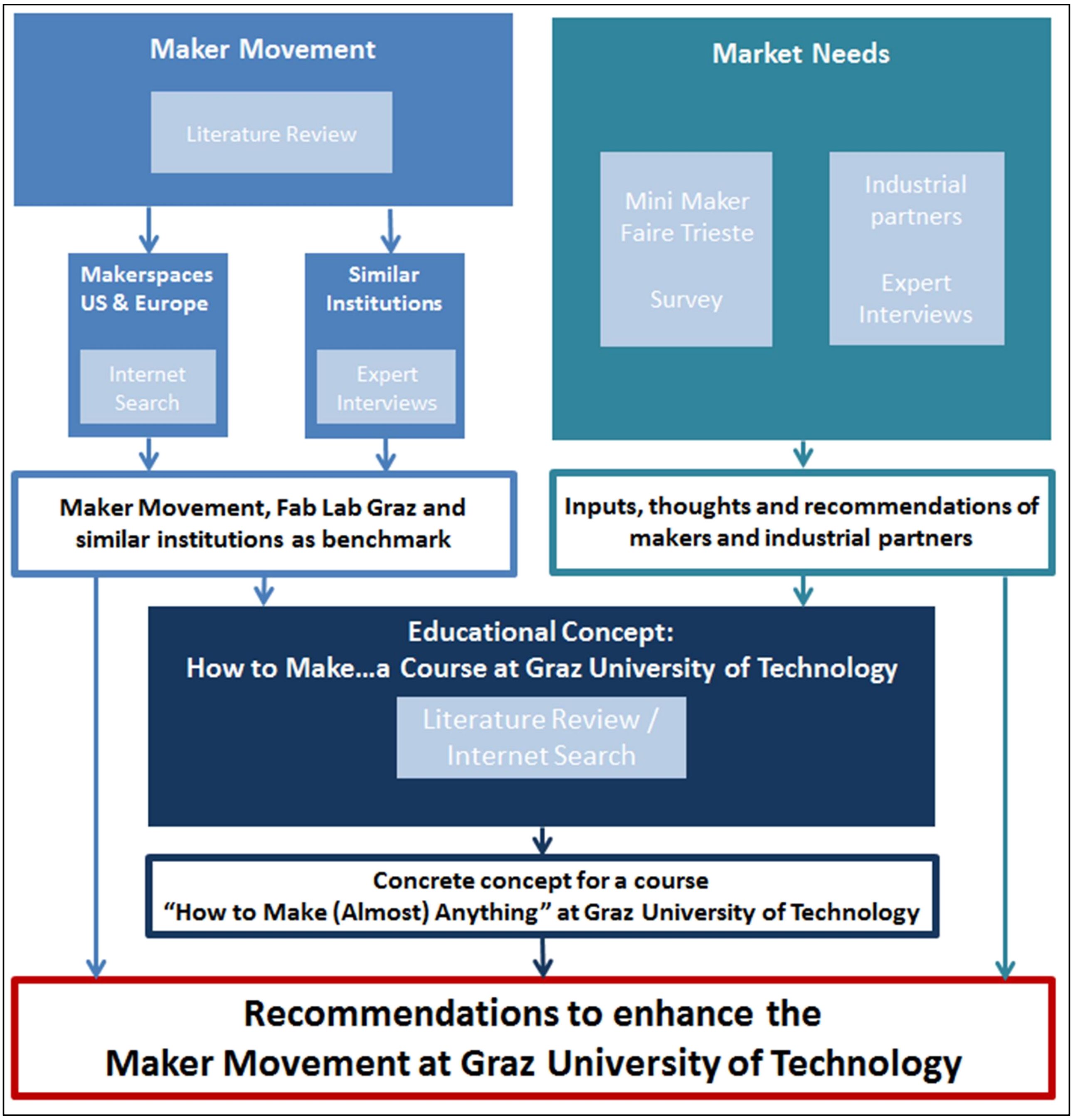

Figure 1: Overall approach

2 Maker Movement

In the following section, the essential steps in the development of the Maker Movement are described. Influences, such as mass customization, open innovation and digital fabrication are mentioned as well as main drivers of the Maker Movement e.g. Makerspaces, Hackerspaces or Fab Labs.

In Figure 2 (see section 1.3) the main contents of block A are illustrated. Section 2 describes information and influences regarding the Maker Movement based on literature. Further, a point of interest of this bibliography is how makers and their environment are embedded in the traditional business world. Section 3 concerns the present situation of the Maker Movement and its encouragement and proliferation at different Makerspaces in the US and Europe. Further, to gain insights into already operating Makerspaces, interviews with operators are conducted.

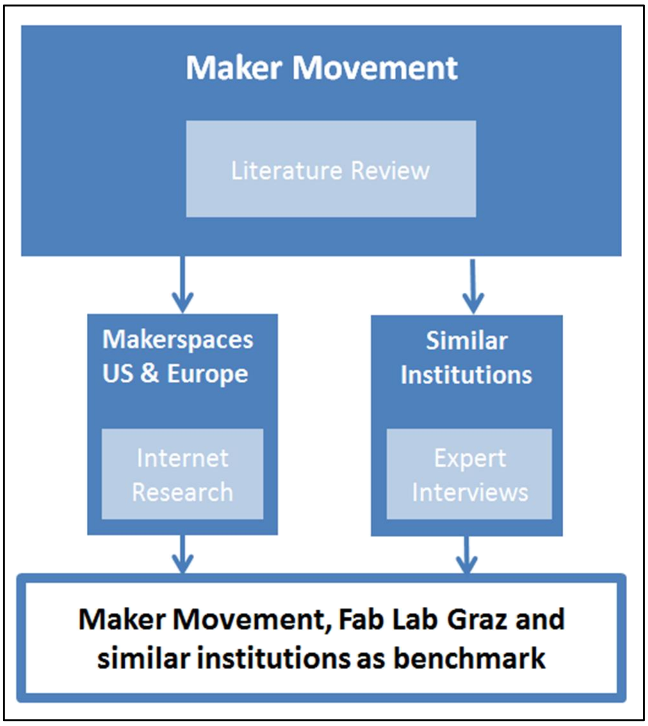

Figure 2:Block A, Maker Movement

2.1 Makers

The collaboration between and organization of makers is the key element of this section. MAKE magazine, founded in 2005, coined the term "Maker Movement".[5]

Mark Hatch described the Maker Movement with the following nine principles in his "Maker Movement Manifesto": [6]

- "*MAKE – Making is fundamental to what it means to be a human. We must make, create, and express ourselves to feel whole.*
- *SHARE – Sharing what you have made and what you know about making with others is the method by which a maker's feeling of wholeness is achieved.*
- *GIVE – There are a few things more selfless and satisfying than giving away something you have made.*
- *LEARN – You must learn to make. You must always seek to learn about your making.*
- *TOOL UP – You must have access to the right tools for the project at hand. Invest in and develop local access to the tools you need to do the making you want to do.*
- *PLAY – Be playful with what you are making, and you will be surprised, excited, and proud of what you discover.*
- *PARTICPATE – Join the Maker Movement and reach out to those around you who are discovering the joy of making.*
- *SUPPORT – This is a movement, and it requires emotional, intellectual, financial, political, and institutional support. The best hope for improving the world is us, and we are responsible for making a better future.*
- *CHANGE – Embrace the change that will naturally occur as you go through the maker journey".*

Chris Anderson postulates: "*We are all born makers*."[7] Within these five words lies the simple truth – everyone can become a so-called 'maker'.

Hobbyists, tinkerers or managers can bring to fruition products of their imagination. The gap or separation from former similar designations like inventors or do-it-yourselfers to makers nowadays is the dedication of high-tech production technologies and a worldwide ecosystem. Today ordinary individuals can invent hardware or software products to solve essential problems, which was years ago impossible without

[5] Cf. makermedia.com/press/fact-sheet/
[6] Hatch (2013), pp. 1-2
[7] Anderson (2013), p. 13

traditional organizational or institutional backing and facilities. Makers now have the capabilities to modernize traditional fields in education, science and economy.[8]
Furthermore, making is connecting. According to David Gauntlett making is not only connecting materials but also entails the connection of people with their social environment and with the world by sharing products and ideas. [9]

In the literature reviewed, three different stages of makers could be identified (see Figure 3).

- *Zero to maker:* The starting point. Two things are necessary: the ability to learn important skills and access to machines and production facilities. [10]
- *Maker to maker:* The next step in the maker evolution is to communicate and collaborate with other makers either in small project teams or by asking for help. [11]
- *Maker to market:* This is the final step where the Maker Movement and the traditional economical ecosystem meet. Only a handful of makers will make this step proceeding to commercialize their ideas and products. [12]

As mentioned in section 1, starting in 1998 with the “How to Make (Almost) Anything” course Neil Gershenfeld focused on the new possibilities for digital fabrication. The Center for Bits and Atoms and its research regarding the boundaries between the digital (Bits) and the physical (Atoms) world showed how far digital fabrication can go. Together with his students Neil Gershenfeld tried to determine the “Killer-App” of digital fabrication – regarding to them its “personalization”. This enables the possibility of producing customized products for just one person – the maker.[13]

United States President Barack Obama encouraged people to become *“makers of things, not just consumers of things”* at the White House Maker Faire (Maker Faire – see section 2.3).[14]

The literature consulted goes even further than President Obama, adding an additional step; from consumer to maker and from maker to active consumer. This leads in mass customization. Mass customization with its goal to provide products customized at mass production prices will increase the competiveness of companies via on-demand

[8] Cf. Hagel (2014), p. 3
[9] Cf. Gauntlett (2011) p. 2
[10] Cf. Hagel (2014), p. 6
[11] Cf. Hagel (2014), pp. 6-7
[12] Cf. Hagel (2014), pp. 8
[13] Cf. Gershenfeld (2012), pp. 5-6
[14] Cf. https://www.whitehouse.gov/blog/

production. The key driver to realize such a profitable small-batch production is a flexible manufacturing process.[15]

Flexible production systems are the inner core of the Maker Movement and this is how the Maker Movement and makers might change today’s institutional business landscape. Driven by innovation in technology and globalization, companies and their environment(s) are in flux. Some areas of the industrial world will be broken down into smaller units and some large-scale entities will continue in different forms. As a reaction there will be greater links and collaboration between scale platforms and innovative initiatives ("maker to market", Makerspaces, etc.). Not only for this will the Maker Movement be the recipient of attention from traditional businesses, it will also be at the center of emerging trends. The possibilities to shape and support the Maker Movement allow traditional companies to shift their resources.[16]

In Figure 3 representative players in the world of making are illustrated. This figure describes briefly the interfaces and the shared interests between the world of making and the traditional business world.

[15] Cf. Anshuk Ghandi (2014), p. 6
[16] Cf. Hagel (2014), pp. 13-14

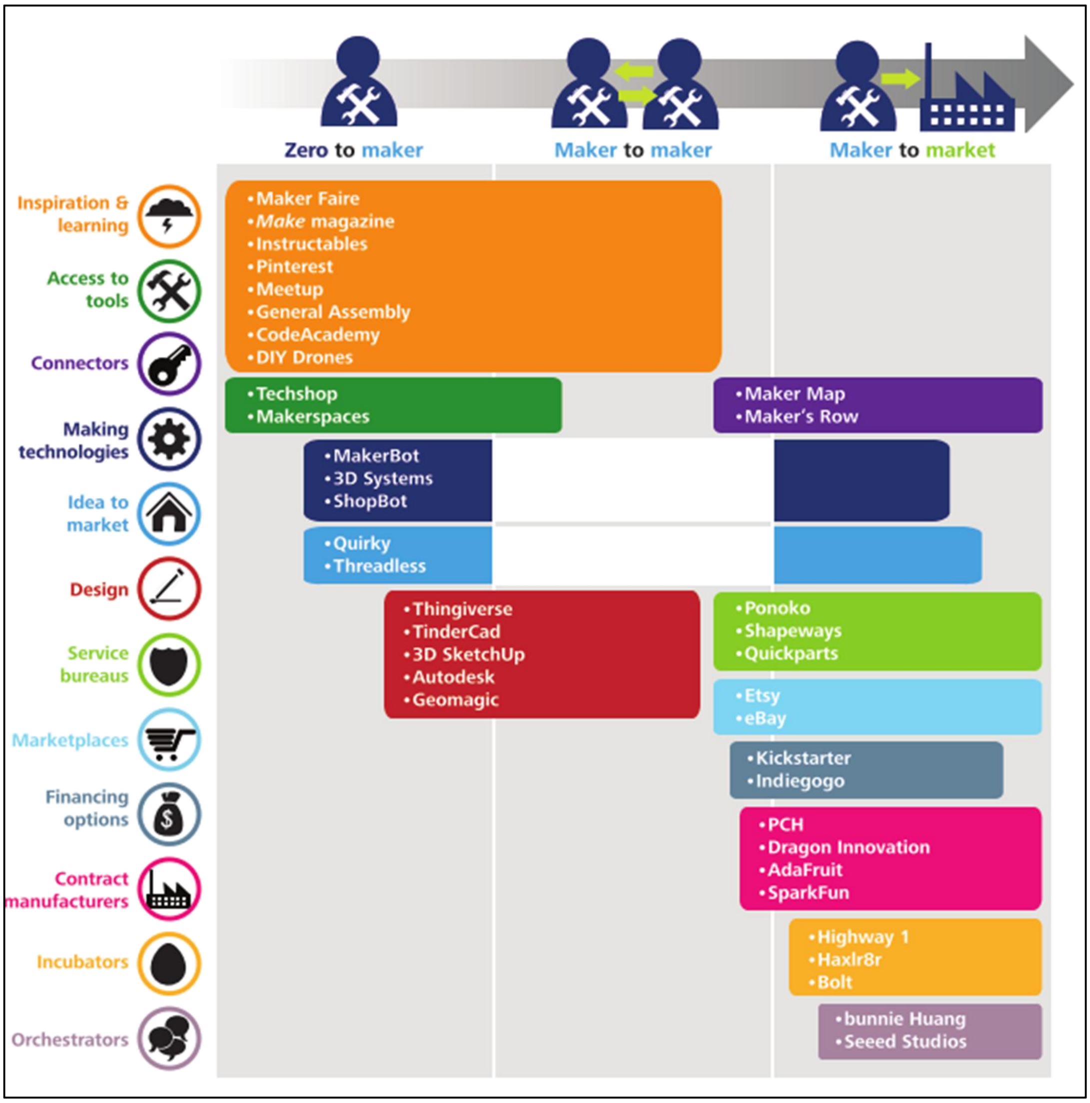

Figure 3: The maker ecosystem[17]

2.2 Types of Makerspaces

So called "Makerspaces" are dedicated places/rooms/laboratories for makers, to work on their own or together in teams on different projects.[18]

Innovative workshops have many names and have evolved out of different movements. Some of the most popular initiatives are "Fab Labs", "Hackerspaces", "TechShop" or "Makerspaces".[19]

[17] Hagel (2014), p. 10
[18] Cf. makerspaceTeam (2013), p. 5
[19] Cf. Mota (2011), p. 5

2.2.1 Fab Lab

Fab Labs, short for “Fabrication Laboratories”, as mentioned above, originated at MIT in 2002 with the intention to apply a prototyping platform for learning and innovation. Fab Labs are places which provide innovative and easy-to-use production technologies for local entrepreneurship and hobbyists. The success of the Fab Lab initiative appears in the impressive list of actually 562 [20] active labs worldwide. Fab Labs are more than just local fabrication sites. All Fab Labs together constitute a global network for innovation and research. They come under the umbrella of the international Fab Lab Association. There are 4 main criteria to fulfill to receive Fab Lab designation. First, Fab Labs provide at least once a week public access to democratize tools for personal use. Second, the founding individuals must subscribe to and apply the Fab Charter. The Fab Charter is a document expressing the commitment to be part of the global network. Third, all Fab Labs share a basic (core) set of tools. Fourth, Fab Labs actively participate within the global network. Knowledge sharing is one of the most central aspects of the Fab Lab community.[21]

Core equipment of each Fab Lab (more details: section 5.5.4):[22]

- Laser cutter
- CNC mill
- Vinyl cutter
- 3D-Printer
- Electronic workspace
    - Soldering station
    - Test equipment (Oscilloscope, etc.)
- Communication/network – Fab Lab video conference server

2.2.2 Hackerspace

The first Hackerspaces evolved in Germany with the intention to provide a physical and inspiring space for groups of programmers to engage in open software development. The development of Hackerspaces spread soon thereafter to the US. Hackerspaces started focusing on electronic design and manufacturing as well as in physical prototyping. Today these spaces offer classes and access to tools, similar to TechShops or Fab Labs. Most Hackerspaces are member-driven and membership fees are the primary source of income. One example of a revolutionary business which

[20] Cf. https://www.fablabs.io/labs
[21] Cf. http://www.fabfoundation.org
[22] Cf. http://wiki.fablab.is/wiki/Portal:Equiment

evolved out of a Hackerspace is “MakerBot Industries”. MakerBot is today one of the leaders in innovation within the 3D printing industry.[23]

2.2.3 TechShop

Similar to the Fab Lab community, “TechShop” is a trademarked name. TechShop is a for-profit organization which provides open access to high-end manufacturing technologies against membership fees. Founded in 2006 by Jim Newton, (Chairman) and Mark Hatch, (CEO of TechShop), all spaces provide their members with woodworking, machining, sewing, welding and CNC tools.[24]

2.2.4 Makerspace

As described above, the term “Makerspace” was coined when MAKE magazine was published in 2005 and is therefore associated with Maker Media. [25]

In practice, there are numerous designations for similar associations such as “co-working spaces” or “innovation labs” for community-based workshops. In the “Grassroots digital fabrication and Makerspaces” study, the different names and organizations were identified, however, it was decided that all facilities will be titled “Makerspace(s)” for the sake of clarity.[26]

The results of the “What are Makerspaces, Hackerspaces, and Fab Labs?” study demonstrated that in their characteristics and external qualities, there exist no substantive differences between the above-mentioned initiatives. Further, 47% of investigated organizations consider the different names and terms interchangeable. The most universal denotation “Makerspace” evolved when Maker Media first published “MAKE magazine” in 2005. There exists no overarching organization; every space identifying itself as a Makerspace forms independently.[27]

According to the Makerspace Team, Makerspace is used as a sort of generic term for Fab Labs, Hackerspaces or TechShops and describes succinctly publicly-accessible places. In the “Makerspace Playbook” (2013) Makerspaces differ from other Initiatives like Hackerspaces owing to their focus on learning and education.[28]

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[23] Cf. Cavalcanti (2013); Cf. Sandra Schön (2014), p. 4
[24] Cf. http://makezine.com
[25] Cf. Van Holm (2015), p. 5
[26] Cf. Smith, Hielscher, Dickel, Söderberg, & Van Oost (2013), pp. 3-4
[27] Cf. Van Holm (2015), pp. 4-11
[28] Cf. MakerspaceTeam (2013), p. 5

Van Holm (2015) identifies differences, noting that Fab Labs in particular focus on educational institutions (schools, universities) and their students. Additionally, Van Holm also determined that each organization has its own culture, specific activities, member interests and goals.[29]

There are likewise arguments centered on what these organizations share. All above-named facilities are driven by the internet as a network and place for exchange and make substantial usage of digital fabrication tools as an interface between digital and material production. [30]

Further, all of these personal fabrication facilities have the common goal of democratizing the process of manufacturing.[31]

As can be seen, a consensus concerning the interrelationship of the organizations above has not yet been reached. For this master thesis, it is important that these programs and their nomenclature will not be used synonymously to refer to each other. Fab Labs, Hackerspaces, TechShops and Makerspaces are distinguished owing to differences regarding orientation and history. “Makerspace” will be used in this thesis as a generic term and as name for organizations that could not be classified in one of the other more specified categories.

2.3 Maker Faire

Another place where making happens is the Maker Faire organized and founded by Maker Media. *“Maker Faire is the greatest Show (and Tell) on Earth”.*[32]

Maker Faire is a place for makers to present their work and what knowledge they have gained out of their projects. Maker Faire started in 2006 with the Bay Area Maker Faire. Only eight years later, in 2014, 215,000 people visited the two major Maker Faires in the Bay Area and New York. Apart from those two headline events, 119 Maker Faires were held around the world in 2014. Overall Maker Faires can be seen as places where innovation and interdisciplinary experimentation meet.[31]

[29] Cf. Van Holm (2015), p 12
[30] Cf. Gershenfeld (2005), pp. 11-13
[31] Cf. Mota (2011), p. 5
[32] Cf. http://makerfaire.com/makerfairehistory/

2.4 Makerspace Ecosystem

The sub-title of this work is “to enhance the Maker Movement at the Graz University of Technology”. Regarding this and the planned enlargement of Fab Lab Graz the following section will focus slightly on Fab Labs and their ecosystems. However, the identified results can be applied also to all types of Makerspaces.

The development started in 2003 with the first Fab Lab founded outside of MIT. From 2003 to 2012 the total number of active Fab Labs around the world has doubled impressively, every 18 months. In 2012 were 100 active Fab Labs.[33]

When this work was began in March 2015 there were 442 Fab Labs registered at “fablabs.io”. As mentioned above, in September 2015 there are 562 registered Fab Labs. It is thus reasonable to state that the global Fab Lab network will continue to grow.[34]

In the environment of Makerspaces a creative community has formed. The community can be divided into two groups. One community-group is the global network of the Maker Movement while the other group is the local community.[35]

Difficulties for Makerspaces arise with the results of the complex environment surrounding these institutions. Only by looking at the local ecosystem can many stakeholders be identified. Based on the ecosystem framework of ‘Bloom and Dees’ (2008), the “Empowering the Hacker in US: a Comparison of Fab Lab and Hackerspace Ecosystems” study made apparent the importance of the ecosystem. Figure 4 illustrates the result of the identified ecosystem for an urban Fab Lab (size 750 m², co-working-spaces, two laser cutters, four 3D-printers and a digital milling machine). The Fab Lab in the center of the ecosystem must serve a large number of beneficiaries on the one hand but has also to satisfy resource providers on the other. Significant effort is needed for the corresponding Fab Lab to build an innovation ecosystem and to inform and demonstrate to its partners that the Fab Lab is actually part of this system.[36]

33 Cf. Gershenfeld (2012), p.48
34 Cf. http://www.fabfoundation.org
35 Cf. http://www.openp2pdesign.org/2013/spaces/what-is-a-fablab/
36 Cf. Guthrie (2014), pp. 5-7

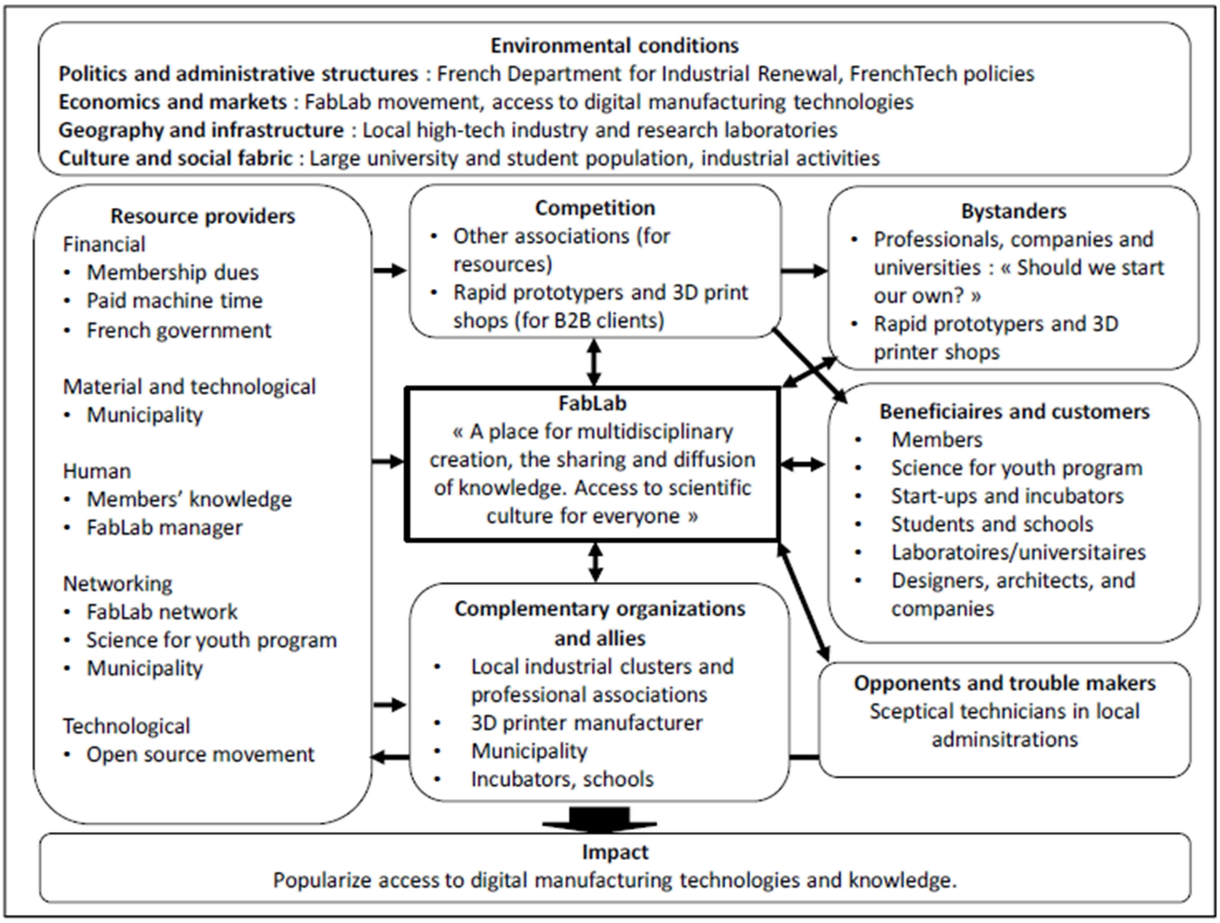

Figure 4: Fab Lab ecosystem[37]

In a frequency analysis of notions carried out in the “What are Makerspaces, Hackerspaces and Fab Labs?” study, the results showed that Fab Labs are more oriented towards businesses. This was one distinctive feature which separated Fab Labs from Makerspaces and Hackerspaces.[38]

Fab Labs in particular address the gap between research and economy in connection with educational and research organizations. This demonstrates the multiplicity of an innovative Fab Lab concept.[39]

The development of such a concept remains an ongoing process. The main focus of Fab Labs and Makerspaces in general is to provide democratic access to digital fabrication tools. However, these institutions are subject to constant change and need to consider a variety of circumstances. In the initial phase, Fab Labs especially were

[37] Cf. Guthrie (2014) p. 7
[38] Cf. Van Holm (2015), p. 15
[39] Cf. Leibnitz-Institut für Regionalentwicklung ind Strukturplanung (IRS) (2014), p.17

planned as university laboratories and concept test sites. Potential use-cases had to evolve and sustainable cost coverage was only a perspective.[40]

Makerspaces must, owing to their difficult place in the ecosystem, rely on sustainable business models. This entails long-term, cost-effective operation in combination with a growing share of proprietary sources of revenue. Further, providing effective support for the global network and fulfilling the goals and values of the Maker Movement are essential.[41]

2.5 Makerspace Business Models

These requirements apply also to the situation of the Fab Lab at Graz University of Technology. In this section 2.5 theoretical information regarding Makerspace business models is presented. The focus is on Fab Labs owing to the situation at the outset at the Graz University of Technology. Nevertheless the results can be applied to all types of Makerspaces.

There exist various definitions for the term business model. Basically, a business model describes the offered value of a company for its customers and the means by which to generate profitable revenue streams. All definitions have three similar aspects in common: First, a business model conceptually represents a real world company. Second, it contains external factors, values and user promises. Third, a business model specifies all relevant stakeholders.[42]

Presently, with more than 560 active and registered Fab Labs, an overall applicable business model for such a laboratory could not be found during the research of existing literature. The overall success and the interests of other institutions to join the Maker Movement show the need for such a business model. Therefore, a business model for a concurrent, self-sustaining Makerspace must be completed. Additionally, many Makerspaces at their outset are funded by public institutions but share the target of becoming self-sufficient within the first three years of operation.[43]

Peter Troxler together with Simone Schweikert developed a business model for the Fab Lab Lucerne. These two authors, thus conducted the first study on the business models of Fab Labs. In this study (Developing a Business Model for Concurrent Enterprising at

[40] Cf. Gershenfeld (2005), p. 14
[41] Cf. Boeck & Troxler (2015), pp. 2-3
[42] Cf. Osterwalder (2004), p.15
[43] Cf. Troxler & Wolf (2010), p. 6

the Fab Lab, 2010) they proposed four key ingredients that a business model for a Makerspace should contain: [44]

1. *Openness:* Cessation of closed door thinking; 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); open learning in communities; center for communities of practice that allow all their members to develop mastery; sharing of knowledge and experience with other members in the community; open organizational formats (built on public-private partnerships).
2. *Interdisciplinary collaboration:* Access for everybody; including opportunities for interdisciplinary collaboration
3. *Effectiveness:* Social interaction; connecting academics and practitioners on equal footing, allowing direct interaction with each other in projects
4. *Transferability:* Exchange of experience, business models, programs, technical issues and solutions in the worldwide network.

In theory, the Fab Lab network already implemented such an approach, enshrined with the Fab Charter's[45] openness as well as interdisciplinary collaboration. In practice however, as Peter Troxler in 2013 attested, the rapid growth of the worldwide-network has made it exceedingly difficult for the network to determine its purpose and its form. Therefore, he proposed that Fab Labs should not focus on machines and making but should instead on social and organizational engineering.[46]

Moreover, Troxler defines two main groups of Fab Labs: First, the *lab as facility* and second, the *innovation lab*. Facility labs provide access to digital fabrication machinery and support their members in the production process (e.g. training). Additionally, innovation labs provide a product-service-system helping their customers to increase the effectiveness of the innovations. [47]

Figure 5 shows the differences in the business model of the two proposed groups.

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[44] Cf. Peter Troxler (2010), p. 9
[45] Cf. http://fab.cba.mit.edu/about/charter/
[46] Cf. Troxler (2013), p.9
[47] Cf. Troxler & Wolf (2010), p. 5

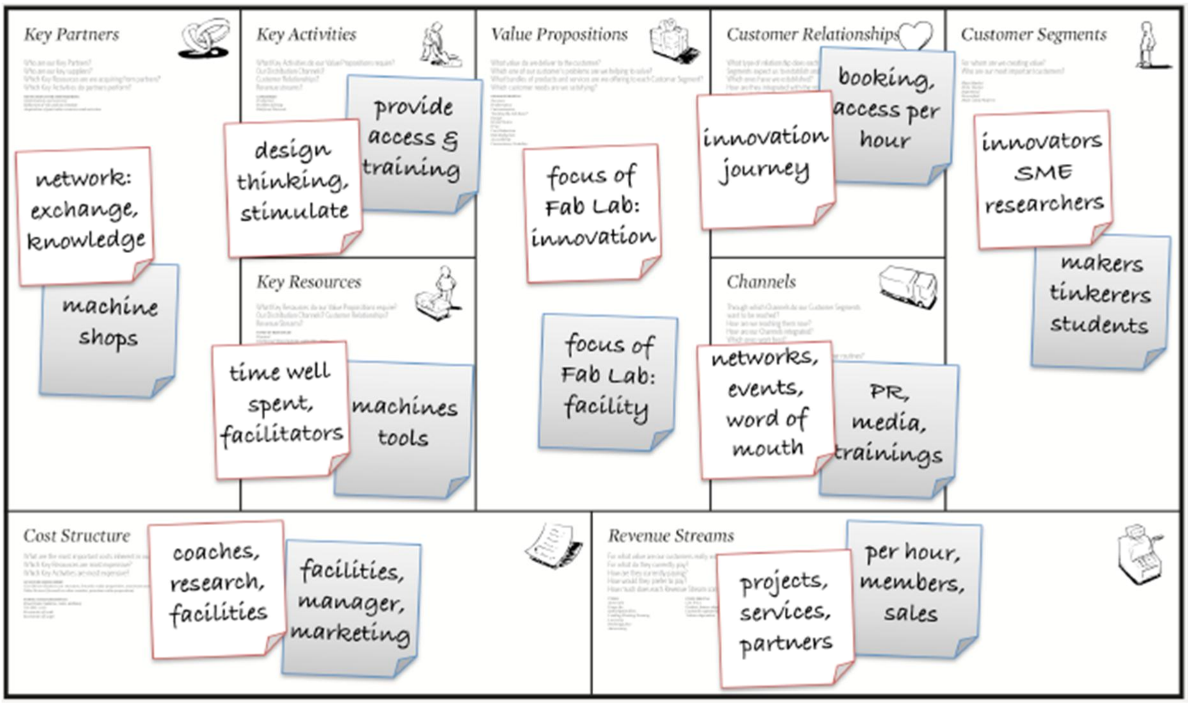

Figure 5: Business Model Canvas "innovation lab vs. lab as facility"

The broader approach, when consulting the figure above, is certainly the innovation lab. Despite this, there are three different measures of success for Fab Labs or Makerspaces as denoted by Peter Troxler[48]:[49]

1. *"The protection of interests and creative freedom of makers*
2. *Wide access to new knowledge, processes and products*
3. *The extent to which it is possible to appropriately and effectively create and capture value"*

The consideration of these measurements and their meaning for the operative work of a Fab Lab may help to develop a business model. This model should contain the creation of value for both, the maker and the Fab Lab. [50]

The value(s) mentioned in item 3 were identified in a study by Anna Seravalli using the example of the "STPLN Malmö" Makerspace with the following three kinds of value created by the STPLN. First, "products and services" satisfying human needs. Second, "human capital" sharing knowledge and developing skills and competences. Third, STPLN is generating value regarding "social capital" through creating social connections within a network.[51]

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[48] Cf. Troxler (2013), p. 10
[49] Troxler (2013), p. 10
[50] Cf. Troxler (2013), pp. 10-11
[51] Cf. Seravalli (2014), p. 115

Business models of Fab Labs should be corresponding to the measures of success and should contain the above illustrated key ingredients. In literature, several partially overlapping concepts for such models were found.

