# The role of academic Makerspaces in product creation

## Matching between hardware entrepreneur's requests and Maker Movement elements on offer

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### INTRODUCTION

A great number of public and academic Makerspaces have been established in the past decade. In 2017, over 1,400 Makerspaces [1] are in existence worldwide. The widespread access to capabilities for designing, manufacturing and distributing in these locations enables individuals (so-called Makers) to invent and build hardware products themselves. As a result Makers can bring their ideas from zero to market maturity. Gershenfeld (initiator of the 1st FabLab) stated that while personal fabrication was long perceived as a science-fiction, with today's digital manufacturing machines any individual can now make anything, anywhere [2].

Despite this development, no clear picture of the players in the Maker Movement ecosystem exists as yet. Various players such as MakerFairs, Instructables, TechShop or Etsy, support individuals in realizing their projects and new players are evolving daily. To clarify the view of the ecosystem this research introduces Maker Movement elements. A Maker Movement element is a collective term for comparable players such as companies, non-profit organizations or platforms, which fulfil similar roles within the Maker Movement ecosystem. Several Maker Movement elements can be categorized in subsystems. On this basis a Makerspaces is a physical location with the purpose of offering a decent amount of Maker Movement elements to individuals.

Also little knowledge on the requests hardware entrepreneurs in the Maker Movement ecosystem are making is available yet. Entrepreneurs have identified a new opportunity and are pursuing that opportunity regardless of the resources they currently have available [3]. Based on this, a hardware entrepreneur is an individual starting her or his business based on a physical product and using certain Maker Movement elements to create the product, for example the company E2T - an Internet of Things-based device plus a Smartphone application for controlling.

The aim of this paper is to identify, describe and structure Maker Movement elements. Furthermore, hardware entrepreneurs are questioned about their knowledge and usage of certain Maker Movement elements to clarify the concrete needs of Maker Movement elements that are offered within the ecosystem.

This research paper is structured in three main segments: The first describes the scientific approach for identification and classification of Maker Movement elements. The second lays down all the information gathered, which is then synthesized to Maker Movement elements and subsystems. The third gives insights into the usage made of Maker Movement elements by hardware entrepreneurs.

### METHODOLOGY

The identification and classification of Maker Movement elements is based on several data sources. First, Maker Movement elements are identified based on a literature review (e.g. scientific publications) and an Internet search (e.g. company websites) with the keywords "Maker Movement", "FabLab", "Makerspace". For the desk research, a MetaCrawler is used to track down the Maker Movement related players, such as organizations, companies, platforms, etc. The desk research was conducted from March 2016 to October 2016. Second, interviews and observations of various Makerspaces in the USA, the EU and China are conducted.

Based on the data gathered, all Maker Movement elements are described, analyzed, and categorized according to similar roles and functions. The result of this step is an overview of the Maker Movement element system. Finally, hardware entrepreneurs from academic Makerspaces are questioned on their usage of specific Maker Movement elements.

### IDENTIFICATION AND CLASSIFICATION OF MAKER MOVEMENT ELEMENTS

#### *A. LITERATURE REVIEW AND INTERNET SEARCH*

Mark Hatch (founder of the company TechShop) described the Maker Movement with the following nine principles in his work 'Maker Movement Manifesto': make, share, give, learn, tool up, play, participate, support, and change [4]. These nine principles give the research a structure for various Maker Movement elements and subsystems.

Deloitte describes the Maker Movement ecosystem from the perspective of a Maker's product creation process. Hagel et al. split up the creation process into three steps: Zero to Maker, Maker to Maker and Maker to Market. Along those three steps various elements in the Maker Movement ecosystem, e.g. reinforcing partners and centralized platforms, are described. According to the authors the Maker Movement could not have had a great impact without these elements [5].

Van Holm mentions that the Maker Movement presents multiple avenues to increase access to digital fabrication tools with the potential for impacts on the quantity and nature of entrepreneurship. The costs for prototyping in particular are cut significantly due to the manufacturing facilities access provided [6].

