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Quantitative Survey and Analysis of Five Maker Spaces at Large, Research-Oriented Universities

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Abstract

Technical universities around the world are opening makerspaces on their campuses: facilities and cultures that afford unstructured student-centric environments for design, invention, and prototyping. Consequentially, there is a growing need to survey and understand emergent trends and best practices, to compare and contrast them. Towards this end, we have conducted interviews at five university maker spaces: Stanford University, Massachusetts Institute of Technology, Georgia Tech, Technical University of Berlin, and at Arizona State University. The comparison of these spaces highlights similarities and differences in the areas' foci, size, accessibility, intellectual property policies, funding and staffing of the surveyed spaces. We extracted quantitative relations between maker space size and number of current registered users, staff supervision composition and staff to user ratio. While the sample size is small, does not span the spectrum of university makerspaces, and does not address crucial cultural factors, this survey and analysis provides an initial dataset and statistics for large, research-oriented institutions and a benchmark for relevant metrics.

Introduction

In the past few years, an increasing number of universities have opened makerspaces, facilities and cultures that afford unstructured student-centric environments for design, invention, and prototyping. In a makerspace, users work side by side on different projects within an open culture of collaboration. Makerspaces are generally equipped with traditional manufacturing equipment, such as manual mills and lathes, more advanced equipment, such as CNC-mills (Computerized Numerical Control) machine tools, and emerging rapid prototyping tools such as 3D printers, along with worktables, chairs, and even couches. Similar to traditional workshops, especially larger makerspaces are divided into areas, based on the materials groups and manufacturing methods.

These spaces exist to facilitate a culture of design, invention, and prototyping. Physical prototyping is a key activity in product development and enables hands-on learning in education: Prototypes unlock cognitive association mechanisms related to visualization, prior experience, and interpersonal communication in ways that favor iterative learning between peers in the product development community.[1] For engineers, idea-generation and prototyping can be combined through hands-on activities.[2] Makerspaces empower their users to develop, build and test physical prototypes. A prototype serves as a milestone and can be used in various stages of the development process to improve communication and learning within a group or organization. It is also an important part of project-centered education and relevant for engineering education. Fisher[3] states that makerspaces "fill a variety of needs within an educational setting. Most importantly, they provide opportunities for people to learn with their hands. Hands-on learning and creation is often devalued in education and seen as meaningless play. However, play has profound educational benefits. Play aids in the development of critical thinking and problem solving skills."

While universities have traditionally focused on transferring theory in the form of teacher-centered lectures,[4] the learning sciences suggest that the more a person is engaged and the more senses are involved, the more a student will learn[5]. The danger of separating the theory from its application is that taught concepts become a mere "list of disconnected facts."[4,6] This suggests that engineering schools react by adding more to the curriculum rather than considering the overall design. "This creates a jam-packed curriculum focused on technical knowledge. Opportunities for the kind of deep learning and understanding that allows students to become, over time, sophisticated, independent learners are lost in the effort to teach everything."[4] The challenge facing engineering education today is not the coverage of technical knowledge, but teaching students deep knowledge.[7] While lectures are a key part in engineering education, there is a lack of applying the knowledge from lectures—to hands-on, project-centered, student-centered learning. Project centered education has the effect of enhancing student retention in engineering programs, motivating learning in upper division engineering science courses and enhancing performance in capstone design courses and experiences.[7]

The concept of makerspaces is not new, but the term itself has a recent origin and is linked to the maker movement.[8] The maker movement is based on the idea of building and creating things, similar to the do-it-yourself (DIY) culture. In contrast to do-it-yourself, the maker movement also has an emphasis on community and sharing. Having originally started in the USA, the maker movement is growing internationally in size and participation.[9] One possibility to provide students with problem-solving-skills are makerspaces inside the university.[10] There is often a sense of "play" involved in the building process at makerspaces.[11] One of the main challenges for introducing a makerspace into an academic setting is to avoid that the spirit of play and freedom is constrained by institutional boundaries.[11]

Several research efforts have been undertaken to survey and compare university makerspaces. Barrett *et al.*[12] describe an ongoing effort to review the state of university maker spaces found through university website searches taking into account different characteristics, both unique and common, across university maker spaces in order to create a baseline that can be used to discover and capitalize on practices being implemented with the most beneficial results. Another large-scale study by Peppler *et al.*[13] called the Maker Ed Open Portfolio Project surveyed dozens of youth-oriented (i.e., K-12) makerspaces and compared where they are situated, who they serve, and the kinds of activities in which their members regularly engage. There are a variety of catalogs of spaces[14] that does not include comparison and analyses. Most efforts that have been undertaken comparing university academic makerspaces focus on qualitative factors such as efforts by Whitmer[15] and another by Wiczynski[16] that explored comparisons of intent, value, challenges, and language as well as highlight unique attributes. Other key attributes of these spaces have been described by the Mentor Makerspace Group: funding, location, tools and machines, staff, safety and liability precautions.[17]