"Fab Lab Iceland" carried out four possible business models to fulfill the different concerns of stakeholders. The proposed business models represent directions for developing a Makerspace.[52]

- *Enabler business model:* Providing know-how and physical goods for existing and newly launched facilities; allows labs to share best practices, e.g. products, workshops, administration etc. [53]
- *Education business model:* Peer-to-peer learning among users and enforcement of the global network of Fab Labs and other Makerspaces; e.g. Fab Academy, individual courses, etc. [52]
- *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; supporting makers to create sustainable businesses[52]
- *Replicated/ network business model:* Providing products and services from the staff and experts to retain sustainable revenues; products and services which can be replicated worldwide[52]

Additionally, Eychienne (2012) proposes the following business models for Fab Labs:[54]

- *"Education" Fab Lab:* Hosted by universities or higher education institutions with students as the primary customer group; open lab days combined with paid prototyping or manufacturing services run by students and small business
- *"Private business" Fab Lab:* Privately funded labs providing digital fabrication facilities and machines for hire, offering services like trainings, and consulting activities
- *"Pro-am, general public" Fab Lab:* Providing access to digital fabrication tools with revenues from services, machine rental, sponsorship and public funding

[52] Cf. http://www.openp2pdesign.org/2013/spaces/what-is-a-fablab/
[53] Cf. http://wiki.fablab.is/wiki/Proposal)
[54] Cf. Eychenne (2012), pp. 26-34

As mentioned above, many Fab Labs must become self-sufficient within three years. To reach this target following sources of income are proposed to gain revenue[55]:[56]

- *Space and equipment rental:* Apart from open access hours, membership fees and additional machine rental fees are possibilities to collect charges
- *Contract manufacturing:* Production on demand, e.g. for businesses or individuals
- *Training, workshops and seminars:* Knowledge transfer from experts for businesses and individuals
- *Project support, feasibility studies and prototyping:* Support and guidance for startups and SMEs during their innovation processes
- *Fab Lab network and available local skills for national and international projects:* Incorporation of local knowledge into international projects
- *Small business incubation:* Expertise offering in different topics, e.g. intellectual property rights, communication, marketing etc.
- *Fab Lab employee as consultant:* Know-how transfer or immediate producer/operator of industrial projects

Most Fab Labs combine several of these sources of income with government grants, or grants from universities and regional projects. In addition many Fab Labs retain support from local industry partners. These partnerships may have an important influence on funding overall.[57]

2.6 Target Groups of Makerspaces

Related to the proposed business models and presented ecosystems of Fab Labs and similar institutions this section focusses briefly on the situation of Fab Lab Graz.

In general the following target groups of Makerspaces are identified (see section 2.4):[58]

- Members
- Students
- Schools
- Designers, Architects
- Start-ups
- Companies

[55] Cf. Troxler (2010), pp. 7-8; Cf. Eychenne (2012), p. 12
[56] Cf. Eychenne (2012), p. 15
[57] Cf. Eychenne (2012), p.16; Cf. Meier & Wirth (2013), p.14
[58] Cf. Guthrie (2014), p. 7

Three main target groups of the Fab Lab at Graz University of Technology have been identified: students, industrial partners and start-ups or entrepreneurs. The identification of relevant connections or relationships between the Fab Lab, the university and the individual target groups will be part of this work.

2.7 Maker Movement Enabling Start-ups

The step "maker to market" is probably the most sophisticated and controversial since not all makers are interested in starting their own business. [59]

Mortara and Parisot (2014) stated that a Makerspace may provide a solid foundation to become an entrepreneur. In "How do Fab-spaces enable entrepreneurship?" 12 individuals were interviewed who used Makerspaces to push their product innovations. The result of this study was the identification of important features provided by Makerspaces. According to different authors and scholars, Mortara and Parisot divide the entrepreneurial process into three stages: ideation, development and commercialization. The stages "development" and "commercialization" were identified as the ones where Makerspaces reduce significantly the barriers of becoming an entrepreneur.[60]

- *Ideation:* Although Makerspaces are known as creative environments, only one out of twelve interviewed entrepreneurs was supported in this stage. It seems that finding an idea and recognizing the value of this idea (commercially) takes place in other contexts.[61]
- *Development:* The study affirms that Makerspaces support potential entrepreneurs the most in converting ideas into prototypes. Further, every of the investigated entrepreneurs benefitted from the expertise of the staff. The interviewed entrepreneurs agreed that the knowledge available at a space (staff and other members) is more valuable than available tools and machines.[59]
- *Commercialization:* This stage contains the steps converting a prototype into a product, reaching the markets and setting up a business. Seven out of twelve start-ups used Makerspaces for the early production phase. Yet, none of the entrepreneurs used the facilities of Makerspaces to scale-up production. This was due to two reasons: (1) tools not good enough; (2) production too time-consuming.[62]

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[59] Cf. Moilanen (2012), p.102;
[60] Cf. Mortara & Parisot (2014), pp. 1-4
[61] Cf. Mortara & Parisot (2014), p. 14
[62] Cf. Mortara & Parisot (2014), p. 15

Even if not all makers are interested in becoming an entrepreneur, makers are increasingly attractive to existing enterprises. The process bringing together companies, partners and customers was described in terms of “open innovation” (Chesbrough, 2006) or “user innovation” (von Hippel, 2005).[63]

2.8 Maker Movement Boosts Established Companies

The traditional closed innovation model describes an enterprise-centered approach. Companies develop via internal research and development (R&D) new products for the market. Simplified, the open innovation model differs according to Chesbrough therein that external sources are involved in the development process.[64]

The complexity encountered in integrating ideas developed outside a company’s sphere of influence led to different forms of intermediaries.[65] Fab Labs as innovative local spaces may serve for companies as such intermediaries and external sources. Therefore, Makerspaces may contribute to a company’s success. Smaller companies and SMEs in particular need access to external information-, knowledge-, know-how- and technology-sources to maintain their innovation capacity.[66]

Nevertheless, the “Open Source Software“ example demonstrated that companies do not have to be involved in the development of a successful product at all. Further, von Hippel postulates that makers in this sense are “users” and able to develop and produce exactly what meets their needs. Manufacturers as not perfect “agents” are no longer needed. Moreover, today’s users benefit from innovative networks (e.g. global Fab Lab-network) by sharing ideas and solutions online.[67]

The impact of Makerspaces on the traditional business world may be seen also in a broader aspect. For enterprises, managing the uncertainty during the development or innovation of new products is a main task. Uncertainties can be differentiated in technical, production, or market issues. For managing those uncertainties, information is needed. Information regarding consumer and market needs (1) and technological and solution information (2).[68]

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[63] Cf. Piller & Ramsauer (2014), p. 28
[64] Cf. Chesbrough (2012), pp. 20-27
[65] Cf. Almiral & Wareham (2008), p. 22
[66] Cf. Herstatt, Buse, Tiwari, & Umland (2007), p. 14
[67] Cf. von Hippel (2005), p. 14
[68] Cf. Thomke (2003), p.25; Cf. von Hippel (1998), pp. 634-635

Therefore, information has to be shared during the whole innovation process by external actors and by various employees within the company to provide the best outcome.[69]

In "A typology of customer co-creation in the innovation process" the authors conducted a two-sided typology of customer innovation. The "frontend" entails the ideation and concept phase of the innovation process. The "backend" refers to the later stages of design and testing.[70] In Figure 6 both frontend and backend are illustrated. By looking at this classification, Fab Labs may be classified into "high community" (creative and open task) and "customer community". Fab Labs thus belong to the groups "communities of creation for idea generation (frontend)" and "communities of creation for concept development and technical problem solving (backend)". Fab Labs, Hackerspaces or Makerspaces are not the only type of so-called customer communities. Different organizations or groups which can be described as "customer community" may run completely independent or also may be initiated and situated directly at companies. Further, it could be identified that innovations come more likely from hobbyist as opposed to professional users (e.g. lead-users).[71]

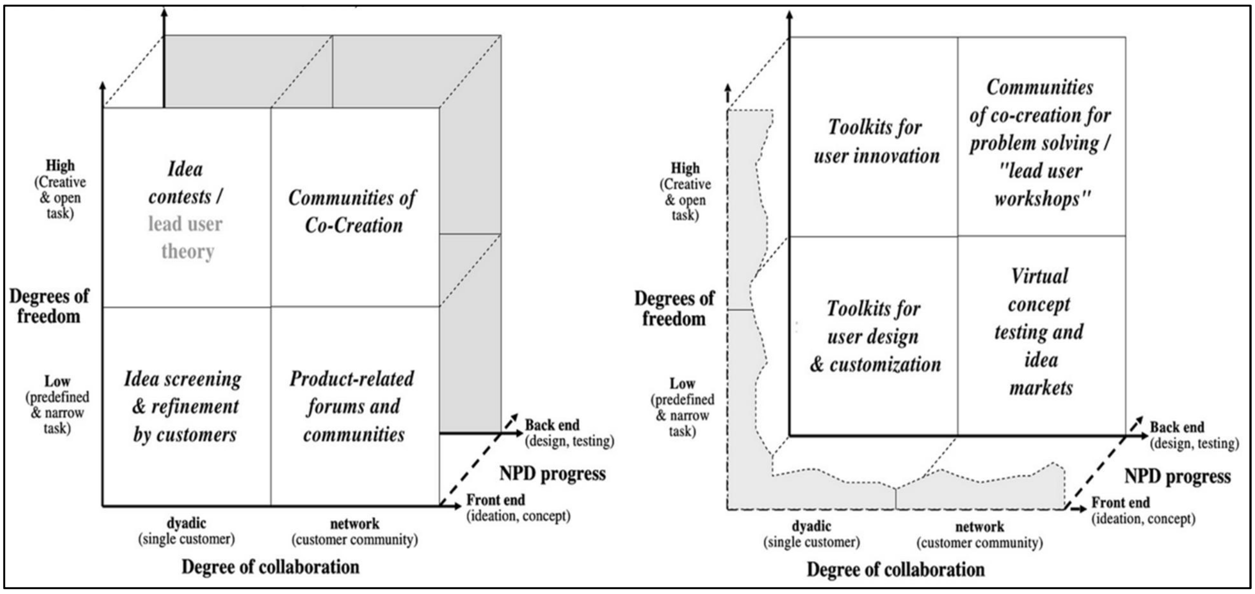

Figure 6: Typology of customer innovation[72]

[69] Cf. Piller, Ihl, & Vossen (2011), p. 2
[70] Cf. Piller, Ihl, & Vossen (2011), pp. 11-15
[71] Cf. Jeppesen & Frederiksen (2006), pp. 49-50
[72] Piller, Ihl, & Vossen (2011), pp. 11-15

Another way to categorize Makerspaces are via different modes of using customer information (Piller et al., 2011). The three categories “listen into”, “ask” and “build” differ regarding the activities companies carry out with customers. Fab Labs can be used by enterprises in particular to “build” together with their customers.[73]

In relation to the possibilities offered by “open innovation” and “user-innovation” (or customer co-creation – Piller et al.) large industrial production machines will play an increasingly minor role. There will be new forms of organizations for the production with distributed business platforms. Apart from mass production, Fab Labs will open new and interesting markets. A, or perhaps the key ingredient to this success is the use of digital fabrication tools.[74]

It can be noted that Fab Labs foster product development as providers of digital fabrication tools in the sense of “open innovation” (Chesbrough, 2006) and additionally in that of “user-innovation” (von Hippel, 2005) directly by the end-user.

If user-innovation and personal fabrication is established in the future, von Hippel proposes three strategic actions for industrial enterprises:[75]

- Companies can produce user-developed innovations for mass market and / or offer contract manufacturing for certain users.
- Companies can sell tools for designing products and / or sell platform-products to support the user’s individual innovation process.
- Enterprises offer complementary goods (products or services) to user-developed innovations.

[73] Cf. Piller, Ihl, & Vossen (2011), p. 7
[74] Cf. Gershenfeld (2005), pp. 11-13; Cf. Boeing (2011), p. 75
[75] Cf. von Hippel (2005), pp. 124-131

In Figure 7 another impact of the Maker Movement on the traditional innovation process is shown. In the past, graduates started to work for companies and these companies pushed their new product towards the customers. The new paradigm demonstrates that consumers now expect that inventions produced by business from graduates of educational institutions meet their needs. Similar to “user innovation”, this approach places the consumers, especially makers, at the center of the innovation process.[76]

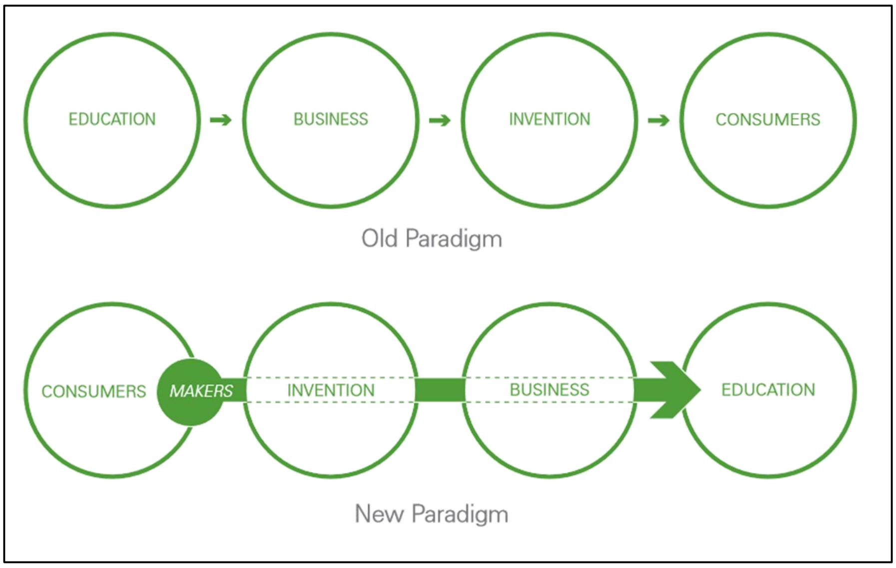

Figure 7: Paradigm shift on traditional innovation process[77]

[76] Cf. National Instruments (2015), p. 4
[77] National Instruments (2015), p.4

2.9 Summary Section 2: "Maker Movement"

The term Maker Movement, minted in 2005 by MAKE magazine, describes the sub-culture of the world of making best. At the center of the Maker Movement is the maker itself. Three different stages of "making" could be identified. First, "zero to maker" as the entrance point to the Maker Movement. Second, "maker to maker" - the process of making is strongly influenced by the spirit of sharing and learning from other users and their projects. Third, "maker to market" as the final and most difficult step where ideas are converted into market conform products.

Making usually happens in dedicated fabrication spaces. Different names and notations for such facilities have been identified. The most important organizations are TechShops, Hackerspaces and Fab Labs. All of these institutions share the goal of democratizing the manufacturing process. "Makerspace" as a term, also minted by MAKE magazine is often used as an umbrella designation for such innovative laboratories.

The Fab Lab initiative was considered as the most relevant for this thesis. By looking closer at the ecosystem of Fab Labs, the following results could be identified:

- Their development can be traced to 2003 with the first Fab Lab outside of MIT. From 2003 to 2012 the total number of active Fab Labs around the world has doubled every 18 months.[78]
- Today there are 562 Fab Labs registered at the Fab Foundation.
- In the environment of Fab Labs, a creative community has formed. The community can be separated regarding the local community and the global Fab Lab network.
- Difficulties for Fab Labs are largely the result of the complex environment surrounding these institutions. A significant amount of effort is needed for the corresponding Fab Lab to build an innovation ecosystem and then to inform and demonstrate to its partners that the Fab Lab is actually part of this ecosystem.
- Fab Labs, particularly those connected or tied to educational and research organizations must address the (difficult) gap between research and economy.

Makerspaces collaborate with entrepreneurs and industry. Based on the literature consulted, it can be stated that during the development phase (converting an idea into a prototype) knowledge transfer and the expertise of the staff in particular are major reasons for entrepreneurial success. The commercialization phase instead showed that only the early production phase can be realized at a Makerspace. For further steps in

[78] Cf. Hielscher, Smith, & Fressoli, 2015 p. 14

manufacturing, most tools available at Makerspaces are not accurate enough or production would be too time-consuming.

The influence of makers and the Maker Movement on established enterprises expresses itself in two innovation theories. Makerspaces may serve as external sources of “open innovation” for organizations. Further, it is key to note that smaller companies and SMEs in particular need access to such external sources. Additionally the Maker Movement may contribute to von Hippel’s theory of “user innovation”. Makers, in this sense are “users” and able to develop and produce exactly what meets their needs. Moreover, today’s users benefit from innovative networks (e.g. global Fab Lab-network) by sharing ideas and solutions online.

These facts show the multiplicity of a sustainable Makerspace concept. An overall applicable business model for such a laboratory is one focus of ongoing research.

3 Market Research of Makerspaces

In order to obtain information about Makerspaces the following two independent research tools were used:

1. *Internet search:* to gather information about the available equipment and business models of Makerspaces in the US and Europe a thorough internet search has been conducted.
2. *Qualitative interviews at similar institutions:* different Makerspaces in the vicinity of Graz were visited. Qualitative interviews with operators of these facilities were undertaken to obtain information about the practical work of these institutions.

The different sources for information provide valuable content regarding the practical work of similar institutions. The results of this section will have an impact on the further scope of this thesis and the development of the Fab Lab at the Graz University of Technology.

3.1 Internet Search

In the following section, data collected during internet research regarding Makerspaces (Hackerspaces, Fab Labs, and other) is presented. Included are in total 68 fabrication facilities, 35 situated in the United States of America and 33 in Europe. A full list with the investigated Makerspaces and the according internet links can be found in Appendix A.1.

The search was conducted using a metacrawler. The different names of the included Makerspaces were utilized as keywords (see section 3.1.1). These names were paired partially with terms like “equipment”, “membership”, “tools”, “size” or “members” to obtain further details. This analysis was conducted in May 2015.

It was assumed that Makerspaces share large amounts of information online in order to attract potential customers. Thus, the accuracy and completeness of the available content cannot be guaranteed.

3.1.1 Reviewed Makerspaces

The Figure 9 details the identified Makerspaces in America, sorted by size and type. Among all the existing labs and spaces in the US, the 34 “TOP-Makerspaces” (per the “Most Interesting Maker Spaces in America” (7/29/2014) article in MAKE magazine) were selected for this evaluation. Additionally, one of the TechShop locations (TechShop San Francisco) is included in this internet search.

According to MAKE magazine, these 34 Makerspaces were not selected because of the available equipment or the number of active members and the size but, rather how these Makerspaces match with their community and inspire their associated makers.[79]

Figure 8: Reviewed Makerspaces in the US

Over the course of this se ction, the size and type of the different Makerspaces will be discussed in further detail.

Figure 9, similar to the above illustration of the American Makerspaces visualizes the Makerspaces in Europe selected for further analysis. As no literature regarding an evaluation of “TOP-European” Makerspaces could be found, the selection of the Makerspaces was completed according to the location (major cities) and the grade of similarity to Fab Lab Graz with special attention towards size, hosting facility and type. This focus explains the different distribution of Makerspace types between the US and Europe.

[79] Make: Editors (2014), pp. 40-45

Figure 9: Reviewed Makerspaces in Europe

3.1.2 Collected Data

Categories of the collected data based on information available online of the selected Makerspaces are illustrated in Table 1. Further, in this section general information about the included facilities is described.

	Type of Makerspace	Hosting Facility	Size of Makerspace	Registered Members
General Information:	- Fab Lab - Hackerspace - Makerspace - Other	- None / Private - Community Project / Non-Profit Organizations - University/College/ Public Institution	- 0 - 250 m² - 250 - 500 m² - 500 - 1000 m² - > 1000 m²	

	Basic Fab Lab Equipment	Wood shop Equipment	Metal shop Equipment	Electronic Tools	Handcraft Tools
Equipment:	- 3D-Printer - Laser Cutter - Vinyl Cutter - 3D-Scanner	- CNC - Drill Press - Table Saw - Band Saw - Sander - Planer - Wood Lathe - Jointer	- Welding - Lathe - Band Saw - Plasma Cutter - Blacksmithing - CNC - Sandblasting	- Soldering - Circuit Board Production Tools	- Sewing Machine - T-Shirt Press

	Access Types	Membership Fee	Opening Hours
Membership	- "Membership Fee" - Open Access - Specific User Group	- Yes / No - Amount - Differentiation - Service	- "24/7" - Specific Opening Hours

Workshops	- Yes / No - Topics

Table 1: Internet search - collected data

Types of Makerspaces:

Figure 10 shows the distribution of the different types of Makerspaces; in total (n=68) “Hackerspace” (44%) is the most common type. Twenty-nine percent are Fab Labs while 24% could not be classified either as Hackerspaces or Fab Labs and define themselves/or can be classified as Makerspaces (for notation, see section 2.2). In the US (n=35) Fab Labs represent 6% of the investigated spaces, whereas in Europe (n= 33) “Fab Lab” is the primary type (55%). In Figure 10, a further difference regarding the designation of “Makerspace” in the US (43%) and Europe (3%) can be seen.

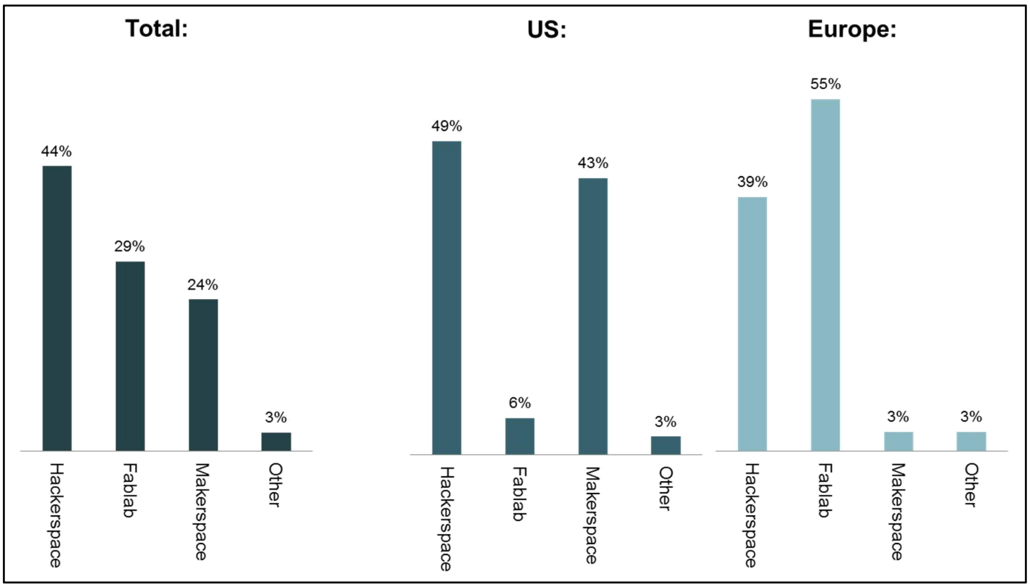

Figure 10: Types of Makerspaces [in %]

Hosting facilities:

Results regarding the hosting facilities demonstrate that 60% (n=68) of all investigated Makerspaces are community projects, organized as non-profit organizations. The distribution is quite similar in Europe and the US. Looking especially at the data of Fab Labs (n=20) in Europe and America shows that 44% (n=18, Europe) and 50% (n=2, US) are hosted by an educational or public institution, whereas only 19% (n=68) of all organizations are funded privately (Appendix A.2).

Size of Makerspaces:

As demonstrated in Figure 11, the distribution of the size in total is well-adjusted with a slight emphasis on the group “0 to 250 m²”. A closer look at the charts for Europe and the US shows differences. In the US, only 12% (n=35) of the labs are among the group from “0 – 250m²” while 26% (n=35) are larger than 1000m². In contrast only 3% (n=33) of the spaces in Europe are larger than 1000m² but 41% (n=33) are “0 – 250m²” in size. Additionally, 19% (n=68) of all investigated spaces do not provide details regarding the size.

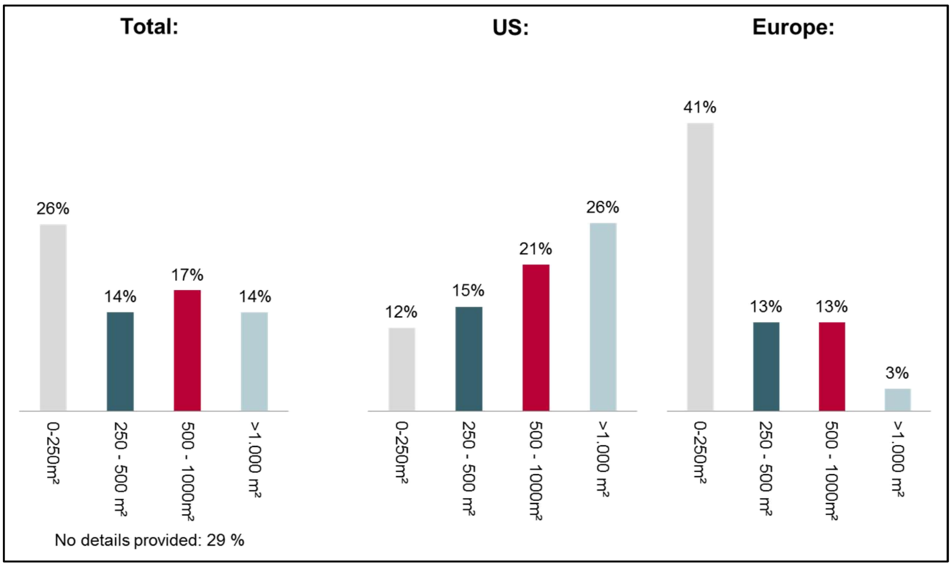

Figure 11: Size of Makerspaces [in %]

Registered Members:

Figure 12 represents the average amount of registered members relative to the size of investigated spaces. With an average of 83 registered makers for groups in the “0 to 250m²” category and 334 members at labs with more than 1000m², the average number of registered members continuously (and logically) increases with the size of the lab. It should be noted that not all active users of Makerspaces have to be registered members. Considering this distinction, it is assumed that the number of actual users is significantly higher.

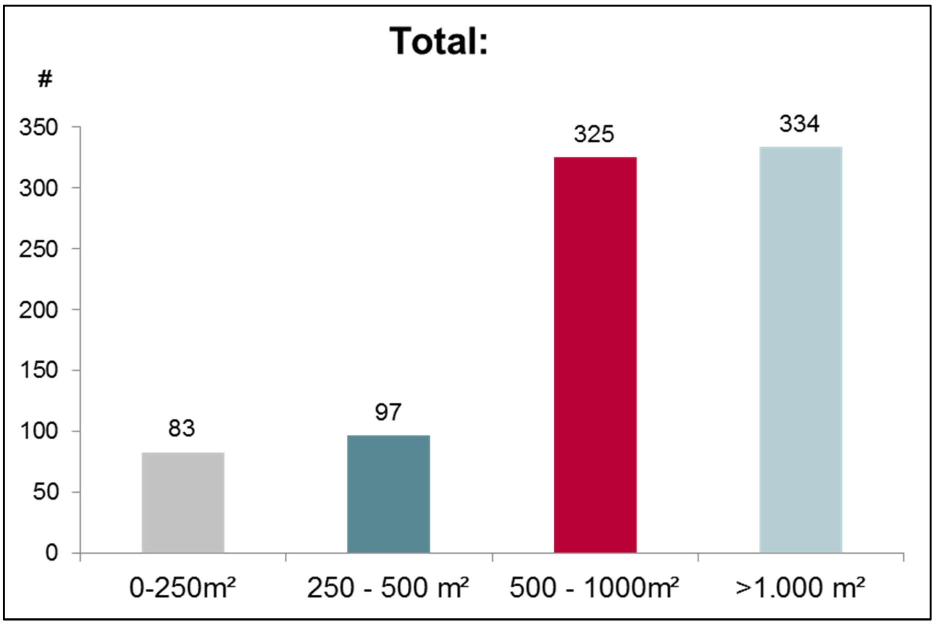

Figure 12: Average number of registered members depending on size of Makerspace

3.1.3 Equipment

The available equipment in Makerspaces is separated into five categories: basic Fab Lab equipment (3D-Printer, laser cutter, vinyl cutter and 3D-Scanner), wood shop equipment, metal shop equipment, electronics and handcraft tools. The results show differences regarding the available equipment according to the allocation

Basic Fab Lab Equipment:

This category includes innovative production facilities. As illustrated in Figure 13, a large majority of spaces provide these technologies. In general, a 3D-Scanner as technology is not common (32%, n=68). The difference regarding 3D-Scanners between Europe (40%, n=33) and the US (20%, n=35) might be explained through the higher number of investigated Fab Labs in Europe and their pre-defined list of tools (see section 3.1.1).

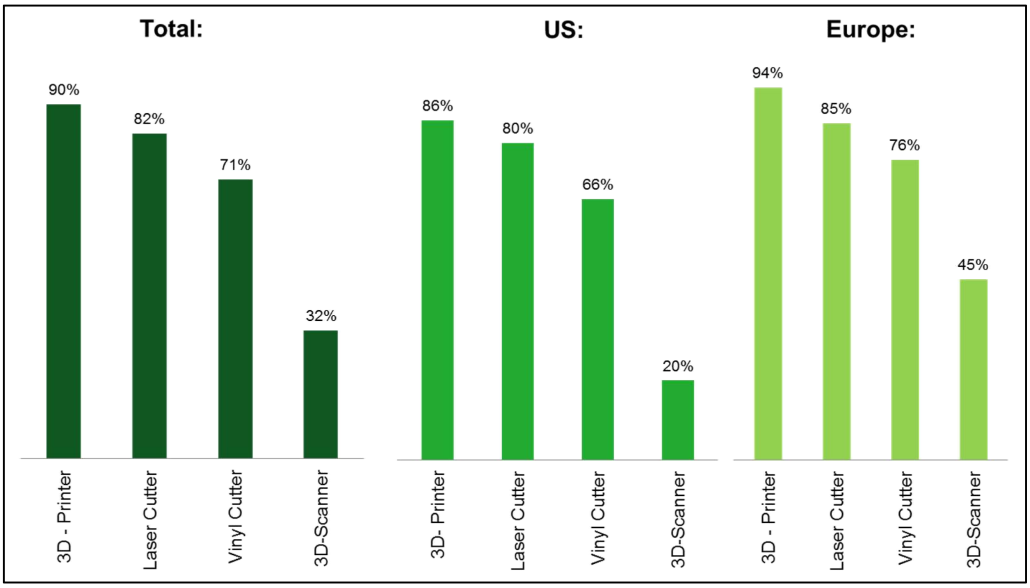

Figure 13: Basic Fab Lab equipment available at Makerspaces [in %]

Wood Shop Equipment:

Figure 14 illustrates the available wood shop equipment. Most available wood shop equipment in Europe as well as in the US are CNC machines. In general, it can be seen that the share of woodworking machines (Saw, Sander, Planer, Wood Lathe, Jointer) in America is higher than in Europe.

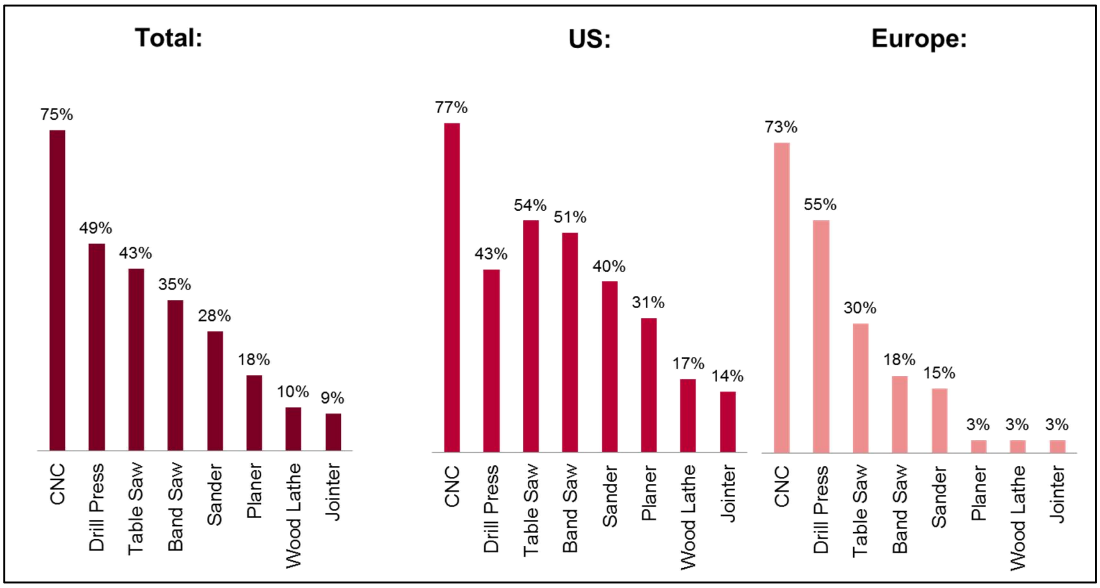

Figure 14: Wood shop equipment available at Makerspaces [in %]

Metal Shop Equipment:

The difference between production facilities provided by European and American organizations is even more clearly depicted by looking at the available tools for metalworking. Generally, it can be stated that metal working plays a minor role in the Maker Movement. Thus, while Figure 15 demonstrates that at least 50% (n=35) of US spaces provide welding tools and turning lathes compared to less than half that number in Europe, metalworking plays a far less significant role in Europe than in the US.

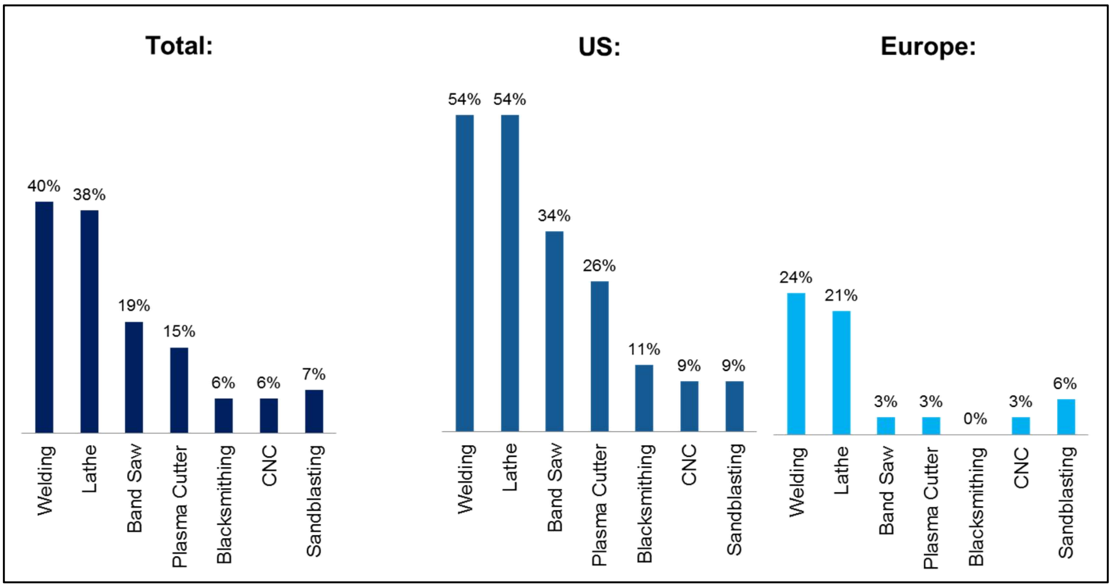

Figure 15: Metal shop equipment available at Makerspaces [in %]

Electronic Tools:

Soldering and circuit board production tools have been identified as common technologies vis-a-vis Makerspaces and electronics. Data regarding test equipment (e.g. oscilloscope, multimeter) could not be recorded. In total 84% (n=68) of all laboratories are equipped with soldering stations. Circuit board production tools are only available at 13% (n=68) of the spaces. In Europe, the amount of facilities with circuit board production tools is higher (27%, n=33) than in the US (Appendix A.2).