Hlubinka et al. argue that Makerspaces grant the opportunity to speed up prototyping in addition to easier sourcing of parts and the direct distribution of physical products online [7].

Many Makers serve as active agents and movers in the international hardware entrepreneurship scene. Some Makerspaces do not house any start-ups per se, but nonetheless they participate in organizing Maker related events such as hackathons. For instance, the founder of the Makerspace Szoil in Shenzhen describes their concept as a place where people exhibit and even sell their products. Beginning with this definition it can thus be a very good entry point for starting one's own business [8].

Makerspaces also facilitate networking with potential cofounders and strategic partners. People can connect better while working and learning together, rather than when interacting in business conferences [9]. Socializing platforms for funding, learning, and accessing tools are crucial for cutting design and production costs. Additionally, finding access to a supplier and distribution network is more likely. Makerspaces often receive grants and thereby have the ability to promote a variety of hardware entrepreneurs [10]. Within such an environment entrepreneurs have the chance to be more easily noticed by potential investors. In addition, venture capitalists and investors are eager to see first-hand the status of the product creations. For example: UnternehmerTUM Makerspace is teaming up with companies such as BMW as also with private investors to support hardware entrepreneurs [11]. Makerspaces tend to be a new kind of incubator or accelerator with the inclusion of support contacts, such as lawyers and marketing groups close at hand [9].

Maycotte stated that Makerspaces have the potential to increase the likelihood of a individulas becoming a successful entrepreneur. Time and costs can be saved by means which are available in the Maker Movement ecosystem. This all starts with access to the technology for first getting the idea off the ground. Furthermore, the support and the collaboration which is given in such spaces advances the development of the product. After the initial phase the Maker community can facilitate funding for the idea and help to recruit talented employees [12].

In Makerspaces, personal support and methodical tools are offered which go far beyond basic idea creation activities. In addition, web communities facilitate access to professional crafting knowledge for everyone at any time. People from different fields are fascinated by the idea of knowledge exchange and contribute to the community. On the other hand, equipment such as 3D printers, laser cutters and milling machines provide the capability to create prototypes in a short period of time. This enables a faster visualization and conception and therefore an improvement of the continuous development process of products [13].

### *B. VISITS TO MAKERSPACES IN THE USA, EU AND CHINA*

The field research was conducted in 2016 and 2017. The following Makerspaces were visited to identify new Maker Movement elements: Artisan's Asylum (USA), CEID (USA), NYC Resistor (USA), TechShop Arlington (USA), NextFab (USA), Columbia Makerspace (USA), Miters (USA), MakerWorks (USA), MakerLodge (USA), Autodesk Build Space (USA), Aalto FabLab (Finland), Design Factory Aalto (Finland), ADD (Finland), FabLab London (United Kingdom), Machine Room London (United Kingdom), HappyLab Wien (Austria), BuildIt! (Estonia), UnternehmerTUM Makerspace (Germany), FabLab IAAC (Spain), WorldMaker Shenzhen (China), HAX (China), Design Factory Tongji (China), FabLab Shanghai (China), Hua Qiang Maker Center (China), and Intel MakerCollider (China).

Every visit consisted of a web search, a tour and an interview with the local staff. First, the Makerspace website was accessed to identify elements. During the tour throughout the space the existence of specific Maker Movement elements was checked. Finally, the local staff was questioned about what they have to offer.

### *C. DEVELOPMENT OF THE MAKER MOVEMENT ELEMENT SYSTEM*

The literature review, Internet search and field research resulted in 80 Maker Movement elements. In the field research, it was clear visible that certain Makerspaces with a specific focus also have special elements on offer.

A syntax is defined for the development of the Maker Movement element system: subsystems are characterized as functions, described by a noun and a verb; elements are nouns, which include various players of the Maker Movement ecosystem.