In this work we present a methodology and metrics for quantitative and qualitative survey of five existing makerspaces at large research-oriented universities. We present results comparing and contrasting their foci, size, accessibility, intellectual property policies, funding and staffing of the surveyed spaces. In the results and discussion, we present quantitative relations between maker space size and number of users, staff supervision composition and staff to user ratio. While the sample size is small and does not span the spectrum of university makerspaces, this survey and analysis provides an initial dataset and statistics for large, research-oriented institutions and a benchmark for relevant metrics.

Methodology

Qualitative interviews were the primary method to gather research data. The main objective was to gain insight from the experience of the directors and staff in makerspaces, as well as other researchers involved in engineering education. However, it is important to triangulate the data from interviews with data gathered through other methods.[18] Thus, results were determined, both through in-depth qualitative interviews, as well as data from other sources, such as online resources and statistics. For the five makerspaces profiled in this paper, interviews were conducted with participants and their organizers with 1-3 persons per makerspace. Interviews generally had a duration of 30-60 min.

Overview of the makerspaces

A sampling of makerspaces at five large, research-oriented universities from the USA and Germany were surveyed, as shown in Table 1. These universities, both public and private. They do not represent a comprehensive set of the spectrum of university makerspaces, but rather a sampling at some of the larger and leading institutions.

Table 1. Overview of surveyed makerspaces

Makerspace	Since	Focus	Location	Users
Product Realization Lab **Stanford University**	1891	Hands-on class projects combining design and fabrication	Palo Alto, USA	Students
Hobby Shop **Massachusetts Institute of Technology**	1937	Possibility to work on personal projects and hobbies	Boston, USA	Students, Staff
Invention Studio **Georgia Institute of Technology**	2010	Early hands-on exposure to machines of undergraduates	Atlanta, USA	Students
Prototypenwerkstatt **Technische Universität Berlin**	2013	Creation of early prototypes for potential business ideas	Berlin, Germany	Students, Alumni
Techshop **Arizona State University**	2013	Empowerment of makers - classes, machines, community	Chandler, USA	Students, Makers

These rank among the top universities for mechanical engineering worldwide, with *Stanford University*, *MIT, and Georgia Tech* consistently ranking in the top five of several university rankings, such as the *Times Higher Education World University Rankings* for engineering and technology and the *Academic Ranking of World Universities*. In brief, these spaces can be described as follows:

- *Product Realization Lab* (*PRL*) at **Stanford University** is a large and well-equipped makerspace, which is deeply integrated into the curriculum of engineering and design students in the form of project-centered classes. Students learn manufacturing and design skills in parallel by designing and building physical prototypes in a hands-on manner.
- *Hobby Shop* at **MIT** is a space with a large wood shop and some other machines for university affiliates, focusing more on personal projects and hobbies.
- **Georgia Tech**, as one of the largest technical universities in the USA, is a good example of how a makerspace can be implemented within larger communities. The *Invention Studio*[19] is a growing makerspace and culture, which is organized by the students themselves with the university in a supporting role. Undergraduate students are introduced to building activities early and build prototypes both inside of class and in personal projects.
- **TU Berlin** represents an implementation of a makerspace at a German university. The *Prototypenwerkstatt* is a relatively small makerspace, empowering entrepreneurial students and spin-offs to produce prototypes of their business ideas in a quick and affordable manner.
- **Arizona State University** is the first university to have a partnership with the makerspace company, *Techshop*. The concept is to have a makerspace in the university, which is open both to the students and the public, providing access to a large variety of machines for building physical prototypes and working in a community of "makers."

Results and Discussion

The five different makerspaces were analyzed and compared using quantitative data obtained from interviews and internal documents of the facilities. These figures highlight similarities and differences in the areas focus, size, accessibility, intellectual property policies (IP), funding and staffing of surveyed spaces. We extracted quantitative relations between maker space size and number of users, staff supervision composition, and staff to user ratio. An overview of the quantitative data is displayed in Table 2.