Handcraft Tools:

Quite similar results for US and European laboratories were identified regarding handcraft tools. Sixty-four percent (n=68) of all spaces provide sewing machines. Heat-presses (27%, n=68) were less represented tools of space-equipment. Other handcraft implements such as glue guns, scissors, pliers and so on were not taken into consideration for this search (Appendix A.2).

3.1.4 Membership Models of Makerspaces

The accessibility of Makerspaces is an important part of the business model for these organizations. How access is regulated and what services are offered are main parts of this section.

Access to Makerspaces:

From the internet research three main access types were identified. First, access granted via membership fee (76%, n=68). Membership fees are by far the most practical approach. The second type of access is termed “open access”. Open access means in this context that there is no barrier to entrance, such fees or other restrictions. Third, Makerspaces open only to a specific user group. Makerspaces hosted by educational institutions open their space partly only to a specific user group (e.g. students). There are two other organizations with such restrictions. The first is the “Double Union Makerspace” situated in San Francisco which is accessible only for female makers. The second organization is “Pier 9” run by Autodesk likewise situated in San Francisco. Pier 9 is only accessible for selected artists and start-ups and in addition access is restricted to certain time-periods.

Supplementary to the usual practical arrangements for access (e.g. membership fee, only specific user group) 76% (n=68) of the facilities have a regular event or hours of operation reserved for the general public with no usage costs (e.g. open day).

In Europe, the amount of organizations with open public events is even higher (94%, n=33). An explanation might be the higher amount of Fab Labs. Fab Labs have to provide public access to their production facilities at least once a week.

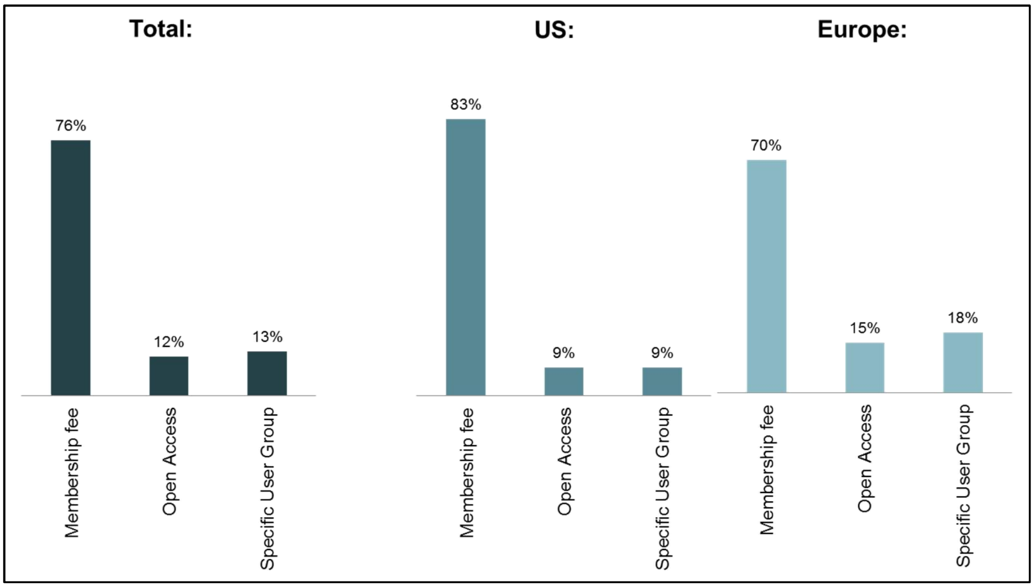

Figure 16: Accessibility of Makerspaces [in %]

Membership Fee:

As described above, membership fees are an important source of income for 76% (n=68) of all spaces. The services included in these fees depend on the possible access time. The following three variants are identified:

- “24/7” access
- Official opening hours
- Specific time packages (e.g. Weekend-Package, After-Work-Package)

Seventy-one percent (n= 52) of all facilities with a membership fee based business model provide their members with 24/7 access to the space. Further, it can be stated that official opening hours are not often used in combination with membership fees.

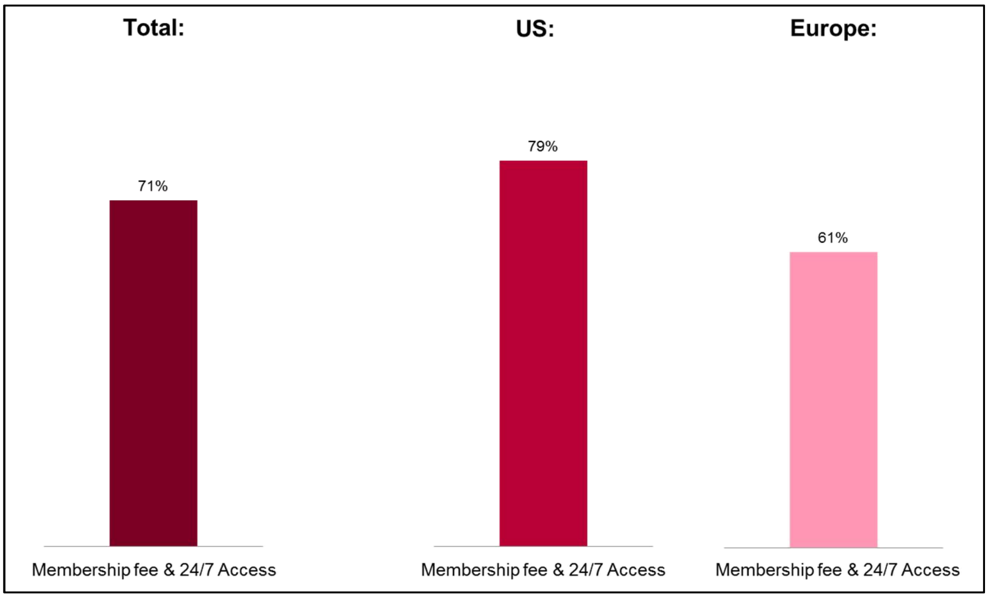

Figure 17: Makerspaces with membership fee and 24/7 access [in %]

In Figure 18, membership fee structures of different facilities are examined more closely. To ensure comparability in terms of services only membership fees for "24/7 access" are taken into consideration. As demonstrated in Figure 17, this service corresponds to the offer of 71% (n=52) of spaces with membership fees.

From examining the size in combination with membership fee amounts the following distribution emerges.

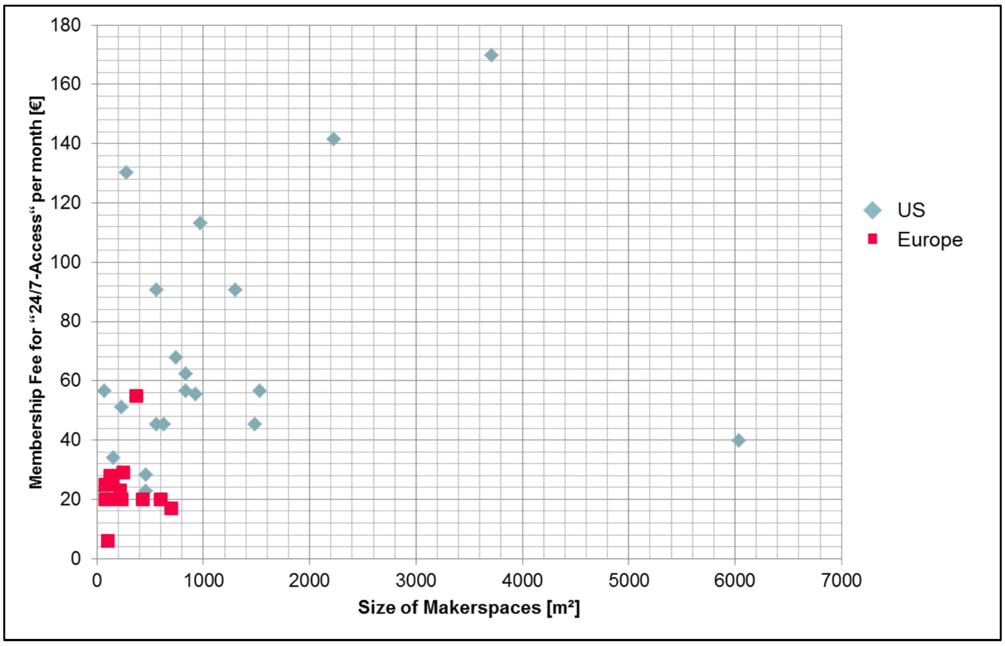

Figure 18: Membership fee per month relative to the size of Makerspace

In Europe, the majority (54%, n=33, Figure 11) of included spaces fall into the “0 – 500m²” category. Examining this area more closely (Figure 19) a limit of 35€ per month was identified for European facilities. This limit of 35€ seems to be relative to the lower limit at American institutions. A few smaller American spaces offer membership below this fee limit. Starting from a size of 500m² (Figure 19) the majority of American organizations fall within a range from 40€ to 120€ per month for 24/7 access.

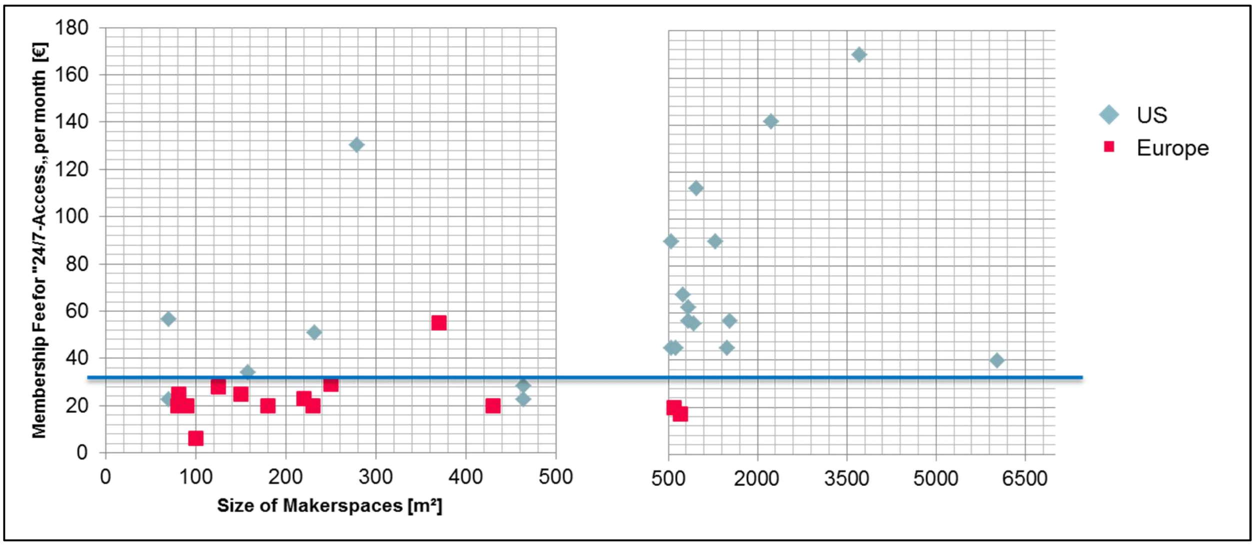

Figure 19: Closer look at membership fee structure relative to size of Makerspace

Business Models of Makerspaces regarding Accessibility:

The different types of accessibility and the membership fee structure are described above. Another source of income and usage barrier for these kinds of facilities exists. This distinction relates to costs per hour for production facilities. There are two different models regarding usage fee for machines:

- Additional machine rates
- No additional machine rates

Therefore, sources of income are mainly “machine rates” and “membership fees”. In combination with the included services three main access models could be identified (Figure 20). All of the included Makerspaces of this internet search can be classified into one of these categories.

	Business Models regarding Accessibility		
	Type I: „Membership Fee“	Type II: „Open Access“	Type III: „Specific User Group“
Membership Fee	Yes	No (Optional)	Yes No
Opening Hours	"24/7" "Official Opening Hours" Packages	"Official Opening Hours"	"24/7" "Official Opening Hours"
Equipment	Additional Machine Rates No Additional Machine Rates	Additional Machine Rates No Additional Machine Rates (Reduced Machine Rate)	Additional Machine Rates No Additional Machine Rates

Figure 20: Access types of Makerspaces

- *Type I "Membership Fee"*
  This type is characterized by access to the space only for paying members with the restriction of regular events open to the general public. Concerning the opening times, as mentioned above, three variants and certain combinations of these variants are common. The majority of such structured Makerspaces do not require additional machine rates. In some cases, additional machine rates have to be paid only for certain machines.
- *Type II "Open Access"*
  Open access means that there are no entrance barriers such membership fees. Every person can visit the space and work with the available equipment. In some of the cases, an optional membership fee is offered in combination with more favorable machine rates. In such an arrangement, official opening hours have been determined as the only option in all corresponding Makerspaces.
- *Type III "Specific User Group"*
  This third type is a combination of the first two types with the restriction that the access is only possible for a specific user group (e.g. females, students).

3.1.5 Workshops

Workshops appear to not be a valuable source of income but rather an instrument for establishing and maintaining an active user community. The results illustrate that with more than 80% (n=68) a vast majority of all Makerspaces offer workshops.

Different variants of the sequence of workshops are found (Figure 21). A further distinction may address the persons who can actually attend the different workshops (members, non-members, etc.). The access restrictions for the workshops are the same as the types of accessibility shown above (i.e. paying members, the specific user group (e.g. students) or 'all').

	Workshops		
Who is holding the Workshop?	Interested User	External Professional	Company Representatives
Costs	Cost Price Sponsored by Makerspace	Regular Price Sponsored by Makerspace	Sponsored by Companies
Frequency of Occurence	Periodical	Single Event	Single Event Periodical

Figure 21: Sequence of workshops held in Makerspaces

3.2 Selected similar concepts in Europe

In Austria and neighboring countries several Fab Labs and different kinds of Makerspaces already exist. In order to gain insight into experiences of the operators and their problems, interviews with five Makerspaces were conducted.

3.2.1 Interviewed Makerspaces:

The interviewed Makerspaces are illustrated in Table 2. Furthermore, facts regarding size, registered members, type of space and hosting facilities are shown. As described in section 3.1.4 one result of the internet search was identification of three overall business models regarding accessibility. The interviewed Makerspaces are classified into the identified types (Table 2). More specific details will be discussed over the following pages.

	Happylab Vienna	**MakerAustria**	**Fab Lab Leoben**	**TiS Bozen**	**Fab Lab London**
Facts Size Members Type	250 m² 1.500 Pers. Fab Lab	800 m² 60 Pers. Fab Lab	120 m² 30 Pers. Fab Lab	30 m² 40 Pers. Fab Lab	370 m² no details-provided Fab Lab
Hosting Facility	Private	Private	Private	Public Institution	Private
Business Model & Accessibility	**Type I: "Membership Fee"**	**Type I: "Membership Fee"**	**Type I: "Membership Fee"**	**Type II: "Open Access"**	**Type II: "Open Access"**
Membership Fee	Yes	Yes	Yes	No	No (Optional)
Opening Hours	Official Opening Hours or 24/7	Official Opening Hours	Official Opening Hours	Official Opening Hours	Official Opening Hours
Equipment	No Additional Machine Rates	No Additional Machine Rates	No Additional Machine Rates	No Additional Machine Rates	Additional Machine Rates (Reduced Machine Rates)

Table 2: Interviewed Makerspaces

Happylab in Vienna is Austria's first Fab Lab having been established from 2008 – 2010 as part of the EU European Regional Development Fund project. In 2015, with about 1500 active members and a second location in Austria at Salzburg with 150 members Happylab is the largest and most experienced part of the Fab Lab community in Austria.

Figure 22: Happylab Vienna

MakerAustria, also situated in Vienna opened in October 2014. Its staff is still in the process of establishing the facilities. In the development process, professional machines are missing but the already existing areas are used frequently. For their current 60 members they are working hard to provide a well-equipped Makerspace and include a strong social component in their business model.

Figure 23: MakerAustria

Fab Lab Leoben opened its doors in February 2015. The Fab Lab was developed in close cooperation with Leoben's city-management and the Montanuniversität Leoben. As of July 2015 with a size of 120 m² and 60 active members, Fab Lab Leoben has much growth potential.

Figure 24: Fab Lab Leoben

The Fab Lab at the TIS Innovation Park in Bozen/Bolzano (Italy) was developed out of a former prototyping workshop. The TIS Innovation Park is a regional public institution with the goal to force innovation and to link economy with science. The services provided include assistance for launching start-ups, developing products together with small and medium sized companies, networking and knowledge transfer. Today's Fab Lab is already too small. Together with the University of Bozen-Bolzano in 2016 a new Fab Lab of 250 m² will be opened in the city-center of Bozen/Bolzano.

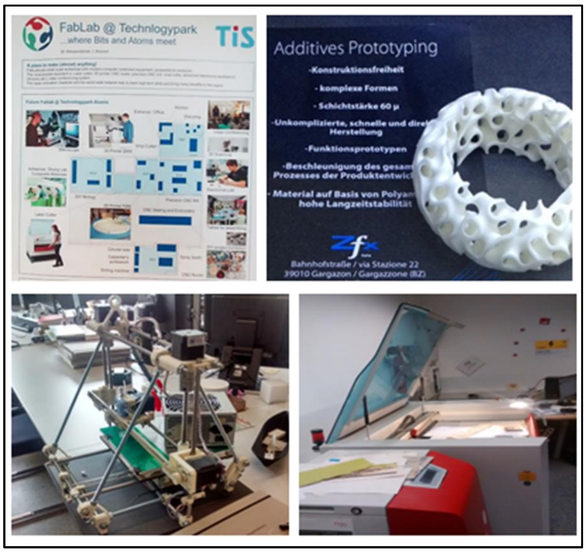

Figure 25: TIS Fab Lab Bozen

The focus of Fab Lab London (UK) apart from providing digital production machines and a space for knowledge transfer is setting up new businesses. As a hardware incubator with special offers to entrepreneurs and companies the goal is to bring innovations to the market (maker to market). A total size of 370 m² and 1,500 people passing through the lab only in May 2015 present an impressive base to reach their goals.

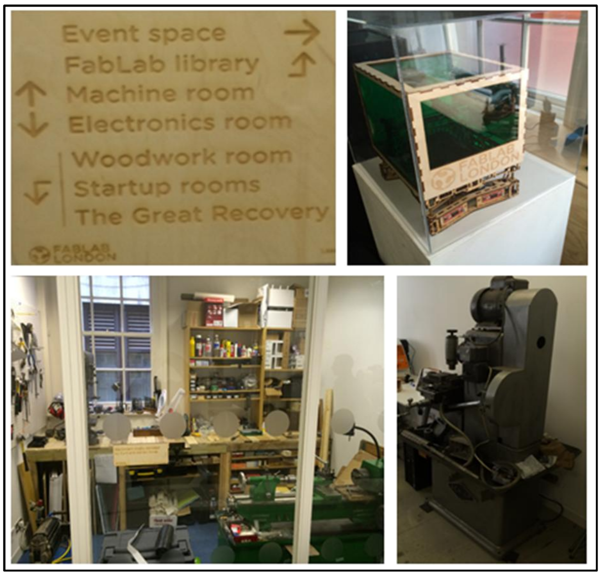

Figure 26: Fab Lab London

3.2.2 Collected Data

In order to gain insight into the work of similar institutions, qualitative expert interviews with the operators were conducted. In Table 3, an overview of collected data is shown. The full questionnaire is illustrated in Appendix A.3.

	Type of Makerspace	**Hosting Facility**	**Size of Makerspace**	**Equipment**	**Registered Members**
General Information	- Fab Lab - Hackerspace - Makerspace - Other	- None / Private - Community Project / Non-Profit Organizations - University / College / Public Institution	- 0 - 250 m² - 250 - 500 m² - 500 - 1000 m² - > 1000 m²	- Fab Lab Equipment - Wood shop Equipment - Metal shop Equipment - Electronic Tools - Handcraft Tools	
Utilization	**Target Group - User Group**	**Access Types**	**Community**	**Machinery**	**Workshops**
	- Students - Hobbyists - Start-Ups - Enterprises - Education	- "Membership Fee" - Open Access - Specific User Group	- Experience	- Introduction - Monitoring - Most frequently used	- Costs - Organized by - Experience
Core Competence	"Lab as Facility" <> "Innovation Lab"				
Prospect	Future potential	Trends regarding equipment	Planned enlargements		

Table 3: Interview questionnaire - similar institutions

3.2.3 Target User Group vs. Actual User Group

The intended target groups of all Makerspaces include hobbyists, students and start-ups. Differences are found regarding schools as target group. Only two Makerspaces of the five examined are focusing on children and education. TIS Fab Lab Bozen, Happylab Vienna and especially Fab Lab London focus more than the other two Makerspaces visited on businesses. The focus among commercial companies in general is on start-ups. Fab Lab London provides special services such as meeting rooms and working spaces for start-ups. The costs for these services vary depending on the financial situation and the degree of innovation. TIS Bozen, as part of the Innovation Park likes to support start-ups and larger companies during the product innovation process.

The actual user groups vary more or less at each Makerspace from the target groups. Only at Happylab Vienna did the target groups match the actual user groups. It seems that other Makerspaces have problems to reach start-ups and traditional enterprises. Happylab Vienna was already successfully involved in the launch of new businesses. Additionally, they worked for different medium-sized and larger companies as technical advisors. Other Makerspaces report that the major part of their users are hobbyists. TIS Bozen e.g. attributes this fact to the limited available machinery and space.

One issue was identified as being especially relevant to the target group of established companies. Traditional enterprises seem to have problems with the unclear intellectual property (IP) situation. Happylab Vienna reports that the first question of larger industrial companies often is in regards to intellectual property and their reservations against the open concept of Makerspaces. TIS Fab Lab Bozen agrees. However, the operator pointed out that enterprises which have together with the TIS Bozen successfully completed a project lost their reservations regarding open innovation and the often mentioned IP-problems. The other three Makerspaces do not cater to industrial enterprises or SMEs with their services. Fab Lab London to gain revenue uses another form of cooperation with enterprises, renting event space to larger companies. Beyond that, there are no further relationships to this target group.

3.2.4 Accessibility of Investigated Makerspaces

Three out of five visited Makerspaces only provide access for members (see Table 2).

Fab Lab London and Fab Lab Bozen can be categorized as “type II - open access” spaces regarding accessibility. Fab Lab Bozen does not charge for the use of their facilities. In the next year, as mentioned above, when the new Fab Lab in Bozen opens membership fees are planned. To keep the entrance barrier low, the membership fee is planned to be 50 € per year at the most. Membership fees at Fab Lab London are only optional and reduce the obligatory machine rates (e.g. machine rate for one hour laser cutting: 42 €).

Membership fees of the three “type I”-Makerspaces start at 5 € per month and climax at 20 € per month. All of the investigated Makerspaces provide specific opening hours for their users. Only the Happylab provides a so called “Large” membership package granting 24/7 access to the Lab and its facilities for 29€ facilitated by a self-developed RFID-System with key-cards. This system provides free access to the lab outside the official opening hours.

An exception is the socially influenced approach of MakerAustria. The sum of 30 € per month for the use of the space and the equipment represents only a recommendation. With a "pay as much as you can" - approach MakerAustria implemented a social aspect of Makerspaces. In the future MakerAustria will provide 24/7 access for their members as soon as possible and will install a RFID-System.

3.2.5 Community

With 1,500 active members at their space in Vienna, Happylab has a very large user base. The founders of Happylab conducted a study regarding the importance of low entrance barriers for Makerspaces. The overall conclusion was that low entrance barriers are necessary to be attractive to different users.[80]

Low-entrance barriers (in the form of low membership fees) or open access models could be identified at all the investigated Makerspaces. Further, events as a form of community-building e.g. workshops (see section 3.1.5) took place in all investigated Makerspaces.

However, the community or the development of a community was described from all operators as critical. First, the community provides the necessary know-how and second, more important only the community brings a Makerspace to life. At Fab Lab Leoben, the operator reported that the base of their community are students, but during the semester breaks the absence of their main user group is obvious.

Another problem was described by TIS Fab Lab at Bozen. Because of the size (30 m²) and the small infrastructure, working parallel is more or less impossible. Therefore, the development of a communicating community is not possible. On the other side, there are active members involved in organizing and handling events. This coupled with the existing network of the innovation park leads the operators to be confident regarding the development of a living community when opening their new space in 2016.

The social approach of MakerAustria regarding membership fees seems to lead to an active and supporting community. It enhances community thinking and also fosters development of the space itself MakerAustria is attempting to establish self-organized working groups for different projects (e.g. development of a CNC).

3.2.6 Most Used Machines and Materials

All of the surveyed Makerspaces with a laser cutter (Happylab, Fab Lab London, TIS Fab Lab Bozen) reported that this is the most used machine. Owing to demand, Happylab has even gone so far as to install a second laser cutter because the existing one is occupied nearly 20h a day.

[80] Cf. Stelzer & Jafarmadar (2013), p. 3

The laser cutter as most used technology is followed in every Makerspace by 3D-Printers. At Leoben, where no laser cutter is installed, the 3D-Printers are the most used machines. MakerAustria reported the most used working area is by far the electronic workshop followed by their 3D-Printers.

The most used materials match with the most used machines. Plywood and acrylic glass are used the most and plastics (ABS and PLA) for 3D printing projects are used commonly. Happylab was the only Makerspace referenced which also utilized handcraft materials (e.g. leather, paper or cardboard). Another exception was the plaster-printer installed at Fab Lab Bozen. In their capacity as supporter for local companies regarding rapid-prototyping, the Fab Lab has approximately 70 orders per year for prototyping in the form of contract manufacturing.

Happylab Vienna started a so called “fabstore” in order to make it easier for the community to get the materials needed. This store offers the possibility to order online in advance and get materials right at the lab during the opening hours. Experiences are positive and the fabstore is self-sustaining but still not a source of income. Fab Lab London also provides their users with a small selection of materials including cardboard, acrylic glass and plywood at the lab. MakerAustria tries to connect their members to make group-orders of different materials to activate bulk discounts.

Concerning machine usage and time slots, Happylab explained that they follow the “first come first serve” principle. For those not wishing to tempt luck, there is the possibility to book machines in advance albeit at cost. The in-advance booking system is not meant to constantly reserve machines by the user and costs 10 € per hour. Similar to the booking system of the Happylab, Fab Lab London has installed an online booking system for the most important machines. For the Fab Lab London this booking system is crucial because the operators charge usage fees per hour. TIS Fab Lab and MakerAustria do not have online booking system yet, but implementing such protocols is planned.

As described above, Happylab Vienna installed an RFID-System. Another benefit of this system is that all machines can only be used by people with the appropriate course of training. Further, the machines won’t continue to operate unless the user stands nearby and confirms presence within a certain time interval. This system provides a control mechanism for the operator if, for example, a machine is not used properly. Operators of the Happylab mentioned that in fall 2015 their keycard system will be released.

As mentioned for Happylab, using a machine requires a short training course in all of the visited Makerspaces. Supporting employees at the different Makerspace are available during official opening hours. These training courses are available in all of the Makerspaces free of charge. Additional free instruction tours for machines are offered every Wednesday, Happylab offers individual instructions to single machines for a fee of € 50. This service is used quite often by members.

According to Happylab Vienna, future equipment has to fulfill the condition that only machines ‘learnable’ within less than one hour will be installed. Further, digital control is assumed for machines to fit into a Fab Lab concept. Fab Lab Vienna e.g. mentioned for future acquisitions a 3D-Printer using ceramic material, a digitally-controlled lathe and an embroidery machine.

MakerAustria and Fab Lab Leoben currently do not have a laser cutter but are both looking forward to install one as soon as possible. Fab Lab Leoben has plans to develop the laser cutter and furthermore a CNC mill for wood, acrylic glass and aluminum on their own. Owing to the upcoming start of the new Fab Lab at Bozen and the (temporary) lack of adequate infrastructure the ‘shopping’ list of TIS Fab Lab Bozen is larger. Envisioned are a CNC-mill, a CNC-embroidery and sewing machine, 4 new 3D-Printers (FDM, SLS) a reflow oven and possibly a circuit board production machine. A metal-workshop is not explicitly planned for installation owing to the limited facility space of 250 m².

3.2.7 Workshops

All of the visited Makerspaces organize workshops for their users. Particularly, Happylab and Fab Lab London focus in their concepts on workshops.

Happylab regularly offers workshops for adults as well as for children and school classes, but children and school classes are not their primary target group. An interesting workshop, the so called “Fab Lab Bootcamp” addresses those willing to learn digital fabrication tools. Two days of intensive training includes digital design (2D, 3D modeling and preparing data for the machines) and digital fabrication. Concrete examples show how to use the fabrication tools. Thereafter, each participant has the possibility to use the Fab Lab for 5 days to realize their own ideas. The course ends after one intense week with a final presentation of the different projects. With costs of 345€ (including access and test materials) the workshop is offered two times a year with extra terms for groups.

Fab Lab London focus even more on education for children (seven years upwards), examples for some courses include “electronics for the young inventor” or “weekend family days”. Further, adult workshops are self-organized by the space and can be modified and adapted to the needs of the participants (e.g. Architecture and Lasers; woodworking). Costs for the workshops cover only the staff costs.

TIS Fab Lab Bozen reports that several workshops have been held in the past years and will be a major point in the future. Some of their workshops are held by external professionals. The workshops remain free of charge for the participants. The approach of Fab Lab Leoben is similar where future workshops and course are planned.

A different approach regarding workshops has been taken at MakerAustria. In the past several workshops were held by staff and external professionals. It was recognized that these workshops required significant resources and space. Therefore, as mentioned, several workgroups consisting of members with different backgrounds were set up to solve given technical problems. Knowledge transfer and community-building is the focus of this approach.

Further, two members of Happylab participated at the six-month training program of the Fab Academy with MIT's Professor Neil Gershenfeld. Every Wednesday, the courses are broadcast from MIT and can be reviewed by the students during the program. With an expenditure of time amounting to 30 hours a week it is an intense and quite expensive ($ 5000) program. According to the operators it cannot be seen as economical for the local Fab Lab in terms of profit. On the other hand it offers a possibility to learn not only for the participant but also for the staff and other Fab Lab users.

3.2.8 Core Competences

Considering Peter Troxler's study about the business plans of different Fab Labs there are two different kinds of utilization concepts – technology providers and innovation labs. During the interview, operators were confronted with a question regarding their Makerspaces core competence.

Fab Lab London as well as Fab Lab Leoben agreed that providing technology is their core competence. Happylab explained that providing technology is only the base. Happylab tries to connect providing technology and accompanying members and their projects during their innovation process. Therefore, Happylab initiated a program called "idea to product" where they cast projects from members (out of 50 applications 10 projects were accepted). These projects were supported from the idea to the final market-ready product during the one year duration of the program. The core competence of the Happylab is the innovation capacity of both members and staff.

TIS Fab Lab at Bozen, as mentioned before, with its presently limited infrastructure answered that their actual installed machinery is not sufficient to be a core competence. However, the Fab Lab benefits from the experience of the surrounding Innovation Park. The Innovation Park has experience in cross-regional innovation processes with 600 business partners. Therefore, the core competence of Fab Lab Bozen is the support of innovation projects in cooperation with their public hosting facility.

MakerAustria with its social approach explains that their core competence is the social aspect together with the therefrom developed community.

The core competences of Fab Lab London as well as Fab Lab Leoben might be categorized, referring to Peter Troxler, as “lab as facility”. The Happylab tries to fulfill both aspects with its “Idea to Product” project to close the gap between being facility provider and innovation lab. TIS Bozen sees itself as an innovation lab and will focus on improving their machinery while continuing to provide expertise to support their users and partners of their innovation network during product innovations. MakerAustria tends to be in Peter Troxler’s categorization a facility provider but with the overall goal of being a community-based social space.

3.2.9 Outlook

Glancing into the future, all of the visited Makerspaces and their operators are more than positively convinced that the Maker Movement trend will continue to persist. Reasons for this outlook include not only the expansions of e.g. Fab Lab Bozen but also the fact that all visited spaces plan new equipment acquisitions. New acquisitions on the one hand provide new production facilities and on the other the necessity to reduce bottlenecks due to heavy usage of certain machines of the same technology.

Happylab Vienna estimates the potential of the whole Maker Movement as well as the potential of their own Fab Lab as substantial and compared it to the early stages of personal computers.

The crucial point for success and the further growth of Makerspaces was directly named by four out of the five interviewed operators with the development and maintenance of an active and living community.

3.3 Summary Section 3: “Market Research of Makerspaces”

The comparison and presence of available tools shows differences according to the allocation. The following paragraphs explain the differences according to the predefined structure of the five categories of tools.

- *Basic Fab Lab equipment*: A difference between US and European Makerspaces regarding Fab Lab tools appears above all regarding “3D-Scanners”. This difference between the US (20%) and Europe (40%) might be explained through the higher share of investigated Fab Labs in Europe. It is quite interesting that only 32 % of all investigated Makerspaces have 3D-scanners. It is assumed that this occurs due to the relatively high starting price of professional 3D-scanners and the needed software tools.
- *Wood shop equipment:* The study shows that the share of woodworking machines (saw, sander, planer etc.) is higher in the US than in Europe. Due to the fact that European facilities are in general smaller than US institutions, it is assumed that the reason for this circumstance might be the required space for an appropriate woodshop.
- *Metal shop equipment:* The internet search demonstrates that metalworking plays a minor role in the Maker Movement. Only every second space in the US provides welding tools and turning lathes. In Europe the numbers for metalworking tools is even lower for local space-concepts. Moreover, the size of the facility may be an appropriate explanation. This is supported by the fact that especially in the US, spaces with more than 1000m² provide these technologies to their members. Additionally, for building up first prototypes, metal is often unnecessary.
- *Electronics:* It is quite interesting that there are no facilities with circuit board production tools in the US. It is assumed that this occurs due the higher amount of European Makerspaces situated at educational institutions that have more interests in particular technologies used in research and education.
- *Handcraft tools:* Quite similar results are identified regarding handcraft tools. Glue guns, scissors, pliers etc. are not taken into consideration in this study.