Maker Movement elements have been combined based on their similarity in order to develop a structured system. The gathered elements were analyzed, checked for duplicates, and finally categorized. 45 Maker Movement elements are identified based on the literature review and the Internet search. 25 visits of Makerspaces plus interviews are conducted, which lead to the identification of 35 additional elements. In total 80 Maker Movement elements are documented, which are then synthesized and categorized in 32 Maker Movement elements and nine subsystems.

## MAKER MOVEMENT ELEMENT SYSTEM

The Maker Movement elements are categorized in nine subsystems, which are described in detail in the following section:

### *A. CONNECT WITH OTHERS - PHYSICAL*

Networking can provide organizations with access to knowledge, resources, markets, or technologies. A key argument for the establishment of a network is that through repeating and enduring exchange of relationships a potential for knowledge acquisition and exchange is created. Within such networks the transfer of knowledge manifests itself through changes in knowledge or performance of the recipient. Knowledge, especially from outside can be an important stimulus for change and organizational improvement [14].

One Maker Movement element in this subsystem is *fairs/ events* like MakerFairs, CES or Hackathons. This element is especially important on the one hand to meet potential customers, and on the other to gather inspiration for new product

ideas. A different element within this category is a *Maker related facility* itself. An online database or a map of those facilities, like provide on Maker's Row or fablabs.io/labs, is helpful to increase the likelihood of collaboration occurring between Makers. Another element is *expert's table* on a specific topic such as the Internet of Things (IoT) developments. Expert's tables are promoted by the companies similar to Meetup.

### *B. CONNECT WITH OTHERS - VIRTUAL*

Technology and globalization affects every aspect of our lives, and the development of the Internet in particular gives Makers the possibility to connect worldwide. On websites like Instructables or Hackster the Maker community generates a large body of content themselves to provide a way to discover, access, and learn new skills as also to exchange information on their latest product creations. This is summarized in the element *crowd based instructions*. Permanent access to open and collaborative network of educators and members worldwide which share ideas, insights, and best practices can generated a big momentum in product development.

The element *open file repositories* like GrabCAD or Thingiverse describe a related concept. Makers share their designs with others mostly for free and everyone can download the files, develop them further and use them in their own product idea.

A different aspect of online communities can be found within the element *community order platform*. Companies like OSH Park give Makers the possibility to upload their PCB (printed circuit board) files, while other community members can agree to order the same PCB, and later a bigger batch of the PCB is ordered which leads to cost reduction for every community member.

### *C. GATHER (HARDWARE) KNOWLEDGE AND SKILLS*

In most Makerspaces, a structure and culture that fosters and facilitates knowledge sharing is established. Learning, networking and getting support is already included in the subsystems described, but knowledge gathering can also be done in a one-to-many style, covered in the element *online blog* that inspires, teaches skills, and helps to solve problems, such as Hackaday. The Fictive Hardware Guide or the MAKE magazine describe in various articles written by experts design guidelines to specific projects, summarized in the *online collection of resources* element. The element *books or printed magazine* can also provide Makers the possibility to learn new skills. The element *webinar/workshop* describes for instance detailed video tutorials for specific equipment or material offered by companies such as Formlabs.

### *D. USE OF OPEN-SOURCE*

The combination of open source software and hardware can boost product creation, because a functional prototype can be realized in a much shorter time frame. The integration of technology is made easy by prepacked kits with a standardized set of tools, and advanced kits with expansion modules. The element *open-source software framework* describes various companies and organizations, which publish code snippets or software frameworks for free. Products like Arduino or RaspberryPi are included in the *open-source hardware* element.

### *E. ACCESS TO PROTOYTPING/ FABRICATION/ MANUFACTURING FACILITIES*

Access to tools for making is an integral part of the Maker Movement itself. Makers today have easy access to industrial standard production facilities provided by e.g. Techshops, FabLabs or by Makerspaces in general. The Maker Movement elements within this category are structured along the equipment on offer: *digital prototyping machines, wood shop equipment, metal shop equipment, electronic workshop, craft machines,* and *testing equipment*. An affordable access to a *cloud computing platform* is gaining ever more importance in the product creation of hardware entrepreneurs in addition to physical tools mentioned. Another element in this category is the possibility of *renting a micro factory* for small batch size production such as the facility at FirstBuild in Kentucky.