Table 2. Overview of the comparison of surveyed makerspaces

	Product Realization Lab	**Hobby Shop**	**Invention Studio**	**Prototypen-werkstatt**	**Techshop**
University	Stanford	MIT	Georgia Tech	TU Berlin	ASU
Age [years]	122	76	4	1	1
User numbers (current registered users able to access the space)	1,700	300	500	50	1,500
Size [m²]	Large: 1,000	Medium: 400	Medium: 300	Small: 100	Large: 1,000
Ratio [users/m²]	1.7	0.8	1.7	0.5	1.5

Total hours supervision T [h/week]	480	80	280	20	470
Ratio [users/T]	0.28	0.27	0.56	0.4	0.31
Staffing	3 Directors 16 Supervisors	1 Director 2 Supervisors	80 Student Supervisors	1 Organizer 1 Supervisor	1 Directors 16 Supervisors 20 Instructors
Open for community use [hours/week]	70	50	35	Only open with transponder	105
Open with special access [hours/week]			168	168	
Funding	1. University 2. Donations 3. Fees	1. University 2. Fees 3. Donations	1. University 2. Industry partners 3. Donations	1. University	1. Fees 2. Events 3. Industry partners
User groups	1. Students	1. Students 2. University affiliates	1. Students	1. Students 2. University affiliates	1. Students 2. University affiliates 3. Outsiders
Equipment	Advanced	Moderate	Moderate	Basic	Advanced
IP	Depends	Depends	Depends	No	No
Classes	Yes	Yes	Yes	No	Yes
Organizing events	Yes	No	Yes	No	Yes
Plans to expand	Yes	No	Yes	No	Yes

Focus

The focus of a makerspace describes which user group the facility is attracting and the purpose they are trying to achieve with this group. Three major categories were identified for the focus of the spaces:

- *Education:* the primary role of the makerspace is to form a learning platform for students, and to incorporate usage of the space into classes and the curriculum. Examples from the surveyed spaces are the **PRL** and **Invention Studio**.
- *Community:* these places feature a larger amount of personal projects on a voluntary basis, which are not related directly to university work, but rather where a community of people with the shared interest of building something can work together. Examples from the surveyed spaced are the **Hobby Shop** and **Techshop**.
- *Entrepreneurship*: spaces focused on actively recruiting founders who want to use the space

to build prototypes for their business idea. An example from the surveyed spaces is the **Prototypenwerkstatt**.

Each of the five spaces fits into one primary category, although in most cases each makerspace supports multiple categories. Both the *PRL* and *Invention Studio* have education as their main focus in common and use the space primarily for classes. The *Techshop* is also focusing on education in the form of many classes, but students in classes only take up a small percentage of total users. Main examples for the *community* category are the *Hobby Shop* and *Techshop,* and with a secondary focus the *Invention Studio*. The *Hobby Shop's* main purpose is to provide students an opportunity to work on their hobbies. *Techshop's* business model, besides its cooperation with *ASU,* includes cultivating a strong community of makers who use the space to realize their ideas. The *Invention Studio* has a large *community* aspect as well through the existence of the *Student Maker Club*. The *Prototypenwerkstatt* is the only facility focusing mainly on *entrepreneurship.* Although there are several examples of businesses being launched from the other spaces, these examples were due to the effects of *community* and empowerment of using a makerspace, but not because the spaces were focusing mainly on supporting founders.

Size

Larger facilities can reach more users and therefore have a bigger impact on the university community as a whole. The size of the spaces can be described both by area of the space and the number of users. It is strongly dependent on funding: bigger spaces require a larger staff, materials, supplies, equipment. The number of current users registered to access the space vs. size of the different makerspaces as is shown in Figure 1.