The decisive factor that affects the differences between US and European Makerspaces and their available equipment seems to be the size of the space. Three aspects need to be considered regarding the deviation in the size of investigated spaces:

- *Maker Movement spreading from the US:* The first Fab Lab was established in Boston in 2002. The first Fab Labs in Europe were established in 2006. Additionally, the first Maker Faire was held in the Bay Area in 2006. The first Maker Faire in Europe was in 2010 in the UK.[81] Another reason for bigger size of spaces is that the first commercial Makerspace opened already in 2006 in the US. Techshops own facilities with more than 1,500 m2 of working space.[82]
- *Different entrepreneurial spirit in US and Europe:* Various studies reveal that business creation in Europe is not as dynamic as in the US. The rate of creation and failure is much higher in the US than in Europe. [83] In the US, it is much easier to take risks and a failure is seen as a lesson that provides experience. In contrast, in Europe failure is a sign of an inability to manage a business. In real terms, European entrepreneurs are liable with their own assets for the losses made by their business. In France, it takes nine years to cover a debt after bankruptcy, whilst in the USA it takes just a few months.[84] Furthermore, there exist many specialized funds which provide experience and networks to entrepreneurs in the US.[85]
- *Selection of investigated Makerspaces:* For the study, we considered the top Makerspaces in the US, but in Europe such an evaluation does not exist.

Further differences might be explained by the higher amount of included Fab Labs and their pre-defined list of basic equipment in Europe. This influence is supported by the fact that these facilities are more often run by educational institutions (e.g. universities).

Based on the outcome of the Internet research conducted, it is recommended to install not only one single machine (e.g. lathe) without support of other technologies for the same material (e.g. plasma cutter, welding facilities etc.). For example, a well-equipped wood shop is preferable to individual machines for both metal and woodworking.

To gain insights into regional individualities the operators of Fab Labs and Makerspaces in Austria and neighboring countries were interviewed. Interview results showed that the laser cutter is the most used machine. One lab already installed a second laser cutter, because the existing one is occupied nearly 20 hours a day. The laser cutter as most used technology is followed by 3D-Printers in all questioned Makerspaces. Additionally, for the spaces only equipment is on site which can be operated by users with less than one hour of training.

[81] Cf. http://makerfaire.com/map/)
[82] Cf. http://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs/)
[83] Cf. Roman, Khan, & Rapaczunski (2011)
[84] Cf. http://www.economist.com/node/21559618)
[85] Cf. Lirzin (2013)

Four out of five interviewed Fab Lab managers affirmed that only providing digital fabrication technologies is not sustainable. It is essential to make a step forward form a “lab as facility” to an “innovation lab”. As an example, one Fab Lab initiated a program called “idea to product” to support selected projects in the process of bringing their ideas to market.

Basically, all analyzed Fab Labs combine or adapt several of the proposed business models in literature. Interesting is that almost all investigated Fab Labs integrate the “incubator business model”.

On the one hand, there are public labs, which provide production facilities, workshops and training as well as support members in their innovation projects (e.g. search for financial sponsorship). On the other hand, there also exist private labs with co-working facilities, which focus on the development of an entrepreneurial community. Revenues are made via machine rates, consultant activities, training and project support for businesses (feasibility studies, prototyping, contract manufacturing). Additionally, one privately funded Makerspace with a "pay as much as you can" approach could be identified. For this space, the social aspect is more important than the availability of production technologies.

All Fab Labs agree that sustainable success is directly related to the establishment and maintenance of an active and living community. Therefore, low entrance barriers in the form of low membership fees and low machine rates are recommended. Further, workshops and team-building events are valuable instruments to develop such a community.

4 Market Needs

This section is divided into two parts which examine the impact of Fab Labs and Makerspaces on the traditional business landscape (see sections 2.7 and 2.8).

1. *Maker Movement enabling start-ups:* A survey at the Mini Maker Faire Trieste is carried out to acquire insights into the needs of actual makers and start-ups.
2. *Maker Movement Boosts established Companies:* Qualitative interviews with industrial partners of the Graz University of Technology have been conducted. These interviews contain information about possible synergies with the Fab Lab Graz and expectations of enterprises on digital fabrication laboratories.

Further, the information gained from these two sources is presumed to be valuable for future workshops and courses held in the context of Fab Lab Graz.

4.1 Mini Maker Faire Trieste

The Mini Maker Faire® is an independent, licensed event for the local Maker Movement. Despite the fact that a Mini Maker Faire is smaller in scale than the "classic" Maker Faire® the vision and the goals are the same.[86] The Maker Faire and its goals are described in section 2.3.

The second Trieste Mini Maker Faire took place on the 9th and 10th of May 2015 in Trieste, Italy. According to the organizers 16,000 visitors attended this year's exhibition with 361 makers stationed at 91 stands demonstrating their work, projects and ideas.[87]

4.1.1 Data

The first goal of the survey at the Mini Maker Faire at Trieste was to gain input on the background of the Fab Lab Graz business model and the intended services. The second goal was to acquire information regarding the equipment that seems important to an attractive group of users. In the following matrix (Table 4) the collected data at the Mini Maker Faire is shown. The questionnaire can be seen in Appendix A.4.

[86] Cf. www.makerfaire.com
[87] Cf. www.makerfairetrieste.it

<table>
<tr><td>General Information</td><td colspan="5">Information regarding the background of exhibitors and their projects</td></tr>
<tr><td rowspan="2">Equipment:</td><td>Basic Fab Lab Equipment</td><td>Wood shop Equipment</td><td>Metal shop Equipment</td><td>Electronic Tools</td><td>Handcraft Tools</td></tr>
<tr><td>- 3D-Printer
- Laser Cutter
- Vinyl Cutter
- 3D-Scanner</td><td>- CNC
- Drill Press
- Planer
- Sander
- Saw</td><td>- Lathe
- Metal Cutting
- Welding</td><td>- Soldering
- Circuit Board Production Tools</td><td>- Sewing Machine
- T-Shirt Press</td></tr>
<tr><td rowspan="2">Focus of Fab Lab Business Model</td><td colspan="2">Accessibility</td><td colspan="3">Emphasis of Makerspace assistance</td></tr>
<tr><td colspan="2">Importance of an exclusive time-slot</td><td colspan="3">- Access to production facilities
- Knowledge transfer
- Community / network
- Financial support
- Finding product idea</td></tr>
<tr><td>Topics</td><td colspan="5">- Tools & Equipment
- Rapid Prototyping
- Product Development
- Entrepreneurship</td></tr>
</table>

Table 4: Data collected at the Mini Maker Faire Trieste

The survey was issued only to exhibitors at the Mini Maker Faire. These exhibitors are assumed to be already either in the phase of launching a start-up or so-called lead-users. Visitors at this event were not provided with surveys. From the 91 exhibitors, 25 questionnaires were returned, indicating a response rate of 27,41%.

Four different types of exhibitors could be identified. The classification refers to the stages of makers (section 2.1). According to this 67% (n=25) of the exhibitors were at the “maker to market” stage. Platforms (4%, n=25) and education or science projects (17%, n=25) can be classified as “maker to maker”. A list of the exhibitors included in this survey and internet links to their projects can be found in Appendix A.5.

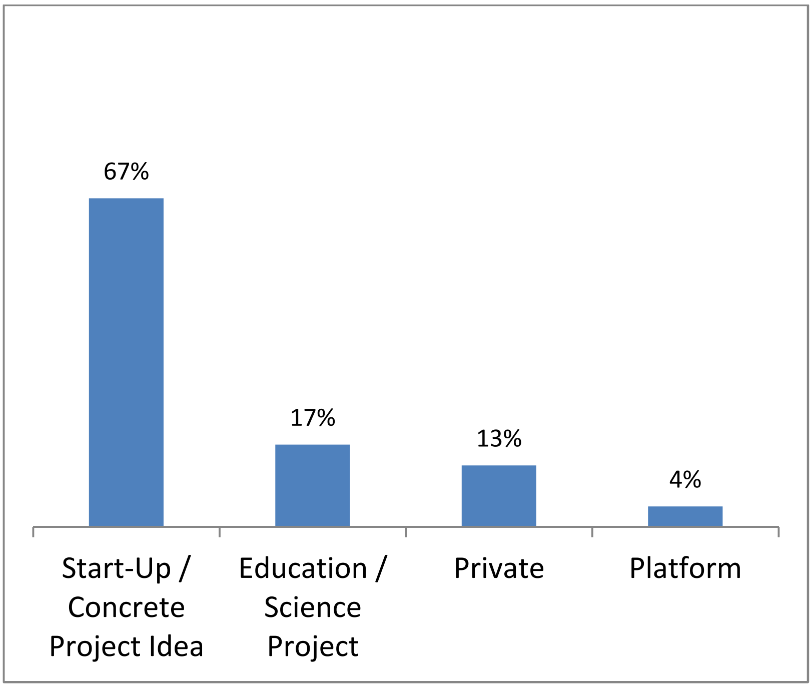

Figure 27: Exhibitors at the Trieste Mini Maker Faire [in %]

4.1.2 Equipment

The exhibitors were interviewed about their desired equipment. Similar to the classifications used during the internet search, the equipment is segmented into five categories. For wood and metal working equipment there is no segmentation between different technologies with the same purpose (e.g. saw instead of table saw or band saw). All results are summarized and illustrated in Figure 28.

According to the makers interviewed, 3D-Printers (92%, n=25) and laser cutters (83%, n=25) are the two most desired production machines for Makerspaces. Also 63% (n=25) would like to have access to a 3D-Scanner followed by 42% (n=25) who would like to work with a vinyl cutter.

Most interviewed makers (67%, n=25) would like to have access to a CNC and 54% (n=25) would like to work with a drill press. Other woodworking facilities are not that important to any majority.

Figure 28 demonstrates that metal cutting (79%, n=25), turning lathe (67%, n=25) and welding (54%, n=25) represent important metal working technologies for the makers interviewed.

The results demonstrate the importance of electronic tools. Circuit board production tools in particular, with a share of 79% (n=25) are as important to makers as metal cutting technologies or e.g. a laser cutter.

Handcraft tools like sewing machines and heat presses with shares below 30% (n=25) are not among the most desired Makerspace tools.

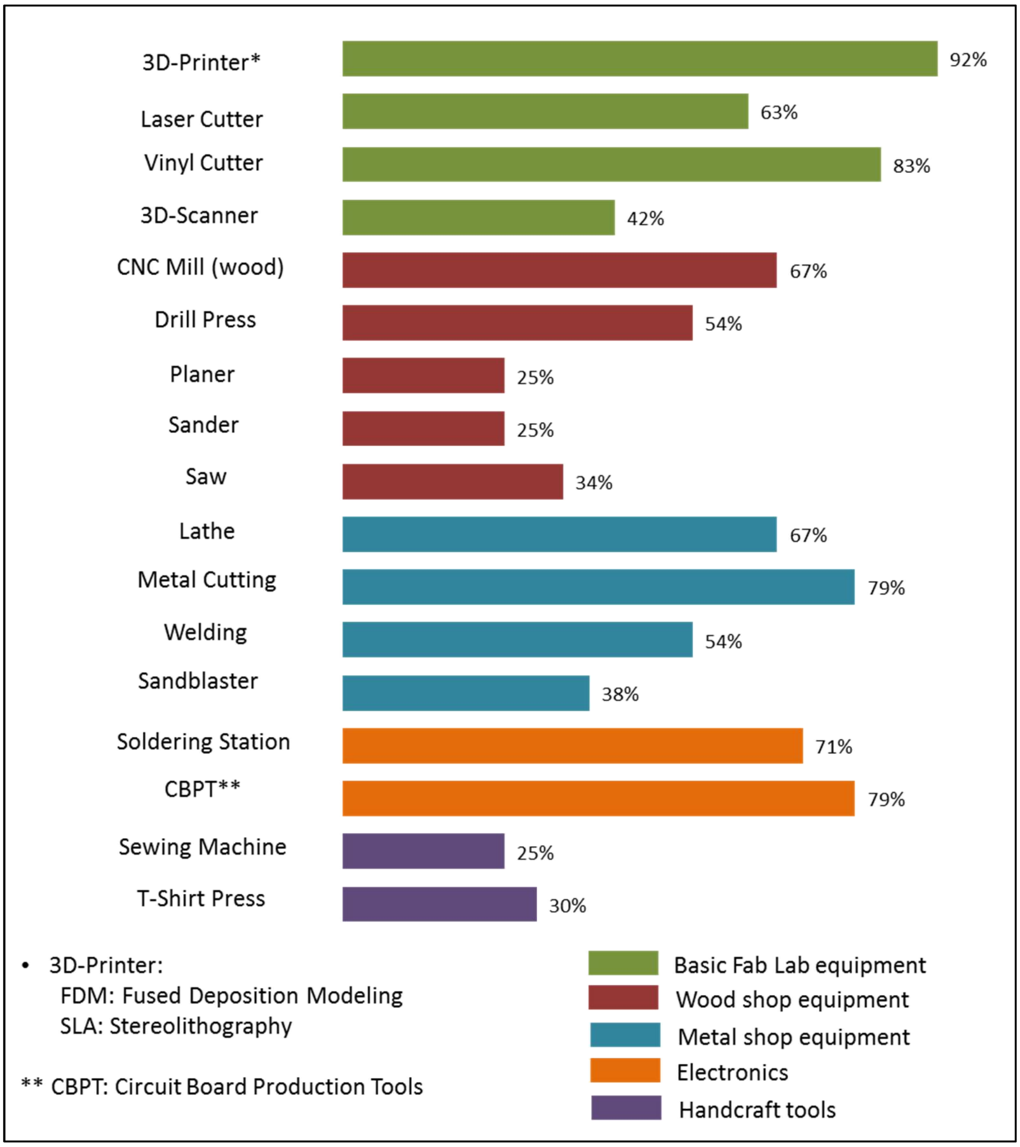

Figure 28: Interesting equipment according to exhibitors interviewed [in %]

4.1.3 Focus of Fab Lab Services

The following assessments of the survey at the Mini Maker Faire focus on the services offered by Fab Lab Graz. The results regarding workshop topics are of interest not only to the “start-up” target group, but also to that of another target group: “students”.

Mortara and Parisot state that a Makerspace may lower barriers in the development and commercialization stage of startups, e.g. given the possibility to produce a prototype, providing a working place, finding suppliers and production facilities, knowledge transfer etc. (see section 2.7). The objective was to determine how a Makerspace may support the establishment of a new start-up. The result highlights that knowledge transfer is seen as the most valuable contribution (Figure 31).

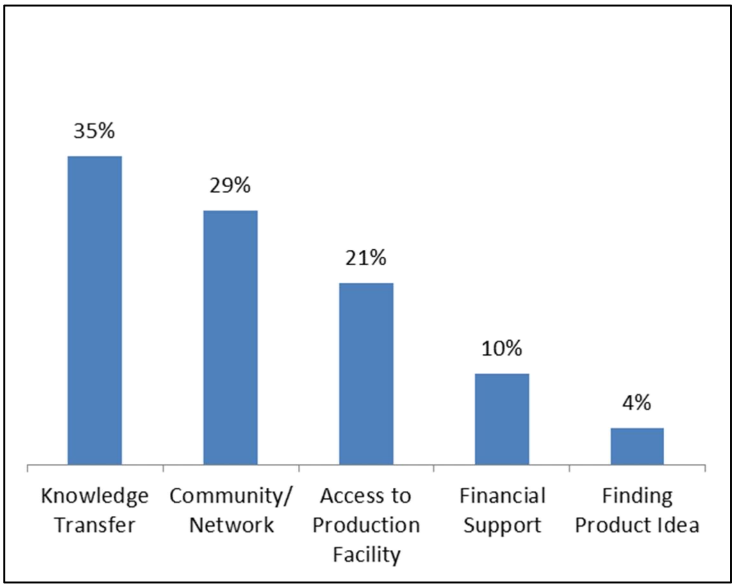

Figure 29: Areas of interests according to exhibitors interviewed [in %]

There is certainly a correlation between Figure 29 which identifies “knowledge transfer” as a valuable contribution for users and the internet search which showed that more than 80% of all facilities offer workshops. Assessing possible workshop topics with a 5-point-Likert Scala (from “not interesting - 1” to “very interesting - 5”) the following results were obtained (Table 5).

Topics	Total	Not interesting	Rather not interesting	Rather interesting	Interesting	Very interesting	Total
Product Development	25	8%	8%	25%	42%	17%	100%
Tools and Equipment	25	4%	4%	8%	54%	29%	100%
Rapid Prototyping	25	0%	13%	33%	33%	21%	100%
Entrepreneurship	25	8%	17%	13%	33%	29%	100%

Table 5: Possible workshop topics according to exhibitors interviewed

In the area of knowledge transfer 83% (n= 25) of the interviewed exhibitors stated that the topic “tools and equipment” (machine operations and machine capabilities) is “interesting” or “very interesting”, followed by “entrepreneurship” (63%, n=25) and “product development” (58%, n=25); “rapid prototyping” (how to build prototypes) reaches 54% (n=25; Figure 30).

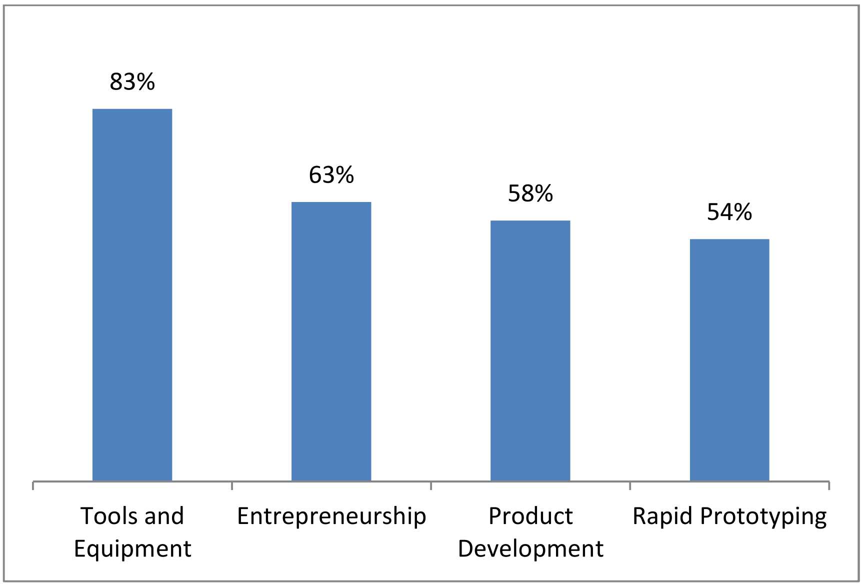

Figure 30: Interests for different workshop topics according to exhibitors interviewed [in %]

One element of the new concept at the Fab Lab Graz is to offer exclusive time-slots to selected start-ups. With this survey it was intended to ascertain how important such an offer for the actual target group was. The response to this question received a 4.04 (arithmetical mean) on the 5-point-Likert Scala. Referring to Figure 29 and "Access to production facility" the value indicates that exclusive time-slots could be considered extremely appealing as an element of the future Fab Lab business model.

4.2 Industrial Partners

Industrial partners of the Graz University of Technology were identified in section 2.6 as valuable stakeholders of the Fab Lab. These organizations are resource providers and actual users of the lab. In order to gain insight into their ideas and expectations qualitative interviews are conducted. As part of the qualitative expert interviews a quantitative survey (similar to the interviews at the Mini Maker Faire, section 4.1.1) was conducted.

4.2.1 Collected Data

One of the goals of the qualitative interviews was to garner insights regarding the expectations and thinking of industrial partners. The information obtained is categorized into the following groups (Table 6). The full questionnaire is available in Appendix A.6.

<table>
<tr><td>General Information:</td><td colspan="4">Facts
- size of enterprise
- industrial sector
- Department of interviewee</td></tr>
<tr><td>Maker Movement</td><td>- Awareness of Makerspaces and the trend maker Movement</td><td colspan="2">- Strengths / opportunities and weaknesses / risks of Makerspaces in the traditional business world</td><td>- Possible potential of Makerspaces in traditional business landscape</td></tr>
<tr><td>Technology</td><td colspan="2">- Internal Workshops for Rapid Prototyping
- Digital Production facilities and utilization</td><td colspan="2">- Future trends of digital fabrication tools
- Possible impacts of these innovative technologies</td></tr>
<tr><td>Innovation</td><td colspan="2">- In which phase of the innovation process are Makerspaces valuable</td><td colspan="2">- Open innovation
- User Innovation</td></tr>
<tr><td>Fab Lab at Graz University of Technology</td><td colspan="2">- Possible synergies
- Practical priorities and interesting content for the business model of the Fab Lab</td><td colspan="2">- Fab Lab Equipment
- Wood shop Equipment
- Metal shop Equipment
- Electronic Tools
- Handcraft Tools</td></tr>
</table>

Table 6: Interview questionnaire - industrial partners

The industrial companies interviewed are illustrated in the following table. In this table, the sizes of the companies are provided. For this, the definition for SME's of the European Commission (Turnover ≤ 50m € and ≤ 250 employees[88]) are applied. No smaller or micro-businesses were interviewed. In this context large-scale enterprises do not meet the requirements of SME's. Further, the industrial sectors and the departments where the interview partners are engaged at the companies are shown.

Company	Size of enterprise	Industrial sector	Department
A	large-scale enterprise	Electronics	Business excellence
B	large-scale enterprise	Electronics, Technology	Technical sales & distribution
C	SME	Automotive	Research & development
D	large-scale enterprise	Welding technology, energy industry	Research & development
E	large-scale enterprise	Energy industry	Engineering
F	large-scale enterprise	IT, Technology	Business development
G	large-scale enterprise	Automotive	Engineering innovation
H	large-scale enterprise	Automotive	Innovation management

Table 7: Interviewed industrial partners

4.2.2 Industrial Partners and the Maker Movement

We have already determined that the impact of the Maker Movement on the traditional business landscape is growing (see section 2.8). The results of these interviews, particularly relating to awareness of Makerspaces could not confirm this trend. Makerspaces and the Maker Movement was only well-known to company A. However, company A is presently endeavoring for synergies with Makerspaces. Fab Lab Graz was familiar to three companies. All of them participated at an event of the Institute of Industrial Management and Innovation Research. For all of the interviewed industrial partners, except company A, this was their first concrete contact with the Maker Movement.

Strengths and Weaknesses of Makerspaces (according to the interviewed companies) in the traditional business landscape are described in Table 8.

[88] Cf. European Comission (2003), p. 4

Strengths, Opportunities	Weaknesses, Risks
Living Community: All of the interviewed enterprises mentioned that a living community paired with interdisciplinary approach is one of the most interesting aspects of Makerspaces.	**Intellectual Property (IP) issues:** Similar to different studies in literature six of seven companies mentioned possible IP-problems first. However, the companies are not disposed negatively towards Makerspaces owing to IP-problems. Rather, it is only important that there are clear rules of what will happen with potential products/ideas.
Makerspaces as external source for companies: Three participants mentioned that Makerspaces are especially interesting for SME's and start-ups. Two large-scale companies are confident that a Makerspace would be an interesting source of information for them. Further, all of the interviewed companies mentioned the low financial barrier for access to what are most likely not daily-used technologies	**Gap between Makerspaces and the traditional business landscape:** The problem of the gap between preceding and ensuing processes (industrial production and the market) was mentioned during two interviews.
Makerspaces as Rapid Prototyping Workshops: Five companies confirmed that Makerspaces are optimal spaces for employees to work on their own ideas and produce first design-prototypes. Further, Makerspaces act as a "playground" or spaces for learning-by-doing and therefore learning from mistakes which do present mentioned advantages.	**Collective Agreement:** The risks and responsibility of accidents during working hours at the Makerspace.
Generating new ideas: The majority do not think that the ideation takes place at Makerspaces. makers or in this sense employees have concrete ideas prior to arrival at a Makerspace. However, the further development of such ideas was mentioned often as one of the strengths of Makerspaces.	

Table 8: Strengths/opportunities and weaknesses/risks of Makerspaces

Further, the potential of Makerspaces in the following categories were assessed:

- *“Interdisciplinary approach”:* The potential for an interdisciplinary approach of Makerspaces based on the conducted interviews is huge. The companies pointed out that a creative and living community is crucial for the transfer of know-how and the development of a valuable network.
- *“Access to digital production facilities”:* Access to the tools and machines is especially interesting for start-us and SME’s. The mix of different technologies and the Makerspaces as “playground” is attractive for a majority of the interviewed companies.

- *“Know-how transfer”:* Requirements for a valuable transfer of know-how are facilitated by the representation of different disciplines at the Makerspace. The uncomplicated process of sharing solutions and new opportunities is interesting for enterprises.
- *“Access to community”:* The potential of creative makers as sources of ideas was mentioned. Further, the possibility to learn from users how new technologies and solutions are applied is valuable for companies.
- *“Skill enhancement”*: Workshops operated at Makerspaces are seen as possible avenues to train employees regarding new production technologies.

4.2.3 Technology

The presence of facilities at companies similar to Makerspaces, the usage of digital production machines and the impact of such facilities in the near future on businesses offer several interesting topics regarding technology. Further, intriguing and desired production facilities for Makerspaces according to the interviewed companies are described.

Only company D has a workshop similar to a Makerspace with its accessibility as well as the tools and machines being similar. Employees of different departments have the possibility to use the workshop. Three out of the seven interviewed industrial partner are not possessing of any workshop focused on rapid prototyping. The other three companies have prototyping workshops with metal working machines and an electronic workspace. However, only certain employees are allowed to use these facilities.

The technologies listed below are already in use at some of the interviewed organizations. In the following the actual usage and future applications are described.

- *3D-Printer (FDM, SLA):* One company already uses 3D-printers in production. Another uses 3D-printers for functional prototypes. The other interviewed institutions see 3D-Printers as a means to produce first design-prototypes in the development phase.
- *Selective laser sintering (SLS):* Selective laser sintering is according to the interviewed experts a very complex technology for complex solutions. It is or is going to be used in the near future especially at the product development stage for feasibility studies.
- *Laser cutter:* Laser cutters are interesting for metal cutting as opposed to blanking. One company already uses laser cutters in their production process.
- *CNC Mill, CNC Lathe*: Both technologies are used in high-precision production processes. In the future, the usage of these technologies will increase according to all of the interviewed companies.

- *3D-Scanner:* Four companies are actually interested in this technology. Reverse engineering, gathering CAD-files for tool making and process stability regarding quality management are possible use-cases.

All of these digital production facilities will in the near future have an impact on the traditional business landscape. The product development process is one of the business units benefitting from these production facilities. Product development is not gaining in speed, but the efficiency and quality of the final product will increase. Further, the development of multi-functional parts offers a possible use-case for digital production machines in R&D departments. The future impacts of digital machines on the production process and logistics are not seen as high. One application is the production of spare parts and customized products. The business model itself, according to companies interviewed, is not influenced by new possibilities provided by digital production machines.

4.2.4 Innovation

In the literature consulted, the two theories of user innovation and open innovation indicate that Makerspaces provide ideal environments for their application (see section 2.8). Open innovation is implemented at all interviewed companies. Supplier and customer relationships in particular are the focus of the institutions. Two companies are explicitly interested in user innovation. They stated that Makerspaces and their creative environment are ideal to learn from actual users. Further, the companies are interested in an interdisciplinary environment with companies from other industries in the sense of open innovation.

The potential for Makerspaces at different stages of the innovation process is illustrated In Figure 31. The interviewed experts see Makerspaces as especially valuable owing to their user community. Further, the possibilities to produce design prototypes in the idea-acceptance phase are one of the most valuable arguments for including Makerspaces in the innovation process. Five companies can imagine producing functional prototypes and small batch series' at Makerspaces.

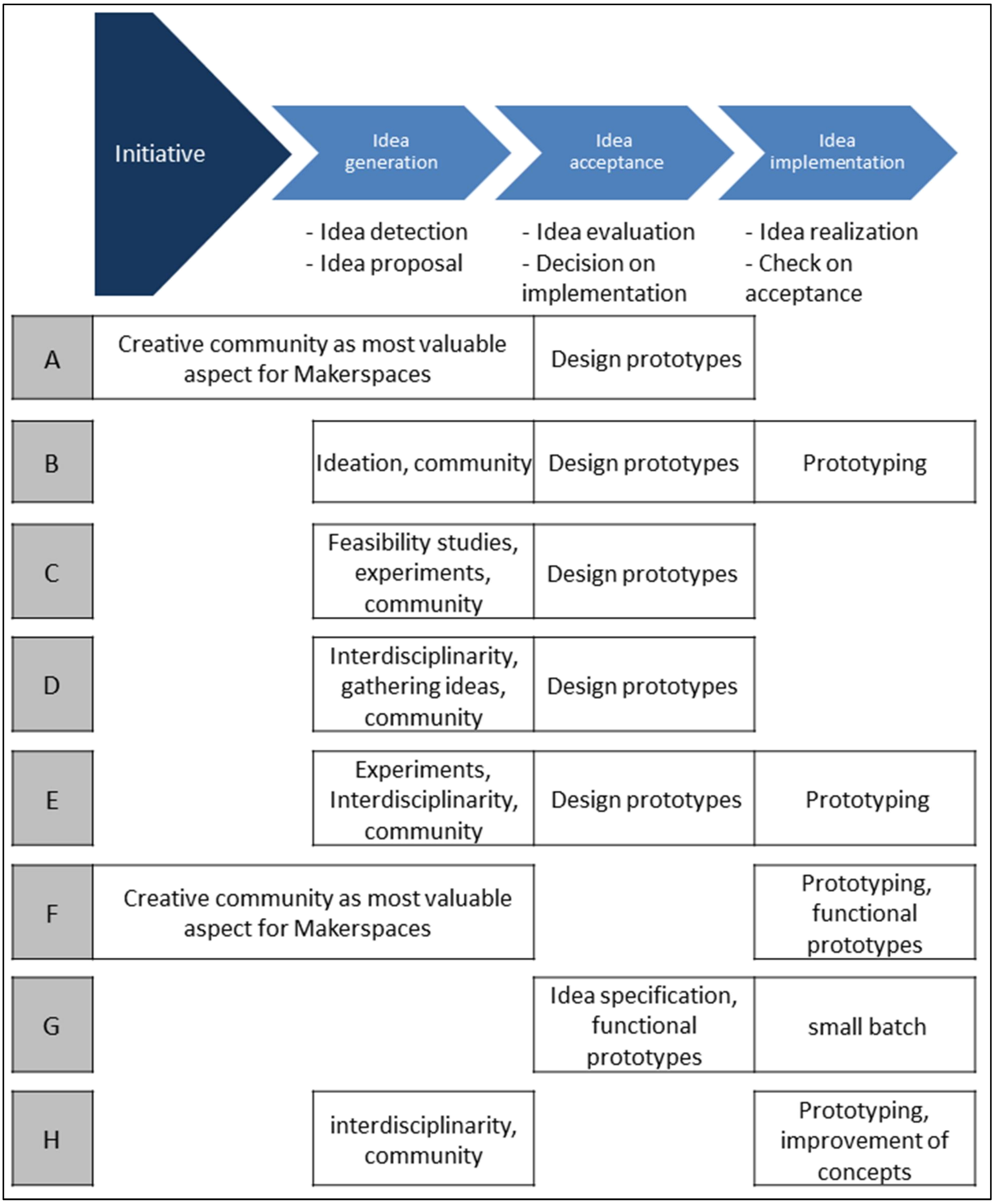

Figure 31: Potential of Makerspaces in the innovation process[89]

[89] Innovation process: Cf. Thom (1992), p.9

4.2.5 Synergies and Expectations - Fab Lab Graz

Similar to the evaluated information regarding desired tools and machines of makers at the Mini Maker Faire Trieste following figure illustrates interesting production machines according to industrial partners.

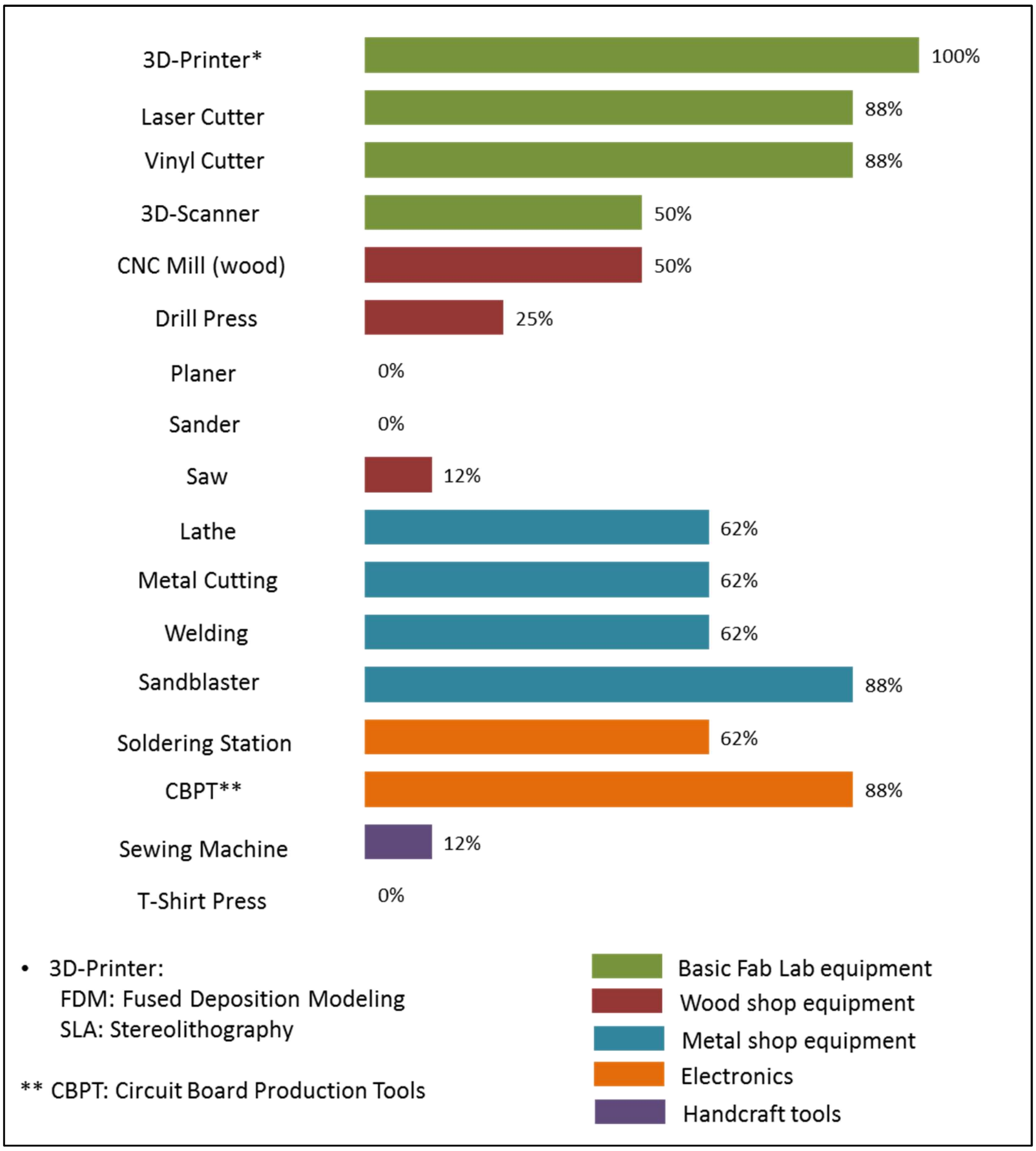

Figure 32: Interesting equipment according to interviewed companies [in %]

For the future concept or business model of the Fab Lab Graz determining possible synergies and expectations of the industrial partners is valuable. Different potential synergies could be identified during the interviews conducted. All of the interviewed enterprises are interested in collaborative projects. The possible know-how transfer from the academic institution, the user-community and the network of different industries is probably the most desired outcome of such projects. Therefore, a living and active community is an expectation shared by all of the industrial partners.