### *F. USE OF MAKER (CAX) SOFTWARE*

Computer-aided software for designing and simulating (CAx) is much more affordable today and Makers can use this on standard computers [15]. Maker Movement elements such as free *3D design software* (SketchUp*)*, *2D design software* (Inkscape), *simulation software* (Simscale*)* and *developer tools for electronics* (Upverter, KiCAD, etc.) are included within this subsystem.

### *G. ACCESS TO INTERNATIONAL SHIPPING VENDORS*

Access to lower-cost, small-batch manufacturing, particularly in hotspots such as Shenzhen (China) has increased, which makes small batch production for hardware entrepreneur's projects more economical and viable [5].

The element *contract manufacturer for low volume* includes for instance Seeed Studio, a Shenzhen based company. Seeed Studio has specialized its offer to custom made PCBs and PCBs assembly for low volume projects at an affordable price. This gives Makers the possibility to test their product in a bigger customer group without the need for major financial backing.

Another element is *platform for distributed manufacturing* like Fictiv, 3D Hubs or Additively. On these platforms Makers instantly get on the one hand a quote for a certain part and on the other hand they can order the part made from any other desired material. These platforms do not own any production machinery themselves, but have access to a distributed network of companies willing to produce parts even for a very small batch size. Thanks to these platforms hardware entrepreneurs can either start their production without taking a big financial risk, or also move up to bigger batch sizes. This type of production can be scaled appropriately when involving more than one supplier.

Starting from a wide availability base for open-source hardware components various suppliers for these parts plus extension modules or pre-assembled sensor modules are now available. These suppliers, such as Sparkfun or Adafruit, are summarized in the element *access to electronic parts supplier*.

Getting the right raw material for products can be difficult for an individual, because in some cases the correct raw material is unknown and most raw material suppliers ship only to other business partners. The element *raw material in lowest volume (material library)* includes for example the German based

company Modular. Modular sells over 30,000 different articles and also runs material libraries in Makerspaces.

### *H. GET SEED CAPITAL FUNDING*

The Maker Movement element *crowd funding* describes platforms like Kickstarter or Indiegogo. Kickstarter is a tool for Makers to obtain feedback on their ideas, and if they share them they may be able to get financial support to produce them. In the past few years 13.2 million people supported projects with investment of over 3.17 billion USD [16].

Another element is *crowd investing*. In contrast to crowd funding crowd investing focuses on equity. Investors provide investment capital for a business and receive ownership of a small piece of that business in return for their money. Companies like Companisto collect cash investment from the crowd and dedication and, when a project is successful in these pursuits, earn a return on their initial investment.

### *I. GET IMMEDIATE CUSTOMERS FEEDBACK*

The Human-Centered Design process describes ongoing feedback, recommendations, and adaptions of product creations as essential for the success of a project [17].

The element *peer-to-peer e-commerce* includes websites such as Etsy or Shapeways. A Maker can start his or her own web shop on those websites within minutes. Then s/he receives customer feedback to terms of the quantity of articles sold and later in the form of customer reviews. In various locations the renting of a facility such as a shelf in an existing physical store to sell their own products is also popular among Makers. This is included in the element *rent a physical space.* Kaufhaus Kollective in Munich is an example for this initiative.

## USAGE OF THE MAKER MOVEMENT ELEMENT SYSTEM

The knowledge and usage of the Maker Movement element system described was checked through hardware entrepreneurs based on a multiple case study research approach in European's academic Makerspaces, which foster entrepreneurship. Hardware entrepreneurs at the Technical University of Munich, Graz University of Technology and Aalto University in Helsinki were questioned if a certain Maker Movement element is unknown, known or used in their product creations. In total 18 qualitative interviews were conducted in this step, see Figure 1.

It is clear in this context that access to tools and machines is most widely used by entrepreneurs. But the concept of renting a micro factory for the production of a first batch is a concept that is still scarcely known. Taking into account that many product problems and errors are only detected in product ramp-up phase this element can be of real importance for larger scale projects.

The open-source electronic hardware is also a well-known and much used element. Nearly every entrepreneur interviewed mentioned an open-source hardware as being used in their prototype or in final product. Free CAx software especially for product design, is also widely used, even though most interviewees stated that they do not use the free software offered over the long term because of the limited set of functions these software types provide. Free and easy to setup simulation software is scarcely known and not used by the entrepreneurs we have interviewed. Surprisingly, fairs such as MakerFairs are also little used in their work life and databases to find other Maker's facilities are mostly not known. This may be due to the fact that in Europe resources such as The Maker Map still do not include a great many entries. Not used but known are funding platforms for seed capital and peer-to-peer e-commerce website.

| | | Maker Movement Element | Unknown | Known | Used |
|---|---|---|---|---|---|
| **A.** | | **Connect with others (physical/live)** | | | |
| | A1 | Fair /event | 2 | 11 | 5 |
| | A2 | Maker related facility (database) | 12 | 2 | 4 |
| | A3 | Expert's table on xyz | 3 | 5 | 10 |
| **B.** | | **Connect with others (online/virtual)** | | | |
| | B1 | Community order platform | 12 | 2 | 4 |
| | B2 | Open files repository (CAD, norm parts, code) | 3 | 6 | 9 |
| | B3 | Crowd based instructions | 3 | 5 | 10 |
| **C.** | | **Gather (hardware) knowledge & skills** | | | |
| | C1 | Webinar / Workshop / Massive Open Online Courses (MOOCs) | 0 | 8 | 10 |
| | C2 | Online collection of resources | 3 | 5 | 10 |
| | C3 | Online blogs that inspire, teach skills, help to solve a problem | 1 | 1 | 16 |
| | C4 | Books / printed magazine | 4 | 4 | 10 |
| **D.** | | **Use of open-source** | | | |
| | D1 | Open-source software framework | 1 | 3 | 14 |
| | D2 | Open-source (electronic) hardware | 0 | 1 | 17 |
| **E.** | | **Access to protoytping/ fabrication/ manufacturing facilities** | | | |
| | E1 | Digital prototyping machine | 1 | 0 | 17 |
| | E2 | Wood shop | 2 | 6 | 10 |
| | E3 | Metal shop | 1 | 3 | 14 |
| | E4 | Electronics workshop | 2 | 5 | 11 |
| | E5 | Craft machine | 2 | 7 | 9 |
| | E6 | Testing equipment (especially for electronics) | 2 | 5 | 11 |
| | E7 | Microfactory (for assembly) | 12 | 6 | 0 |
| | E8 | Cloud computing platform | 2 | 6 | 10 |
| **F.** | | **Use of maker (CAx) software** | | | |
| | F1 | Free 2D design software | 1 | 11 | 6 |
| | F2 | Free 3D design software | 1 | 6 | 11 |
| | F3 | Free simulation software | 16 | 0 | 2 |
| | F4 | Developer tools for electronics (IoT toolkit, PCB testing, ...) | 2 | 5 | 11 |
| **G.** | | **Access to international shipping vendors** | | | |
| | G1 | Platform for distributed manufacturing | 6 | 7 | 5 |
| | G2 | Contract manufacturer for low volume | 2 | 6 | 10 |
| | G3 | Electronic parts supplier | 1 | 3 | 14 |
| | G4 | Raw material in lowest volume (material library) | 9 | 4 | 5 |
| **H.** | | **Get seed capital funding** | | | |
| | H1 | Crowd funding | 1 | 14 | 3 |
| | H2 | Crowd investment (equity crowdfunding) | 6 | 12 | 0 |
| **I.** | | **Get immediat customers feedback** | | | |
| | I1 | Peer-to-peer (P2P) e-commerce | 2 | 13 | 3 |
| | I2 | Rent a physical space | 14 | 3 | 1 |