Another interesting aspect is the possibility of testing and experimenting with new products and the therefrom obtained user feedback. A summary of all synergies and expectations is illustrated in Table 9.

	Possible synergies	Expectations
A	- Sponsoring, providing resources - Know-how transfer - Partner for Hackathons	- Community - development and maintenance - Space for innovative digital production technologies - Safety
B	- Fab Lab as space for testing and presenting own products - Know-how transfer - Expertise for specified technologies	- Network events - Space for innovative digital production technologies
C	- Prototyping in the sense of contract manufacturing - Fab Lab as external source of information and know-how - Place for employees to develop own ideas	- Community - development and maintenance - Space for innovative digital production technologies
D	- Virtual prototyping	- Space for innovative digital production technologies
E	- Prototyping in the sense of contract manufacturing - Workshops - Know-how transfer	- Community - development and maintenance - Network events
F	- Innovation Workshops - Partner for Hackathons - Sponsoring, providing resources - Shared mentoring for entrepreneurs	- Community - development and maintenance - Space for innovative digital production technologies - Interdisciplinary approach - Virtual development
G	- Know-how transfer - Access for employees	- Community - development and maintenance - Interdisciplinary approach - Protocol for IP-Issues
H	- Access for employees - Workshops, skill enhancement - Ideas competition - Event space - Contract manufacturing	- Community - development and maintenance - Interdisciplinary approach - Protocol for IP-Issues - Safety

Table 9: Synergies and expectations - Fab Lab Graz

Possible areas of collaboration are assessed with a 5-point-Likert Scala (from “not interesting - 1” to “very interesting - 5”). In Figure 33 results valued with four (interesting) or five (very interesting) are illustrated. All of the experts interviewed see “community/network” as an “interesting” or “very interesting” aspect of collaboration with Fab Lab Graz.

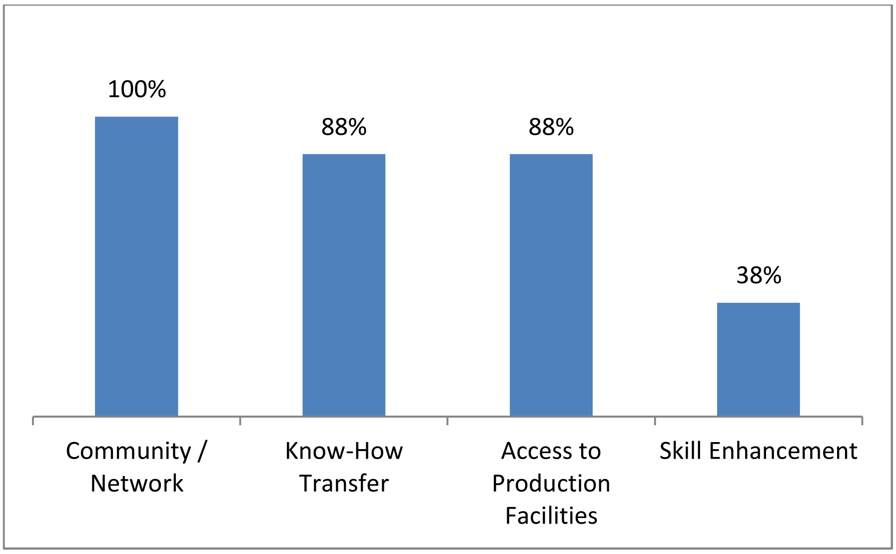

Figure 33: Areas of interests according to companies interviewed [in %]

Interesting topics for know-how transfer and skill enhancement for employees are also assessed with a 5-point-Likert Scale (from “not interesting - 1” to “very interesting - 5”). Similar to Figure 33, the results rated four (interesting) and five (very interesting) are illustrated in Figure 34. All experts agree that rapid prototyping is the most interesting topic regarding know-how transfer. Product development is only of interest to 37% of the experts interviewed.

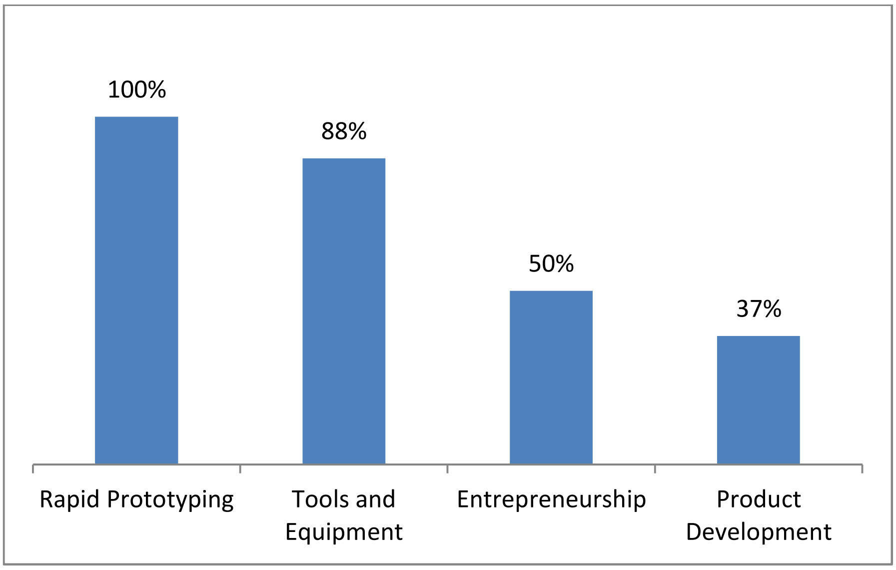

Figure 34: Possible workshop topics according to companies interviewed [in %]

4.3 Summary Section 4: "Market Needs"

The aim of section 4 was to identify areas of interests to possible users. First, surveys were conducted of exhibitors at the Mini Maker Faire Trieste. The exhibitors were identified as so-called lead-users. Second, interviews with industrial partners of the Graz University of Technology were concluded. Industrial partners are both resource providers and possible users of the Fab Lab. Therefore, the obtained results regarding possible synergies and expectations offer valuable information.

The results illustrate desired equipment of an innovative production facility for makers and industrial companies. The focus of the enterprises apart from the basic Fab Lab tools is on metal working. The reason for this focus might be explained by the industries of the interviewed companies. The importance of electronic tools and metal working for both makers and industrial companies is noteworthy.

According to the experts and makers interviewed, the transfer of know-how and community/network present the two most valuable contributions of a Makerspace. The focus of the two interviewed groups differs slightly. Both consider "Tools & Equipment" as base. Rapid prototyping is of note especially for enterprises. It is assumed that this difference is due to the fact that companies have a broader product development approach, a larger range of products and therefore more development interests. Start-ups or makers focus instead on one special idea or product. The difference in the category "Product Development" might be explained with a similar argument. In contrast to traditional enterprises, start-ups usually do not have specialized development departments. The interest of makers and start-ups in entrepreneurship is explained by the need for developing a working business model.

The results of the qualitative expert interviews confirm that the two innovation theories "open innovation" and "user innovation" could be applied at Makerspaces. All of the interviewed experts agree that an interdisciplinary community is the most valuable argument for collaboration with a Makerspace. Especially during the "idea generation" and the "idea acceptance" phase of the innovation process Makerspaces are presumed to be useful. During the idea acceptance phase especially, the possibility to produce design prototypes is appealing to industrial companies. Therefore, the expectations of enterprises include the development and the maintenance of the user-community and the provision of innovative production facilities. Further, industrial companies expect the clarification of problems regarding intellectual property issues.

5 Educational Concept

This section starts with a brief introduction to the theories of didactics (5.1). Didactics is defined and applicable education concepts for Makerspaces are described. Because of the identified relevance higher education in the fields of engineering and applied sciences the basics and methods of active learning are described (5.2). The potentials of Makerspaces in education are discussed and data of implemented Makerspace-concepts at universities are presented.

In section 5.5, a concrete concept for a course at the Graz University of Technology is presented. The main objectives, the learning content and the teaching methods are described. The available and necessary equipment for this course at Fab Lab Graz are also detailed. An overview of the theoretical content of the developed course is illustrated in section 5.5.5.

5.1 Basics of Didactics and Methodology

Didactics in a strict sense refers to the definition of learning objectives and content. In an extended view, however, didactics includes apart from objectives and learning content also learning methods and therefore applicable media.[90]

In this thesis, the common extended view of didactics has been applied.

The core of didactics is the organization of learning and teaching processes. These processes can be divided into two sub-areas. On one side, the "target-dimension" and on the other side the "path-dimension". The target dimension describes the learning content and the learning objectives (what and why). The second sub-area of "path-dimension" describes which methods and media is used during the teaching or learning processes (how and how to).[91]

In the literature consulted, there are various didactic or educational theories and models. The theories describe systems regarding how courses or classes can be prepared and structured by the teaching staff. Examples for such overarching didactic theories are: critical and constructive didactic, learning-theory didactic or critical-communicative didactic. These general didactic theories are not addressed in detail in this work. However, the didactic theories serve as an orientation point for the

[90] Cf. Riedl (2004), pp. 8-9
[91] Cf. Riedl (2004), p. 8

development of new education concepts. General didactic models describe overall asset allocation of teaching and learning processes. Education concepts differ because of their focus on realization and the design of learning processes.[92]

Similar to the explanation of Nickolaus (2008) Jank & Meyer (1991) describe didactic concepts. Based on theoretical models the educational concepts describe the development of a lesson plan. Therefore the interaction of objectives, content and methods is essential.[93]

Examples for student-oriented approaches of didactic concepts are among others:[94]

- Project-based education
- Experiential education
- Open education
- Action-oriented education

Learning processes culminate in two different forms of knowledge. Implicit knowledge (1) is gathered through personal experience and independent activities. Explicit knowledge (2) can be described as theoretical knowledge. Classic university education in the form of courses and seminars leads to strong theory-oriented knowledge. To counteract this practical (experiential-based) teaching or learning methods are essential. Therefore, individual knowledge may be tested by actions and confirmed by practical experiences. Furthermore, new knowledge can be generated with learning from failures being particularly desirable.[95]

The Maker Movement with the maker and making itself in the center already implies that Makerspaces support the areas of active as well as experiential learning. Further, according to the separation of knowledge Makerspaces in education especially support implicit knowledge.

Therefore, the theory and different teaching methods of active oriented education are presented in the following section.

[92] Cf. Nickolaus (2008), p.1
[93] Cf. Jank & Meyer (1991), p. 290
[94] Cf. Jank & Meyer (1991), p. 294
[95] Cf. Markowitsch, Messerer, & Prokopp (2004), pp. 1-11

5.2 Active Oriented Education and Methods

K. Lewin as a pioneer of experiential learning stated that learning results out of the influence of experience and an analytical detachment. The approach of D. A. Kolb (1984) is based in addition to the ideas of K. Lewin on the work of J. Dewey and J. Piaget. Dewey is considered the originator of “learning by doing”. He stated that actions and therefrom extracted experiences are important in the learning process. Piaget describes actions as being crucial for the cognitive development of the learner. According to Lewin, the phase of concrete experience is followed by one of observation and reflection. The next phases describe the further development of abstract concepts and the verification through active experimentation. The results achieved from this cycle are the generation of new knowledge and concrete experiences (Figure 35).[96]

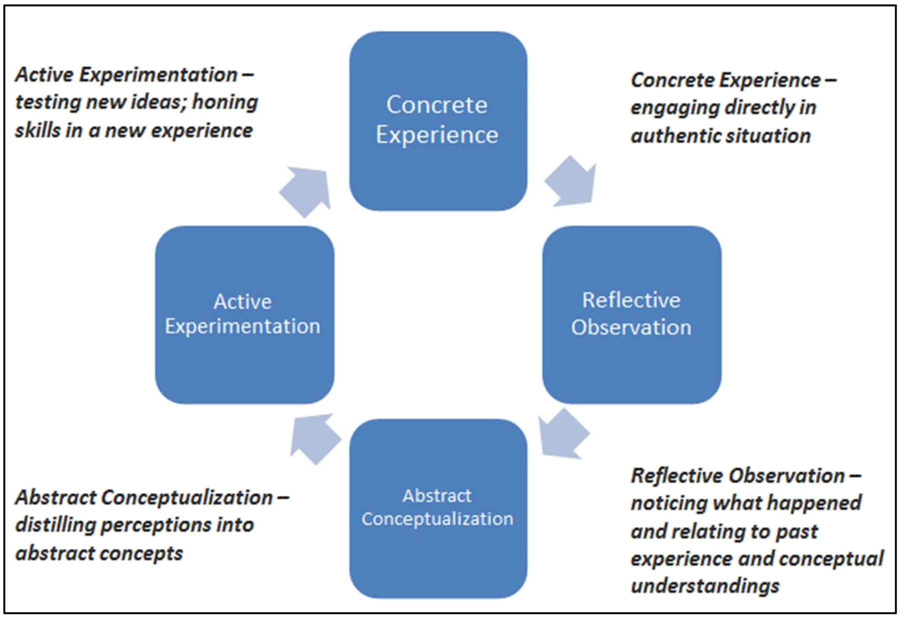

Figure 35 Kolb’s cycle of experiential learning[97]

According to Jank & Meyer (1991) the entire lesson should not be active-orientated. A proper relationship between thinking and acting processes is desirable.[98]

In “How Business Schools Lost Their Way” the authors stated that a curriculum must be infused with interdisciplinary and practical assignments. Further, reflective analyses of complex projects are necessary to gain experiences.[99]

The following reasons for the importance of active education are found in the literature consulted:[100]

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96 Cf. Markowitsch, Messerer, & Prokopp (2004), pp. 28-33
97 http://www2.le.ac.uk/departments/gradschool/training/eresources/teaching/theories/kolb
98 Cf. Jank & Meyer (1991), p. 338
99 Cf. Bennis G. & O'Toole (2005), pp. 9-10

- Increased demands of industry in terms of independent work, competences in the fields of tackling new problems and social aspects
- Learners show more motivation
- Difficulties of students to apply their learned knowledge in practical situations
- Positive experiences in skill enhancement regarding the area of methodological skills, the ability to solve problems and social skills

As described above, the term didactic includes not only teaching and learning contents. Methods and media used are likewise part of a didactic concept. For the action-oriented concept, there are a variety of proposed methods in literature:

- *Project-learning*: Learners work independently on complex real tasks, usually in smaller groups. There are 4 phases: objective, planning, execution and evaluation.[101] Mainly the independent work of the learners should be at the center. The learning content is not only limited to one subject but arises from the interdisciplinary scale and originality of the project. Advantages are practical and collaborative learning, a high motivation and skill generation among the learners. Disadvantages include the high costs for material and bureaucracy for the educational institution.[102]
- *Simulation*: The simulation as a picture of the complex reality places heavy demands on the teachers. The simpler the reality is depicted the more difficult it is to implement acquired knowledge to learners in practice.[103]
- *Business-game:* In the business game, a partial area of the complex reality is depicted. Learners in small groups take a specific role often having different interests. In order to achieve predefined objectives competitive situations occur during the game. These business-games are usually divided into several rounds.[104]
- *Role play:* In this method the learners themselves form the social part of the reality. As an actor the attendees play predetermined roles. These roles are distinguished by different characteristics and values. Experiences are primarily gained through the knowledge that different interests cause different behaviors.

[100] Cf. Nickolaus (2008), p.71-72
[101] Cf. Bonz (2001), p. 105
[102] Cf. Peterßen (2001), p. 236
[103] Cf. Bonz (2001), p. 106
[104] Cf. Bonz (2001), p. 108

- *Case studies:* Case studies analyze issues of practical relevant cases with optional solutions. It is intended to stimulate a discussion among the students. These cases should be made as complex as possible to rule out simple and clear solutions in advance. Case studies are designed to promote problem-solving skills and the ability to make decisions.[105]

5.3 Potentials of Makerspaces in Education

As mentioned in section 1.2, starting in 1998 with the “How to Make (almost) Anything” course instructed by Neil Gershenfeld the development of the Fab Lab initiative started at a university. Further, Neil Gershenfeld was surprised by the will of the students to develop and build. Therefore, it can be stated that the Maker Movement started originally as a course at an educational institution.[106]

The NMC Horizon Report 2014 (a resource of future developments in higher education[107]) confirms the actuality of Makerspaces in education. In universities all over the world students of different academic fields start learning by making and creating. The Maker Movement is increasing the means of hands-on, active learning. To foster media creation, design and entrepreneurship, universities are in the process of changing their course program. It is stated that the Makerspaces trend in higher education will reach its limit in about 3 to 5 years.[108]

Only one year later in the 2015 Version of the NMC Horizon Report Makerspaces were again promoted as learning concepts addressing future needs in education. Interesting is that the upward ceiling concerning the impact on education was reduced to 2 to 3 years.[109]

Further the innovating Pedagogy Report stated that the Maker Movement has the potential to provoke a major shift in education.[110]

The strength of Makerspaces lies in their potential for bringing action-orientated learning (more specific hands-on learning) in combination with project centered classes into higher education.[111]

[105] Cf. Bonz (2001), pp. 108-109
[106] Cf. Gershenfeld (2005), pp. 5-7
[107] Cf. Schön, Ebner, & Kumar (2014), p.1
[108] Cf. Johnson, Adams Becker, Estrada, & Freeman (2014), pp. 14-15
[109] Cf. Johnson, Adams Becker, Estrada, & Freeman (2015), p. 40
[110] Cf. Sharples, et al. (2013), p. 33
[111] Cf. Johnson, Adams Becker, Estrada, & Freeman (2015), p.41

The National Research Council (2004) stated in their report “The Engineer of 2020” that creating, inventing and innovating are essential skills for engineers. Due to this fact and the strength of Makerspaces in education, the assumption that Makerspaces are of special interest in the academic fields of engineering and applied sciences can be supported.[112]

The Georgia Institute of Technology conducted a survey regarding the impact of their Makerspace (The Invention Studio) on students. The following statements regarding the impact of the invention studio in education attest to the positive reception of the facility by the students:[113]

- Serve(s) as cultural hub and meeting place
- Provides access to hands-on, state-of-the-art prototyping technologies
- Support(s) extracurricular activities
- Motivate(s) students for careers involving design, innovation and invention
- Enable(s) students to work on real-world problems

Further, 90% of the students interviewed reported a significant impact on their design skills. Additionally 80% of the respondents confirmed that the maker spaces had a positive impact on their manufacturing skills.[114] Supplementary the authors of the study “Fab Labs in Design Education” stated that Makerspaces empower students to accelerate their ideation and invention process.[115]

Based on the literature, adequate learning spaces are important for education. In their study “Learning Styles and Learning Spaces” the authors stated that the challenge is to create an optimal learning space which meets the needs of each learner. Further, several studies determined that learning needs of students differ significantly by academic fields. This is even more important because one core principle of active learning is the role which students play. Therefrom a more student-centered learning environment is needed. Further, the role of the instructor shifts toward a facilitator mind set. Results of implementing this principle are increased teaching effectiveness and learning outcomes.[116]

Connecting basic principles of learning with Makerspaces in education shows the following overview. Caine & Caine (1990) proposed 12 principles influencing the learning process.

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[112] Cf. National Academy of Science (2004), p. 41
[113] Cf. Forest, et al. (2014), p. 18
[114] Cf. Forest, et al. (2014), p. 21
[115] Cf. Moster-Van der Sar, Mulder, Remijn, & Troxler (2013), p. 632
[116] Cf. Kolb & Kolb (2005), pp. 18-56

Out of these principles recommendations for teaching processes and the learning environment could be gleaned:[117]

1. *"All learning engages the physiology":* Understanding increases when different senses and the body are involved.
2. *"The brain/mind is social":* social interaction and relationships support learning and understanding.
3. *"The search for meaning is innate":* Working on individual ideas and projects increases understanding.
4. *"The search for meaning occurs through patterning / Learning is developmental":* Interdisciplinary content and embedding prior to learning in a superior context foster overall understanding.
5. *"Emotions are critical to patterning":* Motivation and even more demotivation are important factors regarding learning processes.
6. *"The brain/mind processes parts and wholes simultaneously":* Experiences increase when details are embedded in wholes e.g. projects or real life events.
7. *"Learning involves both focused attention and peripheral perception":* Gathering attention is important as well as creating appropriate environments.
8. *"Learning is both conscious and unconscious":* Time to reflect on experiences made fosters understanding.
9. "*There are at least two approaches to memory":* As mentioned, there is a separation between theoretical and experiential knowledge. Stimulating both in an appropriate combination is important.
10. *"Complex learning is enhanced by challenge":* An empowering, supportive and challenging environment fosters understanding.

According to these principles and what we know from the literature consulted, it can be stated that Makerspaces offer especially in the field of applied sciences an optimal learning space.

[117] Cf. Caine & Caine (1990), pp. 66-70;
Cf. http://www.cainelearning.com/wp-content/uploads/2014/04/12-Brainmind-principles-expanded.pdf

5.4 Makerspaces and similar Concepts already Implemented at Universities

During the research phase of this thesis different universities with Makerspaces were identified. In this section, those already implemented facilities and course concepts conducted at Makerspaces are discussed.

In "A Review of University Maker Spaces" the authors carried out internet research into the top 100 Universities in America. Forty of these universities have a Makerspace. This study aims to present an overview of Makerspaces situated at universities, the available equipment and how these spaces are organized.[118]

In order to acquire insight into the courses held in Makerspaces at universities an internet search was conducted. According to "Times Higher Education World University Rankings 2014-2015"[119] the top-ten Universities in the field of engineering and technology were investigated. To separate Makerspaces from traditional workshops Makerspaces have to fulfill the following pre-defined criteria:

- Situated on campus
- Digital production facilities (for definition see section 5.5.4)
- Accessibility for the student body (beside courses)

To identify the different Makerspaces the websites of the identified universities were visited. The search feature of the websites was used to find information regarding Makerspaces. The keywords used in different combinations are "Makerspace", "Fab Lab", "Hackerspace", "workshop", "prototyping", "laboratory", "manufacturing" and "space". Information regarding the availability of Makerspaces at universities, information about existing courses involving the space and available tools were considered as particularly valuable. Further, one course of each University is described in more detail.

Out of the investigated universities 7 have spaces which meets the pre-defined criteria. Three universities (MIT, Stanford and Berkeley) have in this context, two such suitable laboratories. Further, a partnership with a Makerspace could be identified at the ETH Zürich. However, this Makerspaces is not situated on campus and therefore not included in the following evaluation. Two main differences regarding the utilization of Makerspaces at universities could be detected. First, Makerspaces are used in education. Second, Makerspaces are open to students for extra-curricular activities.

[118] Cf. Barrett, et al. (2015), pp. 2-8
[119] https://www.timeshighereducation.co.uk/world-university-rankings

Six out of 10 labs combine these services. Four of the identified spaces are not used actively in education (Table 10).

University	Name	Description	Department	Utilization
Massachusetts Institute of Technolgy –MIT (1)	MIT Fab Lab	CBA was launched by a National Science Foundation award in 2001 to create a unique digital fabrication facility. The Fab Lab at MIT was a starting point for the Maker Movement.	Center for bits and atoms, (computer science and physical science)	Education, Open for students
	MIT Hobbyshop	Fully equipped wood and metal shop. Teaches students thoughtful design by providing tools and training as well as assistance.	"Student life division"	Education, Open for students
Stanford University (2)	Stanford product realization lab	The Stanford Product Realization Lab is a multi-site teaching facility with roots in the Department of Mechanical Engineering and deep synergies with the Stanford Design Program.	Mechanical Engineering, Stanford Design Program, Hasso Plattner Institute of Design	Education Open for students
	create:space (Makerspace)	Create:space is a collaborative Makerspace, open to the Stanford community.	Academic Computing Services	Open for students
California Institute of Technology (3)	Jim Hall Design and Prototyping Lab	The lab is open to the entire Caltech community. Shop hours are 10 am–12 pm and 1–6 pm, Monday through Friday. For personal use of the shop, there is a $10 charge per hour.	Mechanical and Civil Engineering	Education Open for students
Princeton University (4)	Keller Center maker Space	No details provided	Center for Innovation in Engineering Education	Education, Open for students
University of Cambridge (5)	3D printing laboratory	Aim is to allow students to convert product design ideas into rapidly-produced prototyped products.	Engineering Department, Division: institute for Manufacturing	Open for students
Imperial College London (6)	Imperial advanced Hackspace	ICAH promotes interdepartmental collaboration through making and technical development. It is an interdisciplinary hackspace based at Imperial College which is open to all departments - students and staff.	Interdisciplinary	Open for students
University of Oxford (7)	None	None	None	None
ETH Zürich (8)	None	None	None	None
University of California, Los Angeles (9)	None	None	None	None
University of California, Berkeley (10)	Supernode	Supernode is a student run Makerspace located in 246 Cory Hall. This space is open to any member of the UC Berkeley community when the doors are open.	Electrical Engineering & Computing Sciences	Open for students
	The CITRIS Invention Lab	The CITRIS Invention Lab supports faculty, student and community innovation by providing the knowledge, tools and support to rapidly design and prototype products	Center for Information Technology Research in the Interest of Society	Education Open for students

Table 10: Identified Makerspaces at investigated universities[120]

[120] (1) http://cba.mit.edu/about/index.html; http://studentlife.mit.edu/hobbyshop/about; (2) https://productrealization.stanford.edu/; (3) http://www.mce.caltech.edu/research/lab; (4) http://kellercenter.princeton.edu/; (5) http://www.eng.cam.ac.uk/news/3d-printing-laboratory-students; (6) https://www.imperial.ac.uk/advanced-hackspace/ ; (10) http://invent.citris-uc.org/research/

In the following table the identified courses at Makerspaces are illustrated. One course of each university/Makerspace is described in more detail (if more than one are identified, the highlighted course is described, Table 11).

University	Name	Course	Course Description	Duration
Massachusetts Institute of Technolgy (1)	MIT Fab Lab	- **How to Make (Almost) Anything**	The course provides a hands-on introduction to the resources for designing and fabricating smart systems. Emphasis is placed on learning how to use the tools as well as understanding how they work.	Lecture: 1 session / week, 3 hours / session Overall Duration: 1 semester
	MIT Hobbyshop	- **Introduction to Design**	The objective of the course is to enable students through a team-based hands-on product design experience. Learn the process of design, based on the scientific method, to combine creative thinking with engineering principles (physics) to turn ideas into robust reality.	Lecture: 1 session / week 2 hours / session Overall duration: 1 month
Stanford University (2)	Stanford product realization lab	- **Product Realization: Making is Thinking** - Engineering Drawing and Design - Design and Manufacturing - Magic of Materials and Manufacturing - Good Products Bad Products	Students in this project-based seminar develop product realization confidence and intuition using the rich array of tools available in the Product Realization Lab, industry-standard design engineering software, and course readings. Students develop products including soft goods, composite utensils, wearable electronics, mechatronics devices, and a final project of their own choosing.	Lecture: 2 sessions / week 2 hours / session Overall Duration: 3 month
	create:space (Makerspace)	None	None	None
California Institute of Technology (3)	Jim Hall Design and Prototyping Lab	**Introduction to Engineering Design** Engineering Design Laboratory	Introduction to mechanical engineering design, fabrication, and visual communication. Concepts are taught through a series of short design projects and design competitions emphasizing physical concepts. Many class projects will involve substantial use of the shop facilities, and construction of working prototypes.	Lecture: 8 sessions Overall Duration: 3 month
Princeton University (4)	Keller Center maker Space	**Creativity, Innovation, and Design** Engineering Projects in Community Service (EPICS)	The class mission is to give students an understanding of the sources and processes associated with creativity, innovation, and design. The class will consist of readings and case studies as well as individual and group projects.	no details provided
University of Cambridge (5)	3D printing laboratory	None	None	None
Imperial College London (6)	Imperial advanced Hackspace	None	None	None
University of Oxford (7)	None	None	None	None
ETH Zürich (8)	None	None	None	None
University of California, Los Angeles (9)	None	None	None	None

University of California, Berkeley (10)	Supernode	None	None	None
	The CITRIS Invention Lab	- **Interactive Device Design** - Advanced Device Design & Digital Fabrication - Critical Making	This course teaches concepts and skills required to design, prototype, and fabricate interactive devices. The first half of the semester will be dedicated to a survey of relevant techniques in 3D modeling and fabrication. In the second half of the semester, students will propose and carry out a significant design project of their own choice in groups.	Lecture: 2 sessions / week 2 hours / session Overall duration: 4 month

Table 11: Identified courses at university Makerspaces[121]

Supplementary to the courses at higher education institutions the international Fab Academy provides a course as part of the global Fab Lab network. It is a distributed course model broadcast from MIT. The course is based on MIT's "How to Make (Almost) Anything" and focuses on digital fabrication. The access to fabrication tools is provided by the local Fab Labs. The course lasts five month and each week hands-on learning experience is gained through planning and executing new projects. For documentation each student has to maintain an online blog. The tuition fee for the course is $ 5,000 and includes in addition to the broadcast lectures access to the local Fab Lab.[122]

As can be seen in Table 11, the duration of the courses is at least 4 weeks. All of the identified courses use a combination of theoretical input and practical assignments. The courses are often a significant part of the (undergraduate) engineering education. This matches with the identified requirements for engineers and the strength of Makerspaces in hands-on education (see section 5.3). Projects during the courses are often handled in groups. However, long-term courses in particular (e.g. MIT, Stanford) favor individual project-work.

[121] (1) http://cba.mit.edu/about/index.html; http://studentlife.mit.edu/hobbyshop/about;
(2) https://productrealization.stanford.edu/; (3) http://www.mce.caltech.edu/research/lab;
(4) http://kellercenter.princeton.edu/; (10) http://invent.citris-uc.org/research/

[122] Cf. http://fabacademy.org/

5.5 How to Make…a Course at Graz University of Technology

First, a few restrictions must be made. The course will be held as part of the Master- or Bachelor studies of mechanical engineering and mechanical engineering-business economics. Further, a classification of the course as “laboratory exercise” is intended. This supports the hands-on learning approach of Makerspaces in education. Additionally, such a course has the advantage that students of the two named disciplines have to select one of currently ten available laboratory exercises to complete their studies. Such a laboratory exercise must fulfill the following requirements according to the present curriculum of mechanical engineering at the Graz University of Technology:

In laboratory exercises theoretical knowledge is transferred and enhanced to practical experiences. Laboratories aim to teach theoretical input in practical, experimental and/or design work. Additionally, intensive support by the teaching staff is compulsory. An essential component of laboratories is documentation of the work undertaken. Further per the curriculum, each student must choose one laboratory exercise within the scope of three ECTS credits. [123]

ECTS credits relate to an actual working scope for students with one ECTS corresponding to a workload of 25 hours.[124]

5.5.1 Main Focus of the Course

In this section, the content of what should be taught will be answered by defining the main focus of the new course. Regarding the content of the course it is assumed that a valuable source of information is presented by the surveys conducted at the Mini Maker Faire Trieste and the interviews conducted with industrial partners (see section 4.1.3 & 4.2.5).

Therefore, the following topics should be part of the course:

- Tools & Equipment
- Rapid Prototyping
- Product Development
- Entrepreneurship

Further, “Design Principles” as a major focus of the Institute of Industrial Management and Innovation Research will be taught. Additionally, to contribute to the global Fab Lab

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[123] Cf. Graz University of Technology (2007)
[124] Cf. http://portal.tugraz.at/portal/page/portal/Internationale_Beziehungen/ECTS/ECTS_TUGraz

community, digital media should be emphasized. Regarding “Product Development” the V-Model (see section 5.5.5.1) is chosen to be the base for the development process of the pre-defined project.

5.5.2 Didactic Concept and Teaching Method

The course underlays the principles of hands-on learning and is project-based. Therefore two or three students form a team. In a five-day-course, the student teams will work on a pre-defined project. The operation of the available digital production tools is taught with practical exercises. Additionally the project work units and exercises will be completed with basic theoretical knowledge of the defined main course topics (see section 5.5.1).

The overall goal for the student teams is to design and produce a functional prototype. Entrepreneurship will be taught in form of the Business Model Canvas. Therefore, each team has to develop a business plan for their product. In order to fulfill the requirements regarding the documentation each team has to maintain an online-blog for the entirety of the course. The project and the lessons learned will be shared with the online community.

In Figure 36, the schedule of the course is illustrated. Starting on the first day (introduction) the course will be finished after five days. Day 1 and half of day 2 are reserved for theoretical inputs (rapid prototyping, design thinking) and practical exercises with the needed equipment. After the project is presented on day 2, the teams start to work on their products. Days three and four start with presentation of the conducted work and a short group-reflection to garner feedback. On day five, theoretical knowledge regarding business plans (Business Model Canvas) is taught. In the afternoon of the last day, the student teams must present their work. A competition among the different teams is planned.

Grading will be centered on following criteria:

- Design
- Differentiation of design and functions
- Functionality of the product
- Appearance and participation during the course
- Documentation (business plan, online blog)

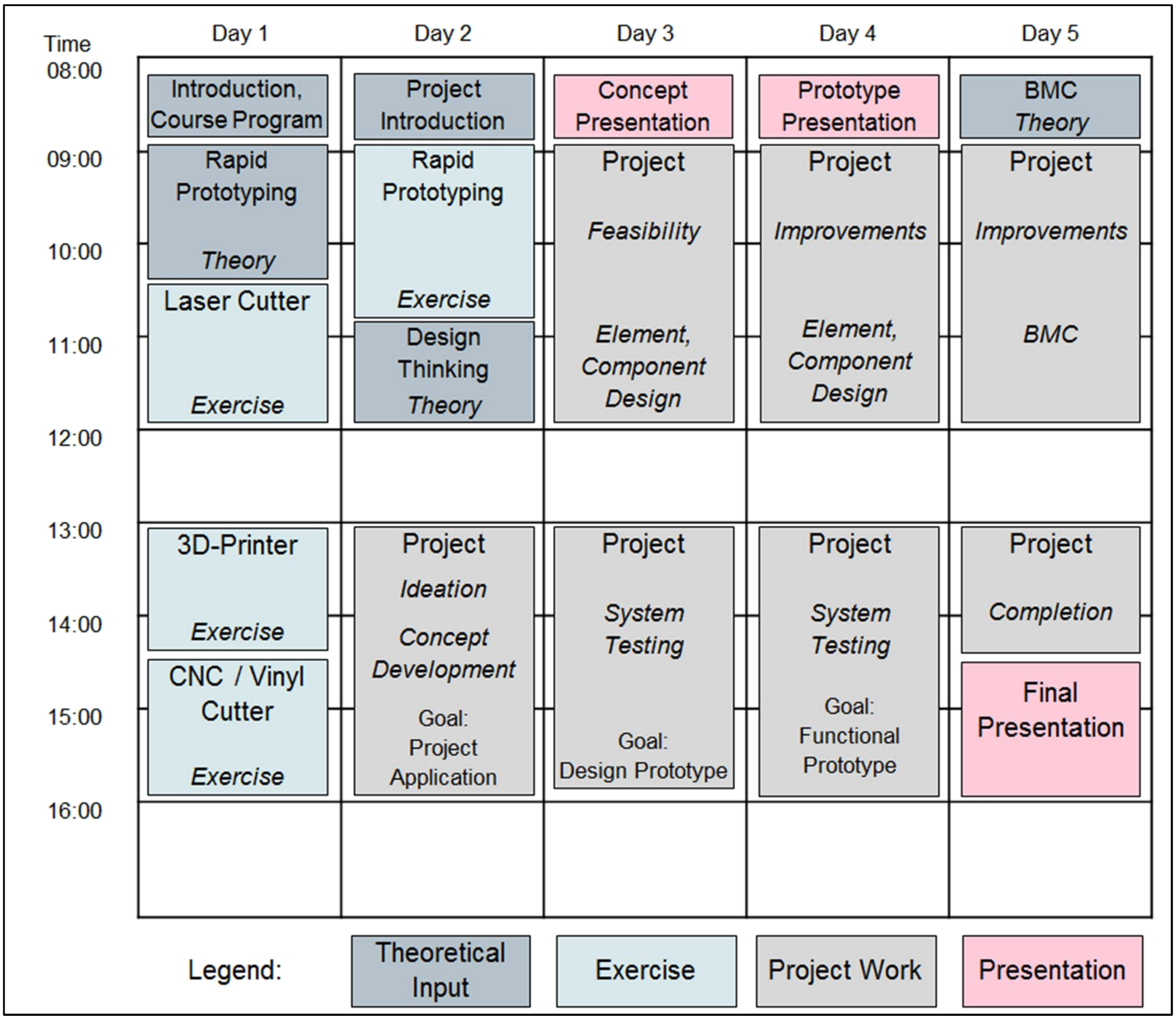

Figure 36: Course schedule

5.5.3 Defining a Project

Requirements for a project are:

- Use of different technologies (e.g. laser cutter, 3D-Printer, electronics)
- Feasibility (e.g. limiting time-factor, costs)
- Creative freedom for the students
- Fun-factor (motivation)

After considering the requirements and discussing the various ideas with the staff of the institute, the following project was chosen: "*Radio-Controlled (RC) Car*". Advantages of this project are the interdisciplinary approach, a reference to the Graz University of Technology and the studies of mechanical engineering, the assumed fun-factor for motivation of the students and the feasibility.

The overall assignment is to design and manufacture an RC-Car. Therefore, the following steps and issues have to be considered.

- Each team must determine and define a target customer group and unique-selling-point for their product (e.g. “we are building an RC-Car for children and therefore our car will be…)
- The development is based on the theoretical inputs of the course (e.g. principles of design thinking have be considered during the development)
- Milestone events during the development phase are:
  - Day 2: the teams have to submit a project application including cost estimation, a list of necessary parts and a short description of their ideas
  - Day 3: a design prototype should be available
  - Day 4: a functional prototype should be available
  - Day 5: final presentation culminating in acompetition among the teams
- Reflection phases are recommended in literature and therefore feedback-rounds after each milestone event or presentation are an important part of the project work
- Documentation of each step in the online blogs of the teams are mandatory

Therefore, the following possibilities for a RC-Car are identified:

1. “*Fischertechnik Control Set + Akku Set + Motor Set*”: Advantages are the functionality and the possibility for re-use. Disadvantage are the costs which are approximately 135€ per car.
2. “*Arduino Car*”: Advantages are the functionality, the expandability, and the lower costs (approximately 50€ per car). Disadvantage is the complexity of the arduino solution.
3. “*Flutter Scout*”: An online-available RC-Car project. All parts, excepting electronic components are 3D-printed. Disadvantage is the high amount of necessary costs for the electronic components (approximately 145 € per car).

Due to the fact that the cars are given at the end of the course to the students (costs) and the expandability of the Arduino solution possibility 2, “Arduino Car” was chosen. In Appendix A.8 a feasibility study of such an RC-Car is described in detail.

5.5.4 Available equipment

As described in section 2.2 the shared goal of Makerspaces is to democratize manufacturing by providing digital production facilities.

In general digital production technologies form a solid object out of a digital model. The advantage of digital production is the possibility to share the data without losses. Further, the possibility to change and correct errors in short time help to manufacture fast, precise and reproducible products. Tools for digital production are e.g. CNC-mills, laser cutters or 3D-printers.[125] Fab Labs share a certain list of tools (see section 2.2.1) which are available at Fab Lab Graz. For the course, the following technologies are identified as important to fulfill the given objectives.

- *3D-printer:* 3D printing is a manufacturing method for the rapid and inexpensive production of models, samples, prototypes, tools and finished products. The technology belongs to additive manufacturing processes. At Fab Lab Graz, the following 2 technologies for 3D-printing are used: (1) Fused Deposition Modeling (FDM) and (2) Stereo Lithography (SLA).[126]
- *CNC mill:* CNC-mills are at present the most-common subtractive manufacturing tools. An extremely fast rotating milling head removes material from the work piece. At Fab Lab Graz, a 4-axis machine with automatic tool changer is installed capable of processing the wood, PVC, resins and aluminum.[127]
- *Electronics:* The electronic tools available at Fab Lab Graz include: Testing equipment (e.g. oscilloscope) and a soldering station. The soldering station in particular will be needed to set-up the steering and power unit of the RC-car project.
- *Laser cutter*: The laser cutter technology is another type of subtractive manufacturing process. A laser is used to cut, etch or engrave materials. Advantages are the accuracy, the speed and the ability to cut complex forms. Limitations of the technology are the materials and the material thickness. At Fab Lab Graz, the laser cutter can process wood, acrylic glass, leather, paper and cardboard up to a thickness of 8 mm.[128]
- *Vinyl cutter*: The vinyl cutter is a drag knife cutter. It plots and cuts in copper and vinyl. Possible use-cases are to label prototypes or produce personalized stickers. As input, a vector graphic format is needed.[129]

5.5.5 Theoretical content

The four identified points of interest regarding explicit knowledge are: V-Model (Product Development), Rapid Prototyping, Design Thinking and Business Model Canvas. As part of this thesis, the four topics for the theoretical parts of the presented concept for a course are described hereinafter. The overall goal is to provide basic information about methods and theories of the different main topics to the students.

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[125] Cf. Bohne (2013), pp. 163-164
[126] Cf. Fastermann (2014) p. 23
[127] Cf. fablab.tugraz.at
[128] Cf. fablab.tugraz.at;
Cf. http://makezine.com/2011/09/01/zero-to-maker-crash-course-in-laser-cutting
[129] Cf. http://wiki.fablab.is/wiki/Portal:Equiment

Further, the students should apply the theoretical knowledge during the project work. This approach, as described in the theory of active education (section 5.2) should strengthen the understanding of implicit knowledge.

5.5.5.1 V-Model

As described in section 5.5.1 the V-Model is going to be the base of the product development process of the “RC-Car” project. This V-Model is taught at the Graz University of Technology in the undergraduate education for mechanical engineers. Therefore the students should experience hands-on what they have learned in the corresponding lecture.

The selected project combines mechanical engineering, electrical engineering and information technology. The V-Model (Figure 37) can be used as a practical guideline for the development of mechatronic products.[130]

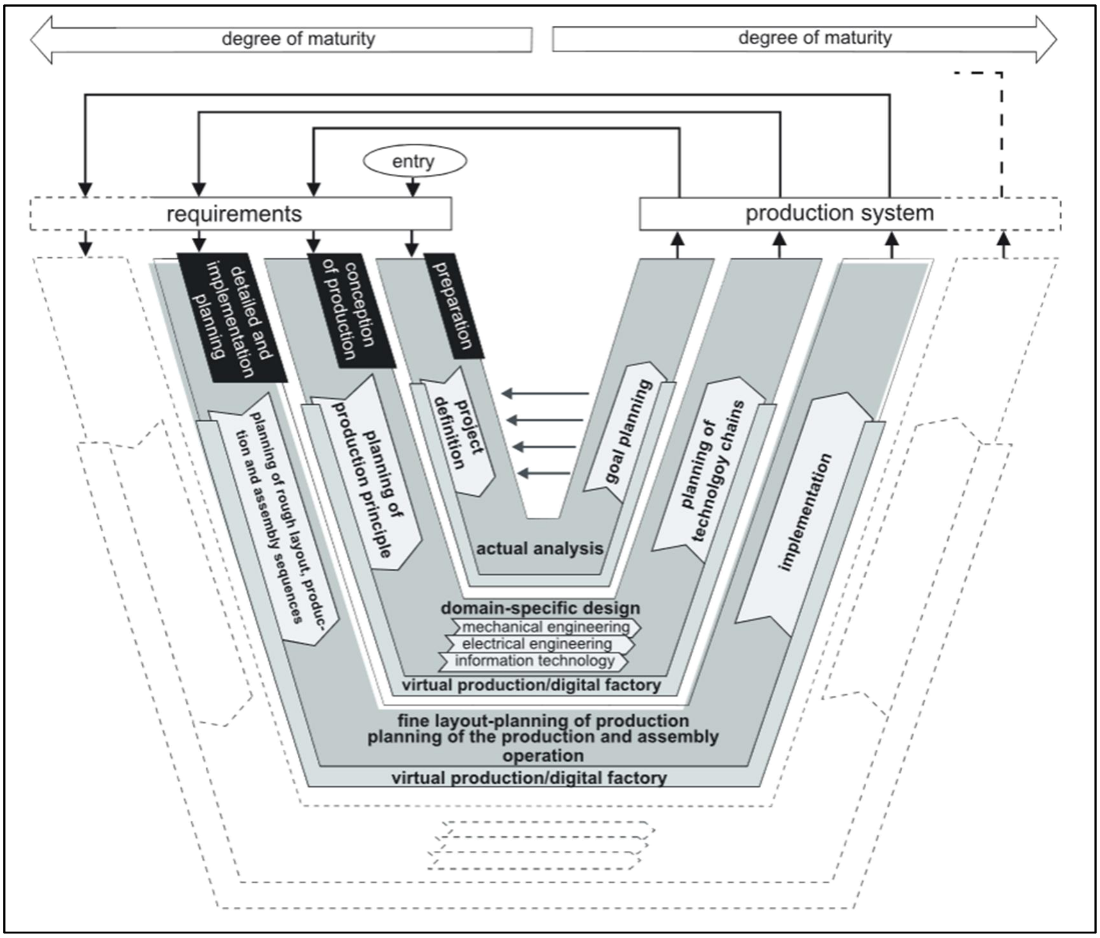

Figure 37: V-model - iterative procedure[131]

[130] Cf. Verein Deutscher Ingenieure (2004), p.5
[131] Verein Deutscher Ingenieure (2004), p.45

5.5.5.2 Rapid Prototyping

In general the traditional process of product development can be separated into five main sections: plan, design, elaborate, and manufacture. At the end of each section an evaluation of the product has to be made. It is assumed that failing fast leads to succeeding faster. The demand for shorter development times, higher product quality and a faster response rate to customer requests leads to increasing product quality making product development a crucial factor in a company's success. [132]

To meet this requirement a method called "rapid product development" was designed. Rethinking the traditional product development process regarding organization, approach and methods are the main aspects of rapid product development. To meet these new requirements "rapid prototyping" plays an important role in up-to-date product development.[133]

In the Figure 42 the role of rapid prototyping in product development is illustrated.

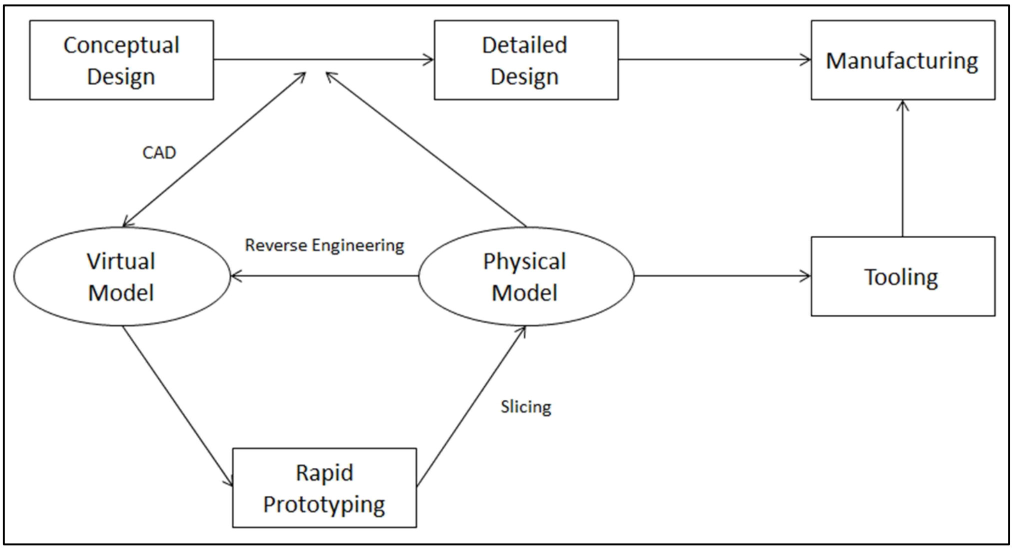

Figure 38: Rapid prototyping in product development[134]

[132] Cf. Bertsche & Bullinger (2007), pp. 19 - 40
[133] Cf. Kamrani & Nasr (2005), pp.136 - 137
[134] Cf. Kochan, Kai, & Zhaohui (1999), p. 5

There are three different types of rapid prototyping according to the actual process phase of the product development:[135]

- *Concept modeling*: Functional prototypes, a physical model of the product which reproduce all or some functions of the final product.
- *Rapid tooling*: refers to rapid prototyping methods which produce a tool used in the series production.
- *Rapid manufacturing*: Describes methods that produce finished parts used directly on the final product.

The focus of the course at the Graz University of Technology is on „concept modeling".

Rapid prototyping or the development of rapid prototyping can be categorized into four main areas. These four areas are: input, method, material and applications. In Figure 39 the "Rapid Prototyping Wheel" is illustrated. This figure depicts the rapid prototyping into its key aspects.[136]

- *Input*: Electronic information describing the real object with 3D data. As illustrated in Figure 38 there are two possible starting points. Data generated out of a computer model or data from the physical model (reverse engineering).[137]
- *Method*: There are a great variety of rapid prototyping methods. Generally the different methods can be classified into the following categories: photo-curing, cutting, gluing/joining, melting and fusing and joining/binding. [132]
- *Material*: The range of materials is according to the methods wide. From paper/cardboard to plastics and nylon or ceramics and metals. [132]
- *Applications*: According to the literature applications can be grouped into (1) design (2) engineering, analysis and planning and (3) tooling and manufacturing. Concerning the industries which can benefit from rapid prototyping there are no limits. [132]

[135] Cf. Bertsche & Bullinger (2007), p. 25
[136] Cf. Chua, Leong, & Lim (2003), p.11
[137] Cf. Chua, Leong, & Lim (2003), p.13

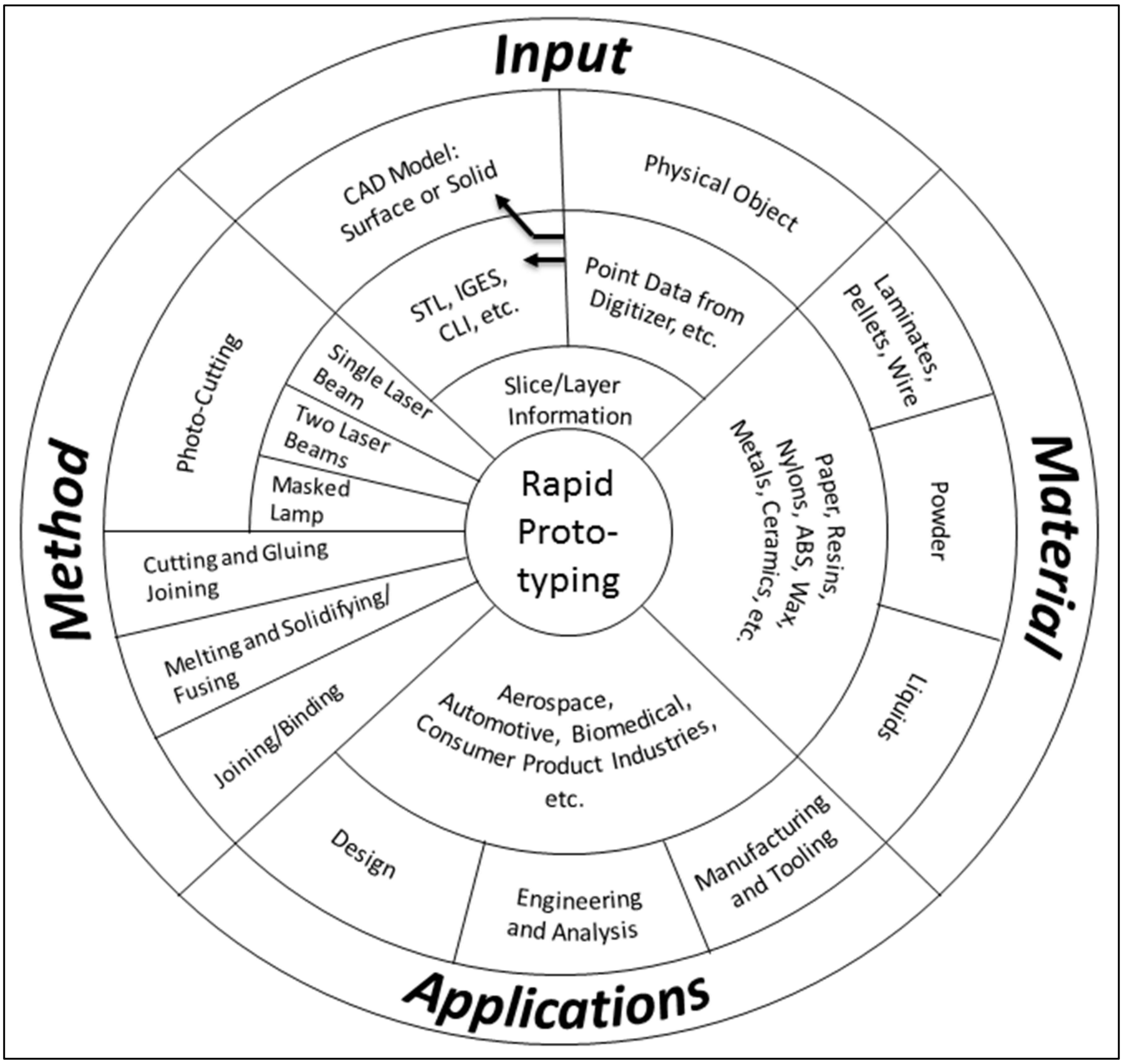

Figure 39: Rapid prototyping wheel[138]

Three fundamental fabrication processes of rapid prototyping could be identified. They are: (1) “subtractive”, (2) “additive” and (3) “formative” processes. All of these processes can be handled by available machines at Makerspaces. These rapid prototyping machines can produce functional parts with quality and finishing close to the final product’s properties. The time needed to produce these parts is relatively short – it can be a matter of hours. Advantages of rapid prototyping can be separated into direct and indirect benefits. [139]

[138] Cf. Chua, Leong, & Lim (2003), p. 12
[139] Cf. Chua, Leong, & Lim (2003), p. 14

Direct benefits are e.g. the possibility to experiment with the product; designers can increase the complexity of the product or the optimization of part design according to customers. Savings are likewise included in the costs. Engineers can reduce the time and costs for the design, manufacturing and verification of tooling.[140]

Indirect benefits address marketing and customers which will benefit from rapid prototyping during product development. Among the indirect advantages are the reduced time-to-market, reduced risk to not meeting customer requirements or the better price performance owing to reduced costs for the manufacturers.[141]

5.5.5.3 Design Thinking:

Design thinking is centered at the intersection of economic viability, technical feasibility and the needs of the user. Therefore it may be seen as a powerful, effective and broadly accessible approach to innovation.[142]

In the study “Conceptions of design thinking in the design and management discourses” the authors investigated the origins of design thinking. They stated that design thinking gathered increasing attention over the past years. The reason for this is the possible impact of design thinking on innovation and management. Further, the authors determined that design thinking is linked closely to “IDEO”, a global design firm.[143] Over the years, IDEO elaborated and applied a human-centered innovation process - design thinking. IDEO’s founder, David Kelley established the Stanford University Institute of Design (d.school).This may be the reason for the pioneering role of Stanford University regarding design thinking.[144] Since 2005 engineering students at Stanford University have the possibility take courses on design thinking. [145]

The design thinking process (see Figure 40) proposed by the d.school consists of five modes. The center of each of these modes is the consideration of the end-user’s needs. Further, iteration is fundamental for good design.[146]

[140] Cf. Chua, Leong, & Lim (2003), pp. 14-17
[141] Cf. Chua, Leong, & Lim (2003), pp. 17-18
[142] Cf. Plattner, Meinel, & Leifer (2011), pp. 22-23; Cf. Brown (2009), p.3
[143] Cf. Hassi & Laakso (2011), pp.1-4
[144] Cf. Myerson (2004), p.4
[145] Cf. Plattner, Meinel, & Leifer (2011), p. 6
[146] Cf. Stanford University Institute of Design (2014), p. 11

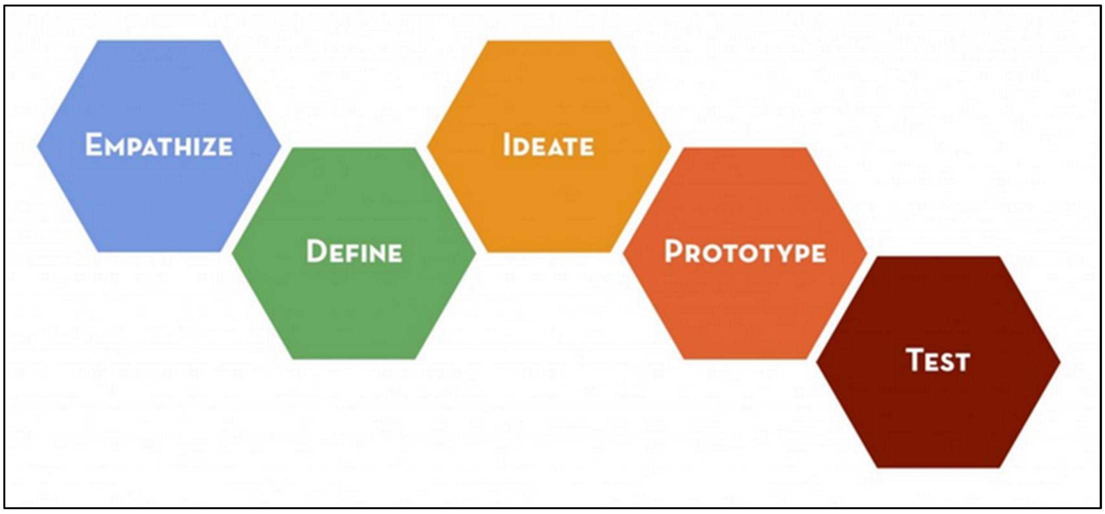

Figure 40: Modes of design thinking[147]

- *Empathize*: Empathy is the inner-core of a human centered design process and design thinking. Understanding the user – their needs, emotions, what is meaningful to them and how they think about the product – is the base of successful innovation. To empathize, the following points are crucial: (1) engagement (interviews, conversations), (2) observation (view users and their behavior) and (3) in general: watch and listen.[148]
- *Define*: The define step of the design process focusses on clarity. Definition of the problem or challenge based on the lessons learned during the empathize phase. The overall goal is to define a meaningful problem statement. Such a problem statement or "point-of-view" should frame the problem, inspire the team, meet the needs of customers while remaining discrete and not broad ensuring feasibility.[149]
- *Ideate*: Ideation is about generating solutions for the defined problems. Unlike the problem statement which should be discrete, the ideation is about generating a variety of different ideas rather than finding the single, best solution. Ideation techniques include: brainstorming, mind mapping, sketching and many more. Further, it is assumed that the combination of several of these techniques delivers especially good results.[150]

[147] http://dschool.stanford.edu/our-point-of-view/
[148] Cf. Stanford University Institute of Design (2014), pp.2-3
[149] Cf. Stanford University Institute of Design (2014), pp. 4-5 [Ibid?]
[150] Stanford University Institute of Design (2014), pp. 6-7

- *Prototype*: The ideas developed during ideation are realized to show, experiment with, and explain the main functions of the design. The experimentation and the feedback of users will especially improve the prototypes. Further, advantages are: problem solving, communication with users, "fail earlier to succeed sooner", or the testing of different possibilities.[151]
- *Test*: Testing the produced prototypes is directly linked to human-centered innovation. Testing increases the understanding of the target customer group. Ideally the test is performed under real-life conditions. Testing helps to refine solutions, learning more about costumers and to refine the problem statement.[152]

5.5.5.4 Business Model Canvas:

Entrepreneurship was identified as an important point of interest for makers and companies. Therefore, the Business Model Canvas will be part of the theoretical and practical content of the course.

As mentioned in section 2.6, various definitions for the term business model exist. Basically, a business model describes the offered value of company for its customers and the way to generate profitable revenue streams. All definitions share three similar aspects: First, a business conceptually represents a real world company. Second, it contains external factors, values and user promises. Third, a business model specifies all relevant stakeholders.[153]

Alexander Osterwalder and Yves Pigneur describe the Business Model Canvas as *"…shared language for describing, and changing business models."*[154] The concept of their model is to provide a systematical structure to think through business models of enterprises. Results are descriptions of the business model and the development of strategic alternatives. The structure the Business Model Canvas proposes consists of nine different blocks (Figure 41).[155]

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[151] Cf. Stanford University Institute of Design (2014), pp.8-9
[152] Cf. Stanford University Institute of Design (2014), pp. 10-11
[153] Cf. Osterwalder (2004), p.15
[154] Osterwalder & Pigneur (2009), p. 18
[155] Cf. Osterwalder & Pigneur (2009), p. 21

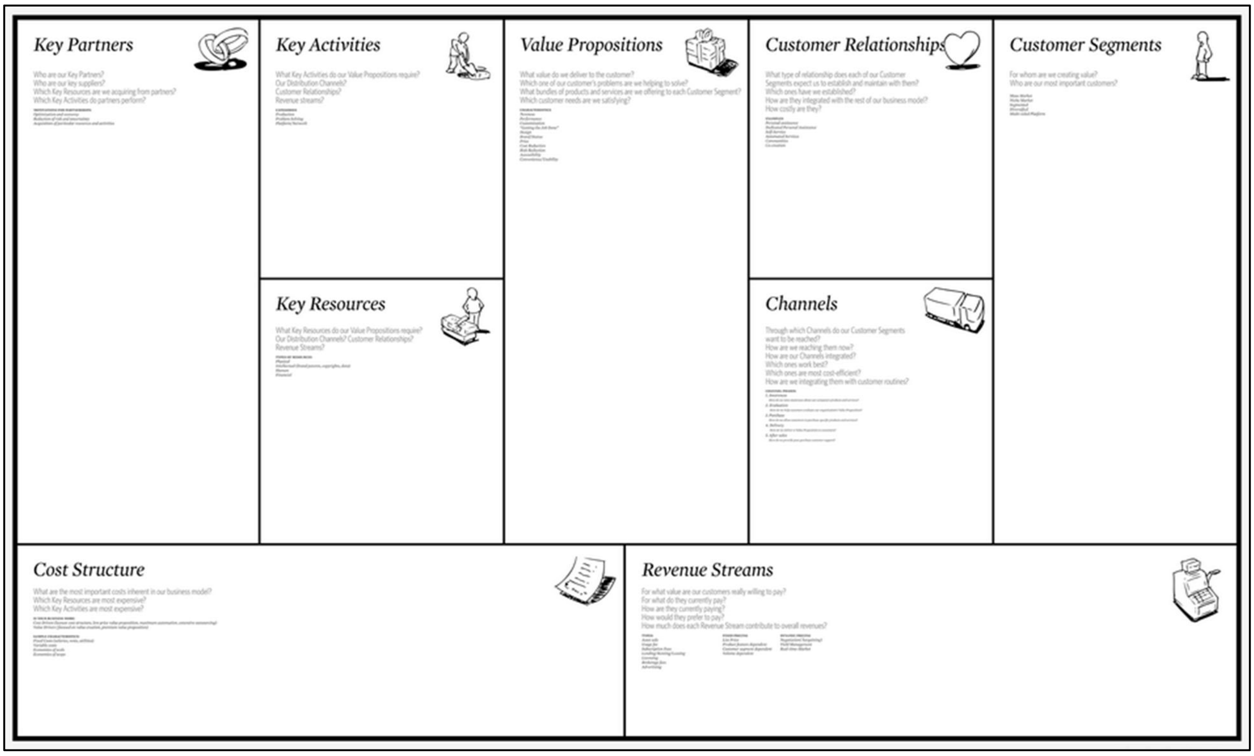

Figure 41: Business Model Canvas[156]

- *Customer segments*: Each organization or enterprise must address profitable customers. To satisfy different customer groups it is necessary to group customers into segments. Segmentation might refer e.g. to the distribution channel, types of relationships or different needs and problems.[157]
- *Value proposition:* The offer a company provides to its customers. The value proposition is the reason for end-users choosing one company or another. Each proposition consists of a package of products or services addressing a different customer segment. Quantitative values delivered to the customer are e.g. price, service or speed. Whereas qualitative values are e.g. the design or customer experience.[158]
- *Channels:* If the customer segments and the value propositions to the customers are determined the channels to reach out to the customers are required. Therefore the communication, sales and distribution channels have to be defined. Functions of the different channels include: increasing the customer experience, providing support, delivering value to the customers or introducing new products.[159]

156 http://www.businessmodelgeneration.com/canvas/bmc
157 Cf. Osterwalder & Pigneur (2009), pp.26-27
158 Cf. Osterwalder & Pigneur (2009), pp.28-29
159 Cf. Osterwalder & Pigneur (2009), p. 30

- *Customer relationships*: The relationship to each customer segment (e.g. personal, automated) is motivated by customer acquisition and customer retention. The influence on the customer experience is immense .[160]
- *Revenue streams*: The value delivered to different customer groups has to ensure a company's survival. It is important for a company to know the sum users are willing to pay for products or services. Two main different types of revenue streams are identified: (1) one-time payments for products/services or (2) recurring revenues.[161]
- *Key resources:* To successfully offer value to customers key resources are needed. Four general types of key resources are proposed: (1) physical resources, (2) financial resources, (3) intellectual resources and (4) human resources. Key resources differ according to the type of business model.[162]
- *Key activities:* In this block, the activities needed for a company to ensure a "working" business model are described. Similar to key resources, the key activities differ on business mode type. Three categories of key activities exist: (1) production (e.g. design activities), (2) problem solving and (3) platform/network (e.g. maintenance of website). [163]
- *Key partnerships*: Living partnerships may enhance the success of a business model. Alliances are made to reduce the risk, to increase the value for customers or to acquire resources. Four types of partnerships among companies are proposed: (1) alliance between non-competitors, (2) partnership between competitors, (3) joint ventures and (4) buyer-supplier partnerships.[164]
- *Cost structure:* The cost structure includes the most important costs of the developed or considered business model. Main aspects are: fixed-costs, variable-costs, economies of scale and economies of scope.[165]

[160] Cf. Osterwalder & Pigneur (2009), p. 34
[161] Cf. Osterwalder & Pigneur (2009), pp. 36-37
[162] Cf. Osterwalder & Pigneur (2009), p. 40
[163] Cf. Osterwalder & Pigneur (2009), pp. 42-43
[164] Cf. Osterwalder & Pigneur (2009), pp. 44
[165] Cf. Osterwalder & Pigneur (2009), pp. 47

5.6 Summary Section 5: “Educational Concept”

Based on several articles and studies it can be stated that the impact of Makerspaces in higher education is increasing. It could be determined that in the academic fields of engineering and applied sciences, Makerspaces are of special interest. Further, the potential of Makerspaces as learning-environments is huge. Compared with 12 principles influencing the learning process it can be stated that Makerspaces are optimal learning spaces.

An internet search of already implemented Makerspaces at universities confirmed the potential. Seven out of 10 Top-Universities with a focus on technology provide at least one Makerspace to their students. As example: at Stanford University the undergraduate students of engineering and industrial design have to take courses which are held in the Stanford Realization Lab. The concepts of courses related to Makerspaces at other Universities (e.g. MIT’s course “How to Make (Almost) Anything”, Fab Academy) were identified as valuable. Therefore, these educational concepts were evaluated and scaled according to the existing resources of the Graz University of Technology.

In order to set-up a concrete educational concept the following four main criteria must be defined: (1) objectives (2) learning content (3) learning methods and (4) used media.