***Fig.1 Evaluation of Maker Movement elements based on 18 interviews with hardware entrepreneurs (numbers indicate amount of nominations)***

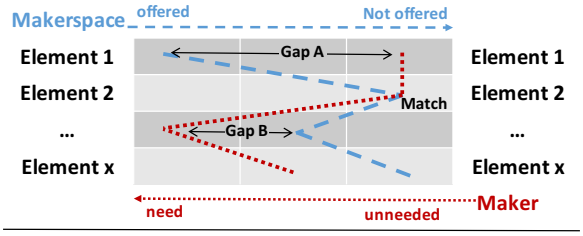
The research conducted reveals that most Maker Movement elements are covered by the identification procedure mentioned, because each hardware entrepreneur interviewed was questioned as to whether any commonly used element is missing, but no new elements arose as a result.

## DISCUSSION AND OUTLOOK

This paper aims to identify, describe and define the structure of Maker Movement elements and also product creation in hardware entrepreneurship. A multiple case study in Europe's leading academic Makerspaces is conducted to learn more

about the request of hardware entrepreneurs and the usage of certain Maker Movement elements.

Many of the identified elements play multiple roles in the product creation and in the Maker Movement ecosystem. Nevertheless, a clearly structured Maker Movement element system is a valuable help as discussed in the following.




Gap A – mismatch: Makerspace is offering a unneeded Maker Movement element
Gap B – mismatch: Makerspace is not offering a Maker Movement element which is needed by Maker
Match: Makerspace offering matches Maker need

*Fig.2 Concept of Makerspace evaluation*

First, the Maker Movement elements can be a base for a classification of Makerspaces; all 25 of the Makerspaces visited in the field research can be classified based on the elements they offer, and then certain patterns can be identified. For instance, Makerspaces have different funding strategies and focuses despite the fact that no classification is currently used; an academic Makerspace is mainly funded by a higher education institution and focuses especially on supporting entrepreneurship. In such an environment, a Makerspace includes different elements to those in a Makerspace situated in a school focusing on a K12 education. Second, based on the recognized patterns the Maker Movement element system can support initiators in setting up a new Makerspace; after defining the purpose and a focus of the space, a selection of specific Maker Movement elements can be made to match the targets. Third, the developed system can be used for Makerspace evaluation, see Figure 2; requests for particular elements can be clarified through interviews with Makerspace operators and users. Furthermore, a link between Maker needs and operator offers and services can be visualized. A Makerspace evaluation can be especially important for an academic Makerspace, because resources are limited and a good match between specific elements and hardware entrepreneurs is essential for promoting more powerful new product creations. Finally, a structured Maker Movement element system can also be used for visualization of functions offered within the Maker Movement. Hardware entrepreneurs can read through each element and if desired they can start using an element. This is vital, because the interviews conducted show that many elements are currently not known to hardware entrepreneurs but would most likely have a positive influence on their product creations.

Makerspaces enable the fruition of new ideas. Zwilling emphasizes that "The Maker Movement and start-ups were made for each other" [9]. Based on several statements by the interviewed hardware entrepreneurs time and cost in product creation can be saved through the use of several available Maker Movement elements. In addition, the quality of the final product can also be increased in some cases. In today's fast changing economy, it is vital to reduce cost and time to market for the development of new products and it is reasonable to assume that community-shared equipment, infrastructure and mutual interests offer a breeding ground for upcoming businesses. Based on these premises, first insights for new research projects will be started to assess cost, time and quality influence on the product creation resulting from the Maker Movement elements. In addition, a clarification of the match between the needs of hardware entrepreneurs and the Maker Movement elements on offer is made.

On the other hand, a continuing research project can attempt to visualize dependencies, interdependencies and interference between each Maker Movement element.

Within the past few years, several hardware businesses have emerged successfully out of the Maker Movement environment and the chance to further prompt this development is given when the right set of elements is provided within the ecosystem.

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