Based on literature, the learning methods and the therefore used media could be identified. The strength of Makerspaces in education is hands-on learning (learning method) and project centered classes (project as media). Hands-on learning enables cognitive development of the learners. Important is that each phase of concrete action is followed by a phase of reflection. Project-centered learning enables learning content not only limited to one subject but arises from an interdisciplinary scale and originality of the project. Advantages are skill generation, practical learning and motivation.

The learning content was derived from the results of possible workshop topics in section 4, market needs: (1) Tools & Equipment (2) Rapid Prototyping (3) Product Development and (4) Entrepreneurship.

After defining the learning content and learning through hands-on experience in small groups an appropriate project must be undertaken. The project has to fulfill the following requirements: include the pre-defined learning content, be interdisciplinary and motivating. Based on these requirements the RC-car project was selected. Students have to design and build a functioning prototype of a RC-car using the infrastructure at Fab Lab Graz.

6 Conclusion

The Maker Movement is increasing its impact on the traditional business landscape as well as on educational institutions. Since the opening of Fab Lab Graz many users have made use of the tools and equipment provided to realize their ideas. Due to the significant rise in demand within a short period of time it became necessary to consider increasing the available space and foster the Maker Movement trend. This thesis aims to enhance the Maker Movement at the Graz University of Technology. Therefore, a review of existing literature, an internet search of leading Makerspaces in the US and Europe, interviews with operators of Makerspaces, actual makers and industrial companies was conducted. The resulting information led to recommendations for the further development and to a concept for a “How to Make (Almost) Anything” course at the Graz University of Technology.

Based on available literature, the success of a Makerspace depends on the protection of interests and freedom of Makers, on providing know-how and on the ability to create and capture value. To ensure success a Makerspace needs to build an innovation ecosystem. Providing tools is not enough, it is essential to make a step forward form a “lab as facility” to an “innovation lab”. Therefore Makerspaces should not focus on machines and making but rather on thinking of social and organizational engineering. The most important point for further growth of Makerspaces is second to operators of Makerspaces the development and maintenance of an active and living community. Therefore, low entrance barriers in the form of minimal membership fees and paltry machine rates are recommended. Further, workshops and team-building events offer valuable instruments to develop such a community.

The results of a literature review postulate that Makerpaces as providers of digital fabrication tools foster product development in the sense of “open innovation” as well as in the sense of “user-innovation” directly by the end-user. All of the interviewed industrial companies are interested in collaborative projects. The possible know-how transfer from the academic institution, the user-community and the network of different industries is probably the most desired outcome of such projects. Industrial partners are confident that Makerspaces are optimal environments for employees to work on their ideas and produce first prototypes. Therefore, certain digital production machines and tools are needed. Results regarding desired machines of companies and actual makers showed that beside basic Fab Lab tools, metal working machines and electronic implements are of special interest. Whereas the internet search showed that metal working technologies are not often part of Makerspace concepts. This may contribute to the fact that the Maker Movement is based on easy-to-use production facilities.

However, it is important that the Fab Lab Graz find a proper solution to offer metal working machines in order to serve a broader range of customers. Further, the following expectations of industrial partners and start-ups could be identified which must also be taken into consideration:

- *Community/network*: Start-ups and large-scale enterprises mentioned that a living community paired with an interdisciplinary approach is one of the most valuable aspects of the Maker Movement. The development and maintenance of such a user-base will be the main task for the Fab Lab Graz.
- *Intellectual property (IP) issues*: Similar to different studies in literature the interviewed companies mentioned possible IP-problems. However, the companies are not negatively disposed owing to the IP-problems. According to the enterprises it is only important that there are clear rules of what will happen with potential products/ideas. Thus, for Fab Lab Graz it is important to set applicable rules in close cooperation with the industrial partners.
- *Collective agreement:* Companies mentioned problems regarding the risks and responsibility of accidents during working hours at the Makerspace. Finding a solution, also for students and hobbyists working at the Fab Lab, regarding the responsibility and safety is a task with high priority.

Based on literature and the interviewed experts, the know-how transfer is one of the most valuable aspects of Makerspaces. Further, the review of the literature indicates an increasing impact of Makerspaces on education. In universities all over the world students of different academic fields start learning by making and creating. The Maker Movement is increasing the means of hands-on, active learning and is assumed to address future needs in education. Project-centered classes in combination with a proper relationship of thinking and acting processes is one of the strengths of Makerspaces in higher education. The potential applies especially to the academic fields of engineering where creating, inventing and innovating are essential skills. Reasons for the importance of active-education are the increasing demand of industry in terms of independent work, dealing with new situations or gained experiences from practical project work. Therefore, a concept for a “How to Make (Almost) Anything” course was developed. Students will work independently on complex real tasks. The learning content is not only limited to one subject but arises from an interdisciplinary scale and originality of the pre-defined project. Based on the requirements for such an interdisciplinary project the students will design and build a radio controlled car during the course. Theoretical content relies to the topics of “Product Development”, “Rapid Prototyping” and “Entrepreneurship”.

All of these facts show the multiplicity of a successful concept for a Makerspace. Further research regarding applicable business models for such a laboratory is needed. The Institute of Industrial Management and Innovation Research as hosting facility should foster greater cooperation with industrial companies and use the capacities of the Fab Lab for education and different courses. As mentioned above, to ensure success a Makerspace needs to build an innovation ecosystem. However, a great deal of effort is needed to foster this and will require several years, especially due to the rapidly changing requirements for such an innovative laboratory.

The fact that during the six month period of this research the number of active Fab Labs worldwide has increased from 442 to 562 shows the impressive development of the Maker Movement. It can be stated that the potential of Makerspaces and their creative environment has not yet reached its zenith.

7 List of References

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10 List of Abbreviations

ABS	*3D-Printer Filament (Acrylnitril-Butadien-Styrol)*
CBPT	*Circuit Board Production Tools*
CEO	*Chief Executive Officer*
CNC	*Computerized Numerical Control*
ECTS	*European Credit Transfer System*
Fab Lab	*Fabrication Laboratory*
FDM	*Fused Deposition Modeling*
IP	*Intellectual Property*
MIT	*Massachusetts Institute of Technology*
NMC	*New Media Consortium*
PLA	*3D-Printer Filament (Polylactic Acid)*
R&D	*Research and Development*
RC-car	Radio Controlled Car
SLA	*Stereolithography*
SLS	*Selective Laser Sintering*
SME	*Small and Medium-Sized Enterprises*

Appendix

							Hosting Facility		
Name	Type of Makerspace	Hackerspace	Fablab	Makerspace	Other	Internetadresse	None / Private	Community Project / "Non-Profit" Organisations	University / College / Public Institution
NYC Resistor	Hackerspace	1				http://www.nycresistor.com	1		
Familab	Hackerspace	1				https://familab.org/		1	
7Hills Makerspace	Makerspace			1		http://7hillsmake.org		1	
Hackpittsburgh	Hackerspace	1				www.hackpittsburgh.org		1	
columbus idea foundry	makerspace			1		http://www.columbusideafoundry.com/	1		
The HackFactory	Hackerspace	1				http://www.tcmaker.org/blog/hackfactory/		1	
Lorain County Community College Fab Lab	FabLab		1			http://lcccfablab.blogspot.co.at/ http://www.lorainccc.edu/Academic+Divisions/Engineering+Technologies/Fab+Lab			1
Arch Reactor	Hackerspace	1				http://archreactor.org/about		1	
Omaha Maker Group	Hackerspace	1				http://omahamakergroup.org/		1	
Bozeman Makerspace	Makerspace/ Hackerspace			1		http://www.bozemanmakers.org/		1	
The Dallas Makerspace	Makerspace			1		http://dallasmakerspace.org/		1	
ATX Hackerspace Co-op	Hackerspace	1				https://atxhs.org/wiki/Main_Page	1		

	"FABLAB"				Wood								Metal							Electronics		Handcraft		
Name	3D- Printer	Laser Cutter	Vinyl Cutter	3D-Scanner	CNC	Drill Press	Table Saw	Band Saw	Sander	Planer	Wood Lathe	Jointer	Welding	Lathe	Band Saw	Plasma Cutter	Blacksmithing	CNC	Sandblasting	Soldering	Printed Circuit Board Production Tools	Sewing Machine	Heat Press	Sonstiges Equipment
NYC Resistor	1	1	1		1									1						1		1		brewery vacuum former
Familab	1	1			1		1		1					1		1								BioLab Dark Room
7Hills Makerspace	1	1			1	1	1	1														1	1	heat press
Hackpittsburgh	1	1	1		1	1	1	1	1				1	1						1				
columbus idea foundry	1	1	1	1	1		1	1	1	1			1			1	1			1		1		Sand casting
The HackFactory		1			1		1			1			1							1		1		Scanning Electron Microscope, Planer
Lorain County Community College Fab Lab	1	1	1		1															1				
Arch Reactor	1	1	1		1	1		1						1						1				
Omaha Maker Group	1																			1				
Bozeman Makerspace	1	1			1								1							1				
The Dallas Makerspace	1	1	1		1		1	1	1	1			1	1		1	1		1	1		1		Sandblasting Cabinet small kiln
ATX Hackerspace Co-op	1	1	1		1		1	1					1	1	1	1				1		1		kiln Biological safety cabinet (part of DIYBio Area)

							Membership			Access Types							Workshops / Classes
Name	Größe [Sqft]	0-250m²	250 - 500 m²	500 - 1000m²	>1.000 m²	no details provided	Membership	Registered Members	Open to general public	Membership fee	Open Access	Specific User Group	Membership differentation	Corporate Membership/Start-Ups	24 / 7	Minimum Fee for "24/7" [$/month]	Workshops / Classes
NYC Resistor	3.000		1				- Membership, core group: Invite only! - Friends of NYCR, support for the space - Memberfee: $75 with teaching $115 without teaching a class	40	1	1			1		1	115,00	- Online booking system - Also for non-members - e.g. "Make along club 12-Month Pass" for 85 $, 15 Workshops all over the year different topics - Arduino & Sensors - Fire the Lazzzzor! Learn to rapid prototype
Familab	4.000		1				- "Maker" Membership: Dues are $50/month. Membership support of FamiLAB includes voting rights, and 24×7 access to the lab - "Booster" Membership: Dues are $100/month. All "Maker" Level benefits + Recognition on FamiLAB.org as a Booster + ability to sponsor another individual at the "Maker" level.	75	1	1			1		1	50	- Classes e.g intro to soldering, intor to rasperry pi,... - Open house, first tuesday every month
7Hills Makerspace	6.000			1			- Keyed Members (24/7) 80$/month - Non keyed members - access during lab hours $40/month - Certain membership process: needs to member as sponsors.	14	1	1			1		1	80	- Every Tuesday: Open Make Night - Possibility to rent the Makerspace
Hackpittsburgh	1.700	1					- Dues – $30 per month for "24/7" - Volunteering – 3 hours of volunteer work or equivalent financial or goods donation, subject to approval by a council member - Open to the public, Friday from 7 pm - midnight	27	1	1					1	30	...any Member of Hackpittsburgh can host a class
columbus idea foundry	65.000				1		- $ 35 / month for "24/7" access, Additional Machine Rates --> also "Start-ups" as members	200		1				1	1	35	- e.g.blacksmithing, electronics, fashion, also "entrepreneurship" or software & programming - Private instructions available for specific project or technique
The HackFactory	9.000			1			Membership dues are $55/month, Regular membership allows you to use any of our tools and equipment (after completing any orientation needed for some specialized tools). Membership includes: 24 hour a day, 7 days a week access to the Hack Factory (e1cluding some events) Discounts on classes (where applicable) Discounts at events Discounts at some local business A vote at Members' Annual Meeting and Special Meetings - Additional "rockstar membership" no further information - Special scholarship program	113	1	1			1		1	55	- MIT/TIG Welding - Glass class - fiberglassing 101 - Laser Cutter Basis - Minne-Fair (Science, Engineering, Art and Technology e1hibition)
Lorain County Community College Fab Lab						1	- Open for students, staff and general public		1		1						- Lectures e.g.CoralDraw for Lasers & Vinyl Cutting
Arch Reactor	2.500	1					- Community Member: public mailing list, only visit the public lounge - Supporting Members $ 15 per month, public lounge and access to private areas if full members are available - Full Member $ 45 for "24/7" access	40	1	1			1		1	45	
Omaha Maker Group	1.200	1						30	1								Bi-weekly meetings where people can collaborate, share resources, create, and learn
Bozeman Makerspace	750	1					Monthly 24/7: $20 per month (Student $15)	15	1	1			1		1	20	Safety, 3D Design, CNC Mill, Arduino basics, welding basics and open buid night (every week)
The Dallas Makerspace	16.500				1		- Monthly $ 50 / annualy $540 - Full access, "24/7" - Additional family members for $10/month or $120/year - Starving hacker ($35/month) for Students, Unemployed,... - Corporate Membership ($150/month or $1,620/year) – This membership is for organizations who wish to supply their students or employees with access to our tools and workspace (one key card, e1tra cards:$50/month)	835	1	1			1	1	1	50,00	- Woodshop 101 - Robot Builder Night - Blacksmithing - 3D-Printing classes - ...
ATX Hackerspace Co-op	8.000			1			- Visitors: Open Tuesday - Patron: "24/7" access to the space, "Pay-as-you-go" $ 85 per month - Co-op membership, $60 per month, "24/7" access and voting rights - Corporate Membership: 5 minimum memberships with a yearly contract Additional Costs: e.g. Makerbot Machine Rate Additional Services: - Member Storage - Coworking (own office and access to the fabrication tools $410 per month	92	1	1			1	1	1	60,00	- Microcontroller Monday - Tuesday Open House - Austin Linu1 Enthusiasts - The Robot Group First Thursday - Software Saturday - Fiber Fab (leather, spinnint etc.) - ATX Hackerspace 101 all co-op members can host a class Additional Working-Groups: - Craft Group - Automotive Group - DiY Bio Group - DiY Electronics Group - DiY CNC Group - ...

							Hosting Facility			"FABLAB"				Wood								Metal							Electronics		Handcraft									Membership			Access Types							Workshops / Classes
Name	Type of Makerspace	Hackerspace	Fablab	Makerspace	Other	Internetadresse	None / Private	Community Project / "Non-Profit" Organisations	University / College / Public Institution	3D- Printer	Laser Cutter	Vinyl Cutter	3D-Scanner	CNC	Drill Press	Table Saw	Band Saw	Sander	Planer	Wood Lathe	Jointer	Welding	Lathe	Band Saw	Plasma Cutter	Blacksmithing	CNC	Sandblasting	Soldering	Printed Circuit Board Production Tools	Sewing Machine	Heat Press	Sonstiges Equipment	Größe [Sqft]	0-250m²	250 - 500 m²	500 - 1000m²	>1.000 m²	no details provided	Membership	Registered Members	Open to general public	Membership fee	Open Access	Specific User Group	Membership differentation	Corporate Membership/Start-Ups	24 / 7	Minimum Fee for "24/7" [$/month]	Workshops / Classes
Lawrence Creates Makerspace	Makerspace			1		http://lawrencecreates.com/		1		1			1									1									1		A wood shop Hand tools Artist tools A design studio with the Adobe Creative Suite (Photoshop, InDesign, and more) Shared training, e1hibition, performance, and practice space Photo studio with lighting (to be installed soon) Art gallery Te1tile studio Metal shop and other prototyping components	5.000		1				- "24/7" access for $ 20 per month - Specified public hours, for public to tour the facility	50		1					1	20,00	- Learn to sew [$20] - 3D Design and Printing [15] -Silk Painting [$30] - Tool Time for Beginners [$10] - Learn improve Photoshop, InDesign & Illustrator skills [$15] - Performance & Presentation: Calming, Focusing, & Flow Strategies (CLEOS) [$35]
HeatSync Labs	Hackerspace	1				http://www.heatsynclabs.org/		1		1	1	1		1		1	1	1	1			1	1						1		1	1	Planer	5.000		1				- Associate $25 per month, voting rights at HYH meetings - Basic $50 per month, includes a storage bo1 - Plus $100 per month, includes a locker instead of a bo1 - Non-Members: Public hours - Mon to Fri from 7 pm to 10 pm			1			1		1	25,00	- for learning how to use tools in the lab there is a "goolge discussion group" where teachers and volunteers find students (e.g. Mill, Lathe, CNC, Laser, Welding or wood Working) - Arduino HakcNight - Young Makers (Every Friday) - Craftagious - Metal Mondays - 3D Printing with Makerbot and RepRap
Milwaukee Makerspace	Makerspace			1		http://milwaukeemakerspace.org	1			1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1		1	1		1	1	Electic forklift Hydraulic Press Sandblaster wood jointer http://wiki.milwaukeemakerspace.org/equipment	16.000				1		- Full-Time Membership "24/7" access and one locker - $40 per month1 - Spouse/Immediate Family Member $10 additional per person for a second key - "Friends of the space" Attend meetings and events, not able to use tools and equipment		1	1			1		1	40,00	- Milwaukee Makerspace Wiki Editing & Use Class - Screen Printing Workshop [$25] (t-shirt, paper print) - Leather-working Class [$30] - Beginner Arduino Class - Beginner DSLR Photography Class - Blacksmithing: Make your own Trivet [$40] - Ceramics Area [$10] - Glass Etching Workshop [$10] - Aluminum Anodizing Workshop at Milwaukee Makerspace [$15] - ... http://wiki.milwaukeemakerspace.org/classes
i3 Detroit	Hackerspace Integrated FabLab	1	(1)			https://www.i3detroit.org https://www.i3detroit.org/wiki/Main_Page	1			1	1	1		1	1	1	1	1	1	1	1	1	1	1	1				1		1	1	Wood Working: Planer, pneumatic nail guns, lathe Metal Working: CNC Mill,	10.000				1		- Full access "24/7" for $ 49 per month - Mentor System	120		1			1	1	1	49,00	- New Member Orientation (Every two weeks) - Open Craft room - i3 Motorsports - Leather Belt Making Class - Welding class [$45]
Techcentral	Makerspace			1		http://www.cpl.org/TheLibrary/TechCentral/TechCentralMakerSpace.aspx			1	1	1	1	1																			sd	Photography, Videography, and Graphics						1	- Access with Public Library Card/Membership, open from Mon to Sat from 10:00 am to 5;30 pm		1	1							- 3D Printing Basics - 3D Cookie Cutter Lab
Pumping Station: One	Hackerspace	1				http://pumpingstationone.org		1		1	1	1		1	1	1	1	1	1	1	1	1	1	1					1		1		Brewing Wood lathe Joniter, Planer https://wiki.pumpingstationon	6.000			1			- Friends of P S:one $ 13,37 per month, donation no access - Starving Hacker Membership $ 40 per month, "24/7" access to the space no voting rights, no storage space for projects or materials - Full Membership $ 70 per month, "24/7" access, voting rights and storage space	400	1	1			1		1	40,00	- Let's Drink and Learn About: Sangiovese - Cryptoparty! - CNC Build Club - Circuit Soldering Workshop - Orientation Class - Solder Party - Brew Day
Louisville Hackerspace	Hakcerspace	1				http://www.lvl1.org/		1		1	1	1		1	1	1	1	1		1		1		1					1		1		Wood Shop: Lathe (Wood)	9.000			1			- Membership, $ 50 per month, voting rights, "24/7" access to the space	60	1	1					1	50,00	- Open Builder Night (every Tuesday) - How to Solder - Digital Electronics for Arduino - Intermediate Microcontroller Workshop, "Beyond Arduino" - LVL1 Summer Camp - Raspberry Pi Bootcamp - ...
Quelab	Makerspace & Hackerspace	1				http://quelab.net/blog/		1		1	1			1	1							1	1						1		1			6800			1			- Sustaining Member: $40, "24/7" access - Friends of Quelab, transferable punchcard - Associate Members, $20 (Same residence as sustaining member	67	1	1			1		1	40,00	- Hacknight, for guests also every Tuesday - Arduino Afternoon - Learn to knit - Personal Locksmithing - ..
The crucible	Hakcerspace	1				http://thecrucible.org/		1						1								1	1			1								56.000				1		Yearly Membership starting from $ 75 to $ 2500 "priority Acces" and discount for classes	35	1	1			1				http://thecrucible.org/spring-2015-session/
ADX Portland	Makerspace			1		http://www.ad1portland.com	1			1	1			1	1	1	1	1	1	1	1	1		1							1		Joiner & Planer, wood lathe vertical mill (Fräsmaschine)	14000				1		- Community Membership $ 50, access to wood & metal shop with purchase of Shop Passes - Craft Lab Membership $ 80, full access with Shop Passes - Free Time Membership $ 150 full access after 5 pmon weekdays and and all time during weekends - unlimited membership $ 200 full access during open hours! Shop Passes: $ 40 for whole day access or $ 100 for 5 shop pass bundle Business Membership: "Rate Packages"	400		1			1	1			Intro to wood (Members $ 84, Non Members $234) Intro to metal ($95 / $245) 3D Printing certification class ($68 / $148) http://www.ad1portland.com/classes/
Delamare Library, Univ. of Nevada, Reno	Makerspace			1		http://www.delamare.unr.edu/			1	1	1	1	1																1										1	Open to the public, seven days a week Same for students of the University		1		1						- "Book a tech wrangler" for consultations, general questions about "how to"
Noisebridge, San Francisco	Hackerspace	1				https://www.noisebridge.net/ https://wiki.hackerspaces.org/Noisebridge		1		1	1	1		1	1	1	1	1					1						1		1			5200		1				Starving Hacker $ 40 per month Full Member $ 80 per month open from 11 am to 11 pm every day	100		1			1				Learn to solder Learn HTML/CSS/JS ...

Name	Type of Makerspace	Hackerspace	Fablab	Makerspace	Other	Internetadresse	None / Private	Community Project / "Non-Profit" Organisations	University / College / Public Institution	3D- Printer	Laser Cutter	Vinyl Cutter	3D-Scanner	CNC	Drill Press	Table Saw	Band Saw	Sander	Planer	Wood Lathe	Jointer	Welding	Lathe	Band Saw	Plasma Cutter	Blacksmithing	CNC	Sandblasting	Soldering	Printed Circuit Board Production Tools	Sewing Machine	Heat Press	Sonstiges Equipment
							Hosting Facility			"FABLAB"				Wood								Metal							Electronics		Handcraft		
Biocurious	Hackerspace	1				http://biocurious.org/		1																									– Lab Sink – PCR Machines – qPCR – Balance – Autoclave – Micropipettes, single and multi-channel – Fluorescent Microscope – Microcentrifuges - ..... http://biocurious.org/about/
Double Union	Hackerspace	1				https://www.doubleunion.org		1		1		1		1															1		1		
Vocademy	Makerspace			1		http://www.vocademy.com	1			1	1	1		1		1	1		1			1	1	1	1		1		1		1		Planer CNC Metal
Ace Monster Toys	Hackerspace	1				http://wiki.acemonstertoys.org		1		1	1	1		1	1	1	1					1	1	1					1		1		Jointer
Autodesk Pier 9	Makerspace			1		http://www.autodesk.com/artist-in-residence/projects	1			?	?	?	?	?	?	?	?					?	?	?	?	?	1		?		?		CNC machines: a waterjet and 5 axis router, multi-material 3D printers, full metal and wood
Artisan's Asylum	Makerspace		1			http://artisansasylum.com		1		1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1		1		1	1	CNC Metal wood lathe Planer
Fourth Floor	Makerspace			1		http://chattlibrary.org/4th-floor			1	1	1	1																					
Nova Labs	Makerspace			1		http://www.nova-labs.org		1		1	1	1		1	1	1	1						1	1					1				
Yale Center for Engineering Innovation and Design	Makerspace			1		http://ceid.yale.edu/			1	1	1	1		1	1			1					1	1									wet lab (microfluid and genetic engineering)
Genspace	Community Biolab				1	http://genspace.org/		1																									molecular and synthetic biology
Techshop San Francisco				1		https://wiki.hackerspaces.org/Techshop_San_Francisco	1			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1	1		1		...siehe Link

Name	Größe [Sqft]	0-250m²	250 - 500 m²	500 - 1000m²	>1.000 m²	no details provided	Membership	Registered Members	Open to general public	Membership fee	Open Access	Specific User Group	Membership differentation	Corporate Membership/Start-Ups	24 / 7	Minimum Fee for "24/7" [$/month]	Workshops / Classes
							Membership			Access Types							Workshops / Classes
Biocurious	2400	1					$ 1000, 12 month membership - access during opening hours			1							- Community Project Night (every Thu)
Double Union	750	1					only Woman! - Step-byStep to get membership - "Key Members" - Application necessary	80		1		1	1		1	50,00	- Open House - CNC Machine Building - Cryptography study group - ....
Vocademy	15000				1		No membership needed to take classes - 3 month plan: $149 / month - 12 month plan: $99 / month - Student plan: $99 / month - For companies: "Multi-Member-Plan" (including class packages...) $?	100	1	1			1	1			e.g. 10 class hour package for $299 (valid every class) 3D Inventors Pack (level 1, 2, 3) for $ 349 ... Electronics and robots Home and Construction Lasercut and engrave Sewing and textiles Machine Shop and CNC ....
Ace Monster Toys	14000				1		Provisional Members (voting) and then Full members all with "24/7" access. Standard $80 per month; Student $ 40 per month, "desk rate" 250 per month			1			1	1	1	80,00	- Sewing 101 - 3D printing interest group - Textile Tuesday - Laser Cutter 101 - ...
Autodesk Pier 9	27000				1		Application All "Artists" receive a $1500 monthly stipend + budget for project supplies "24/7" access Residencies last for 4 month Community: Autodesk specialists, industry professionals and other artists.					1					
Artisan's Asylum	40000				1		With special opening hours: - Weekend warriors: $ 60 per month - Weekday: $ 100 per month - Nights/Weekends $ 100 per month Full access - unlimited $ 150 per month ("24/7") also "co-working spaces"	250	1	1			1	1	1	150,00	Assorted & Multimedia Bicycle Building & Maintenance Business & Marketing CAD, Programming, Design & Engineering CNC Prototyping & CAM Electronics & Robotics Fiber Arts Jewelry/Metalsmithing Machining,...
Fourth Floor						1	Access with library card (opening hours)		1		1						- Mozilla's Maker Party - Intro to web design
Nova Labs	10500				1		Attendee (free) for lectures and classes Associate Member ($50 per month) open hours via Sponsor Member "24/7" access ($100 per month)	70		1			1		1	100,00	- Laser Cutting - Arduino - Raspberry Pi - BeagleBone - IoT - Robotics - 3D Printing - Soap making - Sous Vide - Arts and Crafts
Yale Center for Engineering Innovation and Design	8500			1			Open to the entire Yale University Community "24/7" (training etc needed)					1			1	0,00	Lectures / Courses
Genspace						1	"reasonable monthly costs"			1							- Biohacker Boot Camp - Biotechnology Crash Course - Intro to Syntetic Biology
Techshop San Francisco	24000				1		Membership Fee: $125 per month or $1200 per year ($100 per month for Students or $1000 per year)	1000		1			1		1	125,00	Different Tecnologies, "TechShop Makerspace Acadamey", Events togheter with Companies

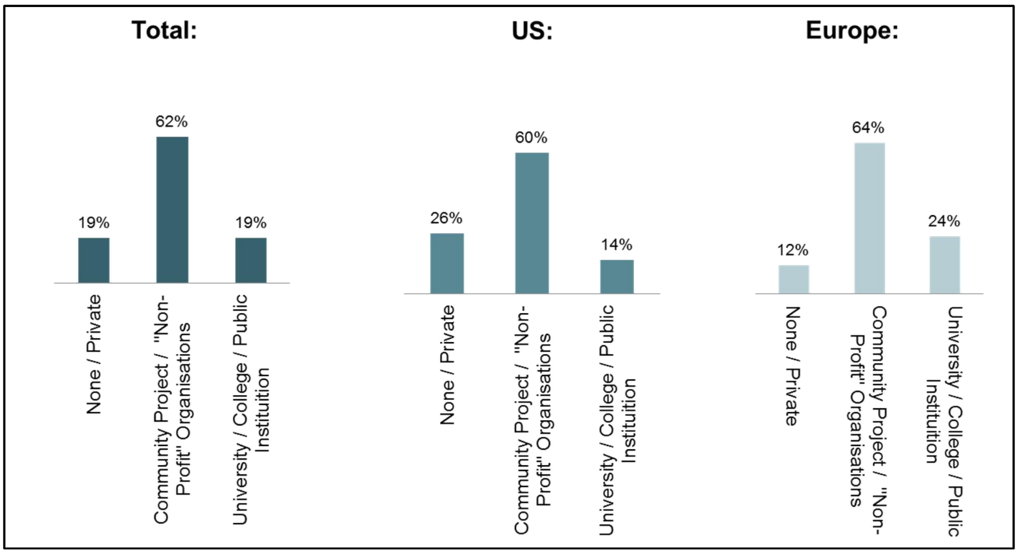
							Hosting Facility			"FABLAB"				Wood								Metal							Electronics		Handcraft								Membership			Access Types							Workshops / Classes
Name	Type of Makerspace	Hackerspace	Fablab	Makerspace	Other	Internetadresse	None / Private	Community Project / "Non-Profit" Organisations	University / College / Public Institution	3D - Printer	Laser Cutter	Vinyl Cutter	3D-Scanner	CNC	Drill Press	Table Saw	Band Saw	Sander	Planer	Wood Lathe	Jointer	Welding	Lathe	Band Saw	Plasma Cutter	Blacksmithing	CNC	Sandblasting	Soldering	Printed Circuit Board Production Tools	Sewing Machine	Heat Press	Größe [sqft]	0-250m^2	250 - 500 m^2	500 - 1000m^2	>1.000 m^2	no details provided	Membership	Registered Members	Open to general public	Membership fee	Open Access	Specific User Group	Membership differentation	Corporate Membership/Start-Ups	24 / 7	Minimum Fee for "24/7" [$/month]	Workshops / Classes
FAU FabLab	Fab Lab		1			https://fablab.fau.de/			1	1	1	1		1	1	1							1						1	1	1	1	70	1					Openlab, opening hours - for the general public Selflab, no helping staff, after the introduciton to the fabrication tools Active tutors get a key permission after some time	d	1		1						- Löten für Anfänger - SMD Löten - Vom Schaltplan zur fertigen Platine - Microcontroller Programmierung
SciFabLab	Fab Lab		1			http://scifablab.ictp.it/			1	1	1	1	1	1															1									1	Scientis of ICTP and "authorized Projects" in the morning (Tuesday to Friday) Visitors (General Public) from 1 pm to 9 pm and Saturday 3 pm to 9pm		1			1					**- Triest Mini Maker Fair (9-10 May)** -Arduino Day -
Happylab	Fab Lab		1			http://www.happylab.at/	1			1	1	1		1	1	1	1	1											1		1	1	250		1				- Small: 5€ per month, access during opening hours - Medium: 19€ per month access during opening hours and one day a week 24 hours access . Large: 29€ per month full access 24/7		1	1			1		1	29	- FabLab Bootcamp - Laubsägen war gestern - Introductioncourses for small groups and individuals
Smart Lab Carinthia	Other				1	http://www.fh-kaernten.at/engineering-it/master/industrial-engineering-management/smart-lab.html			1	1	1	1	1	1															1									1	Open every Tuesday from 4 to 6 pm		1			1					
FabLab RWTH Aachen	FabLab		1			http://hci.rwth-aachen.de/fablab			1	1	1		1	1		1													1	1			60	1					Open from 11 am to 7 pm Everyone has to book a time slot to use the FabLab	200	1			1					Lectures
FabLab Berlin	FabLab		1			http://www.fablab-berlin.org/	1			1	1	1	1	1															1		1							1	- Open from 10 am to 8 pm Mon to Tue - Sat: 12:000 - 6 pm - Pay as you go (e.g. 1 hour 3d printing 10 €) - Membership 50 € per month (also opening hours) and -50% for machine hours.		1	1							- Workshop with Vinyl Cutter - CNC Machining Class - Printing intro Workshop - ...
FabLab Aalto	FabLab		1			http://fablab.aalto.fi/site/			1	1	1	1		1															1				100	1					Students: Wednesday to Friday from 10 am to 4 pm General Public "Open day (Monday or Tuesday" from 12 to 6 pm		1			1					- Classes for students; .Digital Workshop Basics (1 credit unit) - TBC 2015 or independently .Digital Fabrication Studio (2-5 credit units) - TBC 2015
FabLab BCN	FabLab		1			http://www.fablabbcn.org/			1	1	1	1	1	1								1							1		1							1	Three main Workscopes of the Lab FabLab Pro "Fabrication" FabLab Masters "high research and tutoring" FabLab Centre "FabLab for education of young people and the general public"		1	1	1	1					Workshops for e.g. 3d-Printing, Arduion Workshop, etc.
FabLab Amsterdam	FabLab		1			http://fablab.waag.org/		1		1	1	1		1															1		1	1						1	For Business: Hosting facility for events, digital fabrication lab for prototypes For Groups (15 pers.) 1400 exclusive rate per day For Individuals: Create your idea! Reservation of Machines for hourly rate (75€ per hour) open day - Thursday from 10 am to 5:30 pm		1		1			1			Custom made Programm with the Services Staff. Every user must document their work with his own project page (http://fablab.waag.org/projects) also on open days.
FabLab München	Fablab		1			http://www.fablab-muenchen.de/		1		1	1	1	1	1	1														1		1	1	125	1					Individual Membership: 28€ per month and 100€ once Students, Unemloyed,...18€ per month and 50€ once Family Membership 36€ per month and 150€ once	200	1	1			1		1	28,00	
FabLab Leoben	Fablab		1			http://www.fablab-leoben.at/			1	1	?	1	1	?								1							1		?							1	Open to the general public, 2 times a week. For groups (Schools etc.) seperate dates. Students: 10€ per month (for 3 month) Standard 20€ per month (for 6 month) Large Project: 18 € per month for 1 year		1	1			1				Workshops for schools Product Design courses for students/scholls with industrial partners
Machines Room, London	FabLab		1			http://machinesroom.org/		1		1	1	1		1															1		1	1						1	- Visit: free every Saturday - Basic: 7€ per month free sat - Day Pass: 35€ for 1 day access to the machines and the coworking space - Desk Pass: 70 € per month, just co-working - no access to the machines - Member: 140 € (apply to become a member) full access during opening hours - Start-Up: Deskspace, Machine Use, Business Address for 280 €		1	1			1	1			- Not hosted by the staff, Machines Room just provides the space for external workshops and events.
Fablab London	FabLab		1			http://fablablondon.org/	1			1	1	1	1	1									1						1		1		4.000		1				- Member: 50 € per month, 40 % on any machine rates, but no "full access" - businesses, schools --> special memberships		1	1				1			- Hosting external Workshops, event space for hire - Dducation workshops
Fablab TU Graz	Fablab		1			fablab.tugraz.at			1	1	1	1	1	1	1													1	1				40	1							1			1					- Product Innovation Project
FabLab Manchester	FabLab		1			http://manchesterfablab.manufacturinginstitute.co.uk/		1		1	1	1		1	1														1		1	1						1	Open days: Friday and Saturday Services: 3D-Printing, Prototyping (Exclusive time at the FabLab - no IP rights issues), Events, Teambuilding	1800	1		1			1			e.g. Young Fab Academy, How do I...? (basic courses...)
Chaosdorf, Düsseldorf	Hackerspace	1				https://chaosdorf.de/		1		1	1				1														1				180	1					Own Key, Membership for 20 € Step by Step application	80	1	1					1	20,00	- Coding 101 - Phyton - ...
Tecnologia Incognita, Amsterdam	Hackerspace	1				http://technologia-incognita.nl/		1		1	1	1		1	1	1	1	1				1							1		1		150	1					24/7 Access Recommended Membership Fee: 25€ per month Minimum Amount: 5 € per month (social aspect)	100	1	1			1		1	25,00	- Sewing - Open Hackerspace Day - Tooool Meeting
Makerspace, Cambridge	Hackerspace	1				http://makespace.org/		1		1	1	1		1	1	1	1	1					1						1		1		4000 (370)		1				Two different work areas (one only for members) - Membership Fee: 55€ per month for 24/7 Access	100	1	1					1	55,00	- Rasperry Pi - Things that fly - Family Makers - Open HackNight
London Hackerspace	Hackerspace	1				https://london.hackspace.org.uk		1		1	1	1	1	1	1	1	1	1				1	1	1					1		1	1	6500 (600)			1			Membership Fee: 20€ per month for 24/7 Access for Students etc: 7€ per month	1000	1	1			1		1	20,00	- Different Groups and Group Meetings - Open Evenings - Darkroom - BioHacking
µc3, Munich	Hackerspace	1				http://muc.ccc.de/		1		1	1				1							1							1		1		>90	1					Membership (24/7): 20€ per month	130	1	1					1	20,00	- Open Night - Hackfriday - Cryptoparty
Sublab, Leipzig	Hackerspace	1				http://www.sublab.org/		1																					1				220	1					Reguolar Members: 23 € per month Students, Unemployed etc.:12 € per month	42	1	1			1		1	23,00	- CryptoCON 2015 (Event)

							Hosting Facility			"FABLAB"				Wood							
Name	Type of Makerspace	Hackerspace	Fablab	Makerspace	Other	Internetadresse	None / Private	Community Project / "Non-Profit" Organisations	University / College / Public Instituition	3D - Printer	Laser Cutter	Vinyl Cutter	3D-Scanner	CNC	Drill Press	Table Saw	Band Saw	Sander	Planer	Wood Lathe	Jointer
Hackerspace Bremen	Hackerspace	1				https://www.hackerspace-bremen.de/		1		1	1		1	1	1						
c-base Berlin	Hackerspace	1				http://c-base.de/		1		1		1			1	1					
Metalab, Vienna	Hackerspace	1				https://metalab.at		1		1	1	1	1	1	1						
Realraum Graz	Hackerspace	1				http://realraum.at		1		1	1				1		1				
Shackspace, Stuttgart	Hackerspace	1				http://shackspace.de/		1		1	1	1	1	1	1						
Fablab Padova	FabLab		1			http://fablabpadova.it/		1		1	1	1		1							
IT-Syndikat, Innsbruck	Hackerspace	1				http://it-syndikat.org/		1		1	1	1	1								
MakerAustria, Vienna	Hackerspace/FabLab		1			http://www.makeraustria.at/		1		1					1	1					
TiS Bozen	Fablab		1			http://tis.bz.it/de/zentren/produkt entw-neue-technologien/tis-fablab		1		1	1	1		1	1	1					
USINE	Makerspace			1		http://usine.io	1			1	1	1	1	1	1	1	1	1	1	1	1
Fablab Nuernberg	Fablab		1			http://www.fablab-nuernberg.de/		1		1	1	1		1							

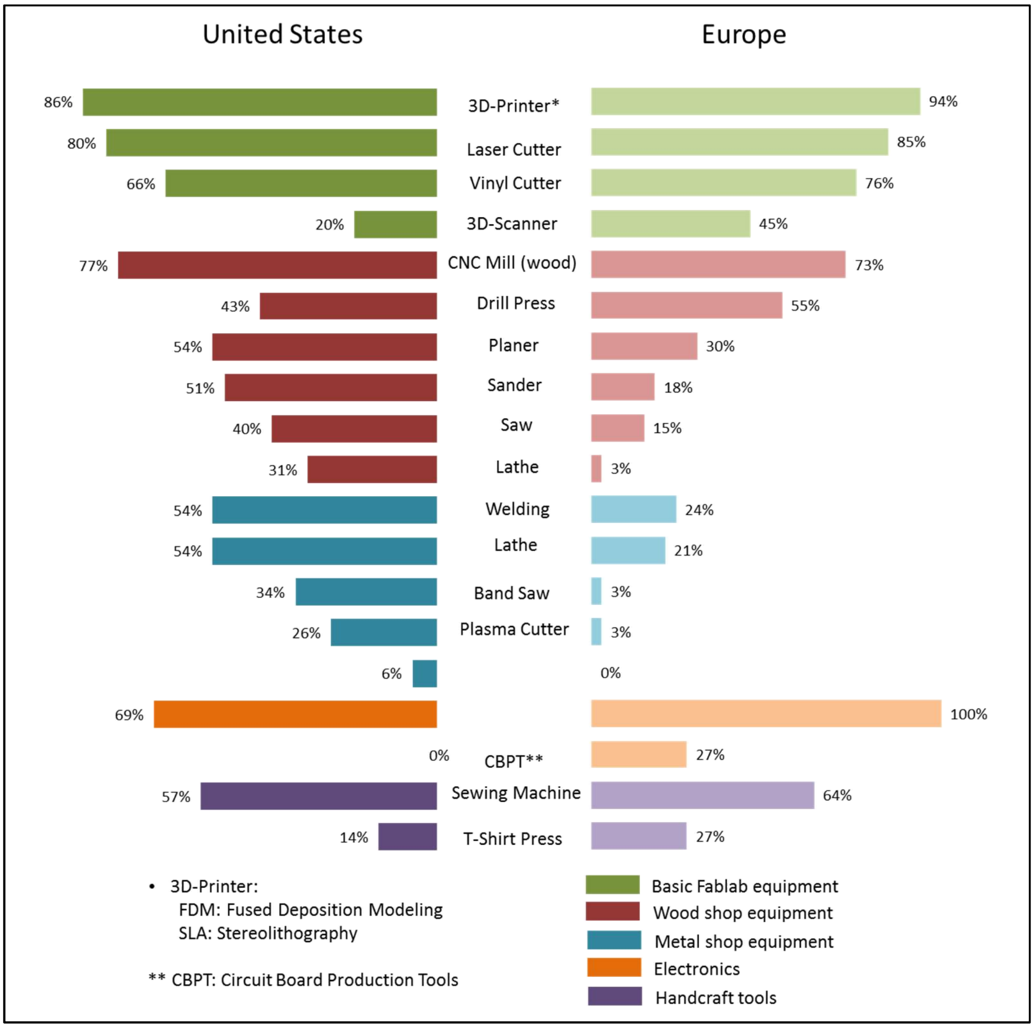
	Metal							Electronics		Handcraft							
Name	Welding	Lathe	Band Saw	Plasma Cutter	Blacksmithing	CNC	Sandblasting	Soldering	Printed Circuit Board Production Tools	Sewing Machine	Heat Press	Größe [Sqft]	0-250m²	250 - 500 m²	500 - 1000m²	>1.000 m²	no details provided
Hackerspace Bremen								1	1	1		80	1				
c-base Berlin								1	1	1	1	700			1		
Metalab, Vienna	1	1						1	1	1		230	1				
Realraum Graz								1	1			81	1				
Shackspace, Stuttgart	1							1	1	1		430		1			
Fablab Padova								1	1			700			1		
IT-Syndikat, Innsbruck								1		1		30	1				
MakerAustria, Vienna								1		1		730			1		
TiS Bozen								1				40	1				
USINE	1	1		1		0	1	1	1	1	1	1500				1	
Fablab Nuernberg		1						1		1		250		1			

	Membership			Access Types							Workshops / Classes
Name	Membership	Registered Members	Open to general public	Membership fee	Open Access	Specific User Group	Membership differentation	Corporate Membership/Start-Ups	24 / 7	Minimum Fee for "24/7" [$/month]	Workshops / Classes
Hackerspace Bremen	Membership Fee for 24/7 access - recommended: 20 €	42	1	1					1	20,00	- Data science lab - 3D-Drucker im Eigenbau - Arduino für Einsteiger - ...
c-base Berlin	Membership: 17€ per month Higher Rates are accepted. ("Fördermitglieder")	550	1	1			1		1	17,00	Groups and Workshops with internal Staff - 3d - Stammtisch - Waveloeten (Antennenbau) - ... Seminares with external organisations
Metalab, Vienna	Membership Fee: 20€ per month (24/7 access)	180	1	1					1	20,00	- Elektronikkurs - Software Workshop - Schlosserpraxis
Realraum Graz	24/7 Access - 25€ per month (Regular) 24/7 Access - 15€ per month (Reduced)	50	1	1			1		1	25,00	- Speech, e.g. Noah Most (Intern. Biohackerspace), - Workshops
Shackspace, Stuttgart	24/7 Access: Reduced: 8€ per month Regular: 20 € per month	250	1	1			1		1	20,00	- Events, e.g. Hardware Startup Meetup (Networking event) - Workshops e.g. CyberPunks - Verschlüsselung, Datenschutz - Speeches, e.g. Communication systems of satelites
Fablab Padova	Booking system for different Machines Membership necessary		1								Arduino start class CNC Start class ...
IT-Syndikat, Innsbruck	Regular 20 € per month Reduced: 5€ per month			1			1				
MakerAustria, Vienna	Pay as much as you can - only certain opening hours		1	1							Alles Holz mit Tischler Karl Arduino Basics ...
TiS Bozen	Free Access during opening hours (Mon-Fri: 09:00 - 18:00)		1		1						
USINE	class 1: Access to the Atelier for 12 months (100€ / month) for 6 month (120€ / month) for 3 months (140 € / month) Class2: Access to Experts (no information) Class3... Class4: Priority Access (no information) Extra Rates for Co-Working and combination packages Extra Rate for Businesses with existing longer than 3 years			1			1	1			- Technical Sessions (Manufactoring skills) - Masterclasses (Product Development, Intelectual Property) - Meetups: TechTonics, practical events
Fablab Nuernberg	Full Membership 50€ per year, on open days "offene Werkstätte" no Membership necessary.	25	1	1							- KidsLab - Evosoft Lab - Workshop "Dokumentation im Fablab" - ...

A.2 Results Internet Search



Hosting Facilities of Makerspaces [in %]



Available tools at Makerspaces in the US and Europe [in %]

A.3 Questionnaire - Similar Institutions

TU Graz | iBL

How to Make (Almost) Anything?

Date/Place: **Contact:**

Facts and Figures:

Active Members:
Size of Makerspace:
Available Equipment:

:

Utilization

Target Groups of Makerspace?

Hobby I Students I Startups I Enterprises I Schools

…actual user group?

Is there already a community and what are difficulties regarding maintenance and development of an active community?

Experiences in collaboration with large-scale enterprises – “Open Innovation”, “User Innovation”

.

How is the access to the lab regulated? Membership fees, opening hours,…?

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Prof. Christian Ramsauer

TU Graz

iBL

How to make almost anything?

Who is allowed to use the machines? How is the access and usage controlled?

What machines are used most often? Bottlenecks…

What materials are most commonly used (Plexiglas, wood, metal ...)?

Problems with occupancy time of the machine (e.g. time pressure)
(Is there a booking-system ?)

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How to make almost anything?

Workshops
What Workshops are offered?

- Who holds these workshops

- Costs

- Experiences

Other:
Core Competences?

How does the cooperation work with members, sponsors, partners, ...?

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TU Graz

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How to make almost anything?

Partners - companies, public. Institutions - organizational form (Gesmbh, club ...)

Outlook

Estimation of further potential growth, interest:

...new facilities

Future Development, machinery trends?

Institut für Industriebetriebslehre und Innovationsforschung
Prof. Christian Ramsauer
christian.ramsauer@tugraz.at

FABLab Manager

DI Matthias Friessnig
matthias.friessnig@tugraz.at

Contact:
Hugo Karre, BSc
hugo.karre@student.tugraz.at

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A.4 Questionnaire - Mini Maker Faire Trieste

TU Graz | FAB|Lab Graz, Austria

FAB|Lab @ Graz University of Technology - Survey

10.05.2015 / Trieste, MiniMakerfaire

Contact: ____________________

____

Product/ Project ____________________

Makerspace/ Fablab ____________________

Most desired tools / equipment

FabLab Tools	Yes	No
3D-Printer	■	■
3D-Scanner	■	■
Lasercutter	■	■
Vinylcutter	■	■

Metal Workshop	Yes	No
Lathe	■	■
Metal Cutting	■	■
Welding	■	■
Sand Blasting Cabinet	■	■

Wood Workshop	Yes	No
CNC/Milling Machine	■	■
Drill Press	■	■
Planer	■	■
Sander	■	■
Saw	■	■

Electronics	Yes	No
Soldering	■	■
Circuit Board Production Tools	■	■

Handcraft	Yes	No
Sewing Machine	■	■
T-Shirt Press	■	■

Other: ____

____

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Hugo Karre, BSc

FAB|Lab @ Graz University of Technology - Survey

In which of the following categories did a makerspace help you with your project the most? (2 categories max.)

access to production facilities	knowledge transfer	community/ network	financial support	finding product idea
☐	☐	☐	☐	☐

What topics of workshops at makerspaces would be interesting for you?

Topic	Not interested					Very interested
Tools & Equipment		1	2	3	4	5
Rapid Prototyping		1	2	3	4	5
Product Development		1	2	3	4	5
Entrepreneurship		1	2	3	4	5

Other:____

How interested are you in an „exclusive time-slot“ to work on your project at a makerspace?

Not interested 1 2 3 4 5 Very interested

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A.5 Exhibitors interviewed at Mini Maker Faire Trieste

Contact	Project / Idea	Web	Start-Up / Concrete Project Idea	Education / Science Project	Private	Platform
Markus Manninger	Private Use / "Acryl Rohr"				1	
Giuseppe De Lorenzo	Stillaqua: Contatore a tempo per doccia con chiave RFID	www.homoandroidus.com/stillaquae	1			
Roberta CAPITANIO	Colletta: Ride bene chi riusa ultimo		1			
Annamaria LISOTTI	Matters of matter: Light interacting materials	www.mattersofmatter.eu		1		
Carlo CAMPANA	3dprintersurgery	www.3dprintersurgery.com	1			
Marco RIGONI	O.N.O.S. - Open Network Object System	www.elettronicaopensource.com	1			
Andrea GORELLI	Shrimp Rover Sarrocchi a spasso per Marte	www.youtube.com/watch?v=JAHuS7Yq3os		1		
Livio TENZE	Braccio robotico controllato da Leap Motion	www.esteco.com	1			
Thomas Axel DEPONTE	FreaKontrol	www.freakontrol.com	1			
Alberto MONICO	Full 3D Scanner: Scanner 3D a 5 funzioni				1	
Mauro OLIVIERI	Comunicare con il laser ed altri esperimenti da radioamatori	trieste.cisar.it				1

Riccardo ERTOLUPI	Vicenza Thunders	www.vicenzathunders.com	**1**			
Fabrizio MESIANO	fél.Fil	felfil.collettivococomeri.com	**1**			
Fabio SANTAROSSA	Todomodo	www.todomodo.me	**1**			
Matteo MARINO	Safe Walk: Bastone per ciechi o ipovedenti	www.matteomarino.it/safewalk	**1**			
Ludovico Orlando RUSSO	PARLOMA	www.parloma.com	**1**			
Michele MARIS	Guglielmino: Telerilevamento da Pico-satellite			**1**		
Vojislav MILIVOJEVIC	Oktopod Studio	www.oktopodstudio.com		**1**		
Giampiero BAGGIANI	Iono	www.iono.cc	**1**			
Alessandro CIANO	BoraMeters				**1**	
Valerio CAMPARI	OpenBuildsItalia	www.openbuildsitalia.com	**1**			
Tiziano ANNULLI	DQuid: platform for the co-creation of connected products and digital content	www.dquid.com	**1**			
Boris ZALOKAR	PoBlocks, PoScope Mega1+	www.poscope.com	**1**			
Giacomo LAVERMICOCCA	Termostato Home Made	github.com/glavermicocca/Termostato	**1**			

Exhibitors - Mini Maker Faire Trieste

A.6 Questionnaire - Market needs, Enterprises"

TU Graz

FAB|Lab
Graz, Austria

FAB I Lab @ Graz University of Technology - Interview

Date/Place:

Contact:
Department:

Company: Employees:
Revenue:
Industrial sector:

1. Makerspaces

1.1 Was the existence of publicly accessible Makerspaces with a focus on digital production present to you?

If so, wherefrom and could you name specific facilities?

1.2 How would you rate Makerspaces as external information, knowledge and technology resources for your business?

Strengths	Weaknesses
Chances	Risks

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FAB|Lab @ Graz University of Technology - Interview

1.3 How would you rate opportunities that a Makerspace provides for your business?

Please describe briefly the potentials!

Interdisciplinarity ______________________________

Access to innovative production technologies ______________________________

Know-how transfer ______________________________

Community/Network ______________________________

Skill enhancement ______________________________

Other ______________________________

1.4 At what stages of the innovation process by Thom would you see the possibilities offered by a Makerspace, as particularly helpful?
(Please select the appropriate phase(s)!)

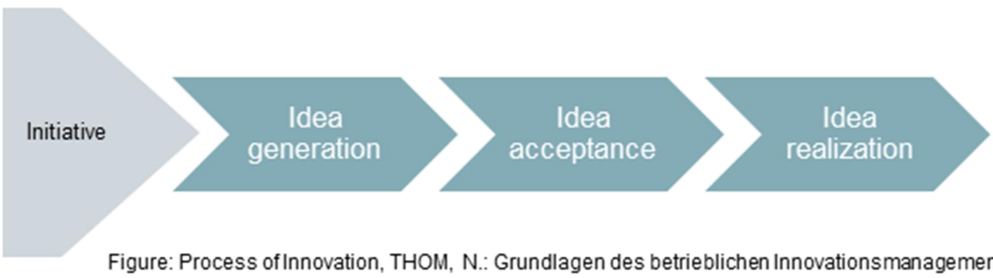

Figure: Process of Innovation, THOM, N.: Grundlagen des betrieblichen Innovationsmanagements

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FAB|Lab Graz, Austria

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2. Technology

2.1. Does your company offer an internal workshop which is specially equipped for (Rapid) Prototyping? If so, who can use this facility?

2.2 Are digital production technologies in use or are specified technologies in the near future of special interest?

3D – Printer	Use case_______________________________
Selective Laser Sintering	Use case _______________________________
Laser Cutter	Use case _______________________________
CNC Mill	Use case _______________________________
CNC Lathe	Use case _______________________________
3D-Scanner	Use case _______________________________
Other	Use case
_________________	____
_________________	____

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2.3 In what business sectors will these digital production technologies have an impact in the future?

Product Development	Impact_____________________________
Production	Impact_____________________________
Logistic	Impact_____________________________
Business model	Impact_____________________________
Other	Impact
_______________	______________________________________
_______________	______________________________________
_______________	______________________________________

3. Innovation

3.1 How would you describe the innovation management of your company?

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FAB I Lab @ Graz University of Technology - Interview

3.2 How are product innovations of employees implemented and rewarded at your company?

3.3 Are the principles of open innovation, as the integration of external knowledge into the innovation process and the dissemination of internal knowledge to project partners, in your company applied?

If so, you can cite specific open innovation projects?

FAB|Lab @ Graz University of Technology - Interview

3.4 Do you think that a design prototype can easer overcome internal obstacles to innovation?

4. Fab Lab TU Graz

4.1 Do you know the possibilities offered by the Fab Lab at the TU Graz?

4.1 Do you see possibilities of synergies between the Fab Lab at Graz University of Technology and your business?

If so, which?

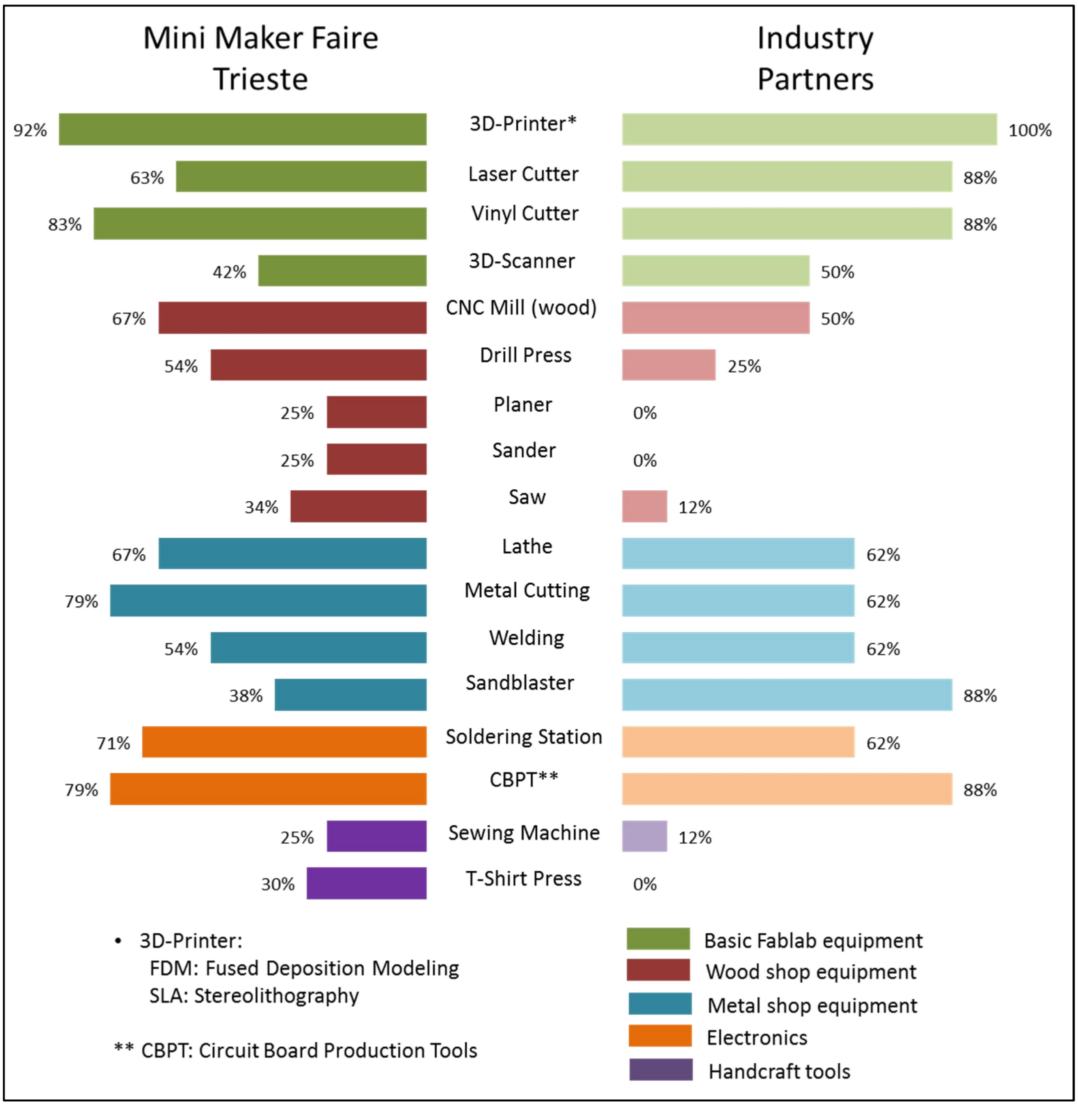
FAB|Lab @ Graz University of Technology - Interview

4.2 In case of cooperation, would a "Relationship Management" (organization of joint events, developments, etc.) by the Fab Lab be useful?

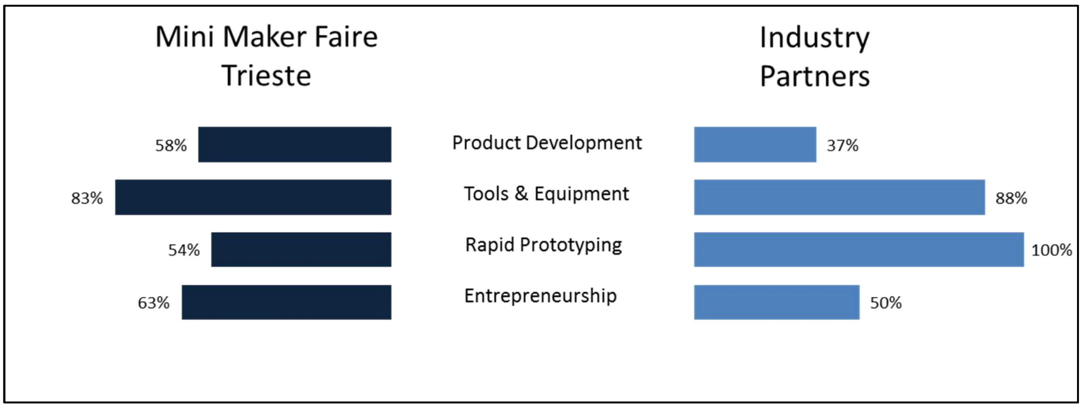
4.3What priorities for the planned enlargement should be in the focus of the Graz University of Technology

Thank you for your efforts and your help!

A.7 Results Market Needs



Market Needs: desired equipment [in %]



Market Needs: interests for different workshop topics]in %]

A.8 Feasibility RC-Car

TU Graz | **Project RC-Car**
Construction Plan | iBL

This project is based on the instructions and work of instructionals.com member "tolik777".

Link: *http://www.instructables.com/id/Simple-RC-car-for-beginners-Android-control-over-/*

1.) Components

2.) DIY Car Chassis

3.) Electronics – Wiring

4.) Arduino Software Application

5.) Android Device
Apps: "Cxem Car 1.X"
"ArduDroid"

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TU Graz | **Project RC-Car**
Components | iBL

Controller (MCU): (10,90 €)
Arduino compatible controler
(http://www.amazon.de/dp/B00OEIMCIW/ref=sr_ph?ie=UTF8&qid=1443433317&sr=1&keywords=arduino+uno)

Bluetooth module: (7,99 €)
Serial HC-06
(http://www.amazon.de/Arduino-Drahtlose-Bluetooth-Transceiver-Serial/dp/B00IY7K41G/ref=sr_1_2?s=ce-de&ie=UTF8&qid=1443433527&sr=1-2&keywords=hc+06)

Motor Driver: (7,05 €)
L298N Dual Bridge DC stepper Motor Driver module
(http://www.amazon.de/Bridge-Stepper-Driver-Controller-Arduino/dp/B00M55TXRY/ref=sr_1_2?s=ce-de&ie=UTF8&qid=1443433638&sr=1-2&keywords=motor+driver)

DC Motor: *(14,99 €)*
2x Gear Motor 400 u/min
(https://www.conrad.at/de/g50-mikrogetriebe-mit-metallzahnraeder-150-498903.html)

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Project RC-Car
Components

Other:

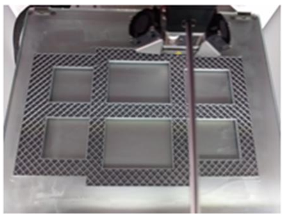
Wires
(http://www.amazon.de/Aukru-female-female-male-female-Steckbr%C3%BCcken-Drahtbr%C3%BCcken/dp/B00PXBVRZS/ref=sr_1_4?s=ce-de&ie=UTF8&qid=1443433821&sr=1-4&keywords=arduino+kabel)

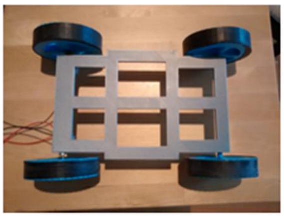
Batteries: 4x AA Battery
1x 9V Block Battery

Self-designed car chassis

Android device (App: Cxem CAR 1.X)

Project RC-Car
3D-Printed Parts





Main frame: Designed with Inventor, a simple frame as base for the electronic parts, the DC engines and the front axle.

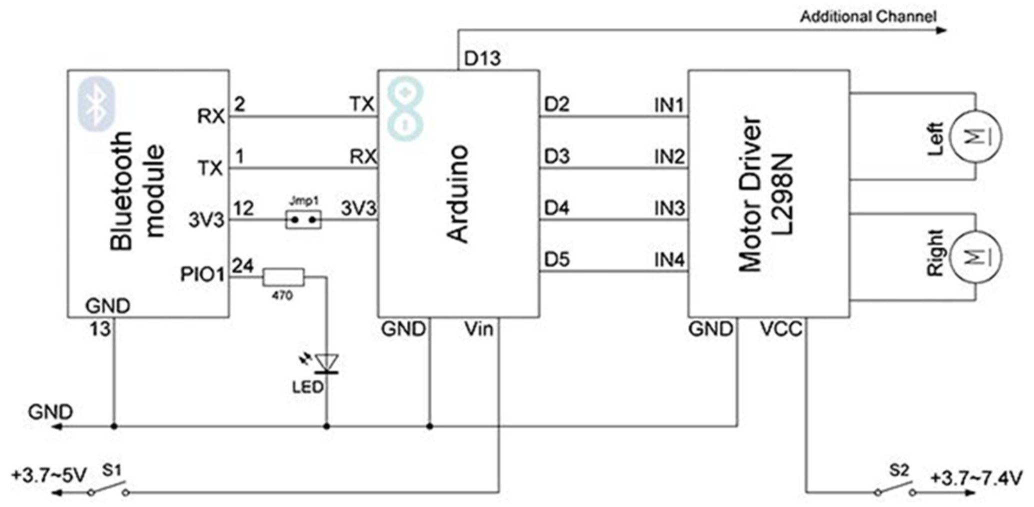
Tires: Designed with Inventor, 2 front and 2 back tires with the according form closure for the motors in the back and the front axle.

Front axle: Designed with Inventor, form closure for front tires.

Battery holder: 3D-files: *http://www.thingiverse.com/thing:331394*

Project RC-Car
Electronics - Wiring

Electronics:



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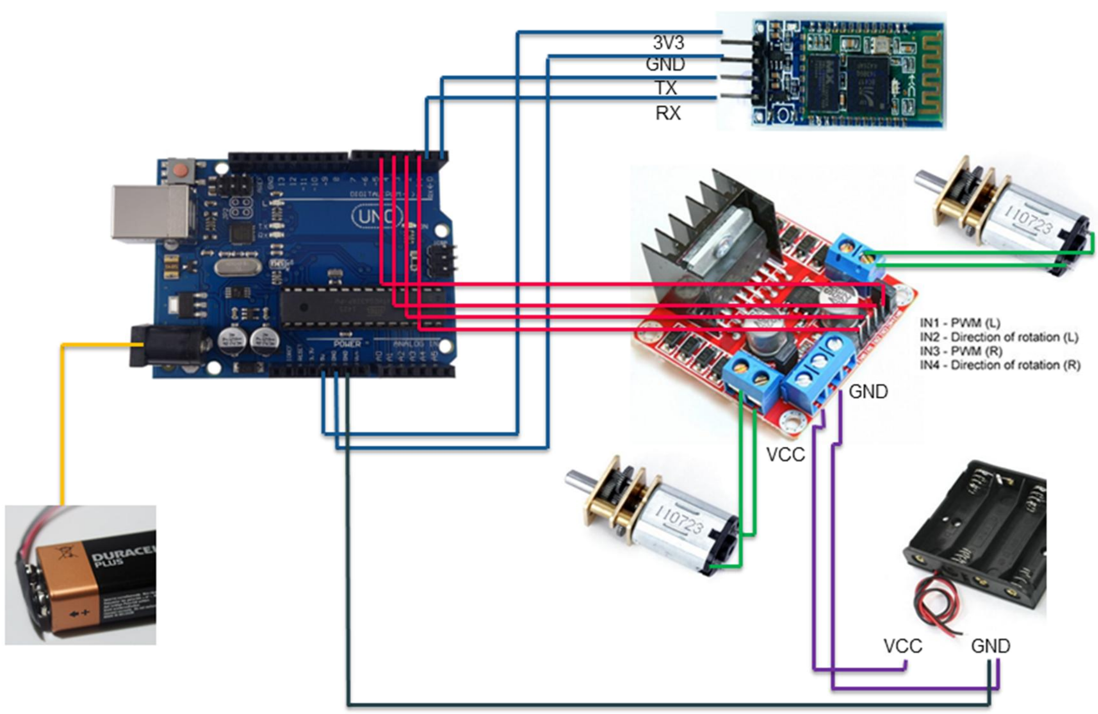
Project RC-Car
Electronics - Wiring



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TU Graz

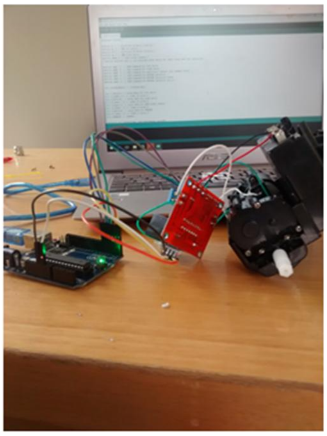
Project RC-Car
Arduino Software Application

iBL

Arduino Software: *https://www.arduino.cc/en/Main/software*

Software: *http://www.instructables.com/id/Simple-RC-car-for-beginners-Android-control-over-/step10/Software/*

1. Connect the Arduino with a PC
2. Open the Arduino Software
3. Insert from the link above the code and upload it to the Arduino



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TU Graz

Project RC-Car
Android Device

iBL

Download Link: http://solderer.tv/wp-content/uploads/2013/04/BL_4WD_1_3.apk

Identifying MAC address of the Bluetooth module: App: “ArduDroid” – Google Playstore

After identifying the MAC address of the Bluetooth module with the App “ArduDroid” insert the MAC address at:

App: Cxem CAR – Settings – MAC address.

With this few steps you are able to control your RC-Car with an Android-Smartphone.

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