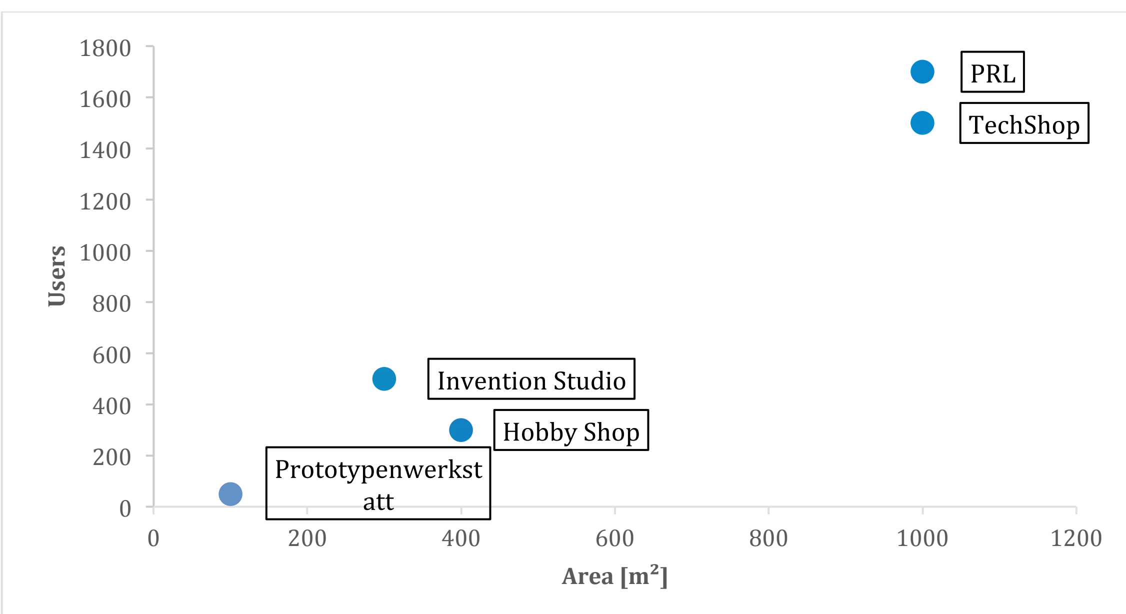

Figure 1. Current users registered to access the space vs size of surveyed makerspaces

We also computed the ratio of users per area for each surveyed makerspace. Ratios for users per square meter in the surveyed spaces range from 0.5 users/m² at the *Prototypenwerkstatt* to 1.7 users/m² at the *PRL* with one user per square meter as good estimate. This is an important value when planning a new space.

When looking at the focus of the spaces in relation to size, it becomes apparent that the *small* space *Prototypenwerkstatt,* has a niche focus on entrepreneurship as a subset of other maker activities. In the other spaces all making activities are welcome, including education and personal projects. The preliminary indication of this study is that smaller spaces with limited capacity may be optimal when focused on one specific area and user group, but our study did not systematically explore this hypothesis.

Accessibility and intellectual property (IP) policies

The accessibility of a space determines the range of people who have access to a space. The higher its accessibility, the more user groups have access to a space. Three levels of accessibility can be identified at the surveyed makerspaces:

- Basic accessibility – Students only (*PRL* and *Invention Studio*)
- Medium accessibility – Students and other university affiliates (*Hobby Shop* and *Prototypenwerkstatt*)
- High accessibility – Everyone (*Techshop*)

Limiting a makerspace only to students, as in the case of the *PRL* and *Invention Studio*, can have benefits for the educational focus of a makerspace. Since only students are using the space, the makerspace can concentrate on creating an environment that supports learning. However, allowing different user groups, such as alumni and university staff in the makerspace, appears to be more beneficial for the community aspect of makerspaces, such as the *Hobby Shop* and *Techshop*. Funding sources and liability issues with universities can influence accessibility. For example, in the case of the *Invention Studio*, funding is provided by companies that want to hire the students, and university liability policies only cover student users.

In terms of intellectual property (IP), the makerspaces are divided into universities, where the rights of inventions, created in the space, belong to the university and makerspaces, where the IP belongs to the creators:

- IP restrictions – Inventions of graduate students only are owned by the university (*PRL*)
- No IP restrictions – Inventions are owned by the creator (*Hobby Shop*, *Prototypenwerkstatt*, *Techshop, and Invention Studio*), assuming that the users are not university employees working on extramurally-funded research.

In the majority opinion of those surveyed, IP restrictions can negatively affect on the creation of innovation and entrepreneurship. Students, who are serious about commercializing their idea, may have to find a different space to work on their ideas. In the case of the *Hobby Shop* there is a non-defined area, because in theory the university might have a right to own the innovations, but due to the focus on personal ideas, this was never enforced and there is no interest in doing so. The data shows a correlation between the accessibility and the IP restriction. In the case of

Techshop and the *Prototypenwerkstatt*, many users work in the space in order to invent things and work on business ideas, hence an IP restriction would limit the users significantly. Hence, if entrepreneurship is part of the focus of a makerspace, IP restrictions should be minimized.

Funding

Funding plays another important role for the makerspace, because it is often a limiting factor for the size, staff and equipment. The source of funding also generally determines how the money is used. For example: if a source of funding was from a certain department in the university, the given department would assumingly have a large interest, that the makerspace will support the specific department by hosting classes or allowing access for research projects. Among the spaces investigated, there are five different major sources of funding: user fees, university, donations (e.g. from alumni), industry partners, events.

Apart from the small *Prototypenwerkstatt*, each space has multiple sources of funding. As a small space, which does not require as much funding as the larger spaces, a single source is enough for the *Prototypenwerkstatt*. Private donations, which usually come from university alumni, are an additional source of funding for the *PRL*, *Hobby Shop* and *Invention Studio*. *User fees* are supplementing the funding of the *PRL*, *Hobby Shop* and *Techshop*, but to a different extent – while the user fees make up a major part of the funding at *Techshop* and about 30% of the funding at the *Hobby Shop*, fees at the *PRL* only cover less than 10% of the total funds. Both, the *Invention Studio* and *Techshop*, are free for users. The users only need to cover the cost of the material they require to build their prototypes. *Invention Studio* and *Techshop* are also cooperating with industry partners for funding. In the case of the *Invention Studio*, the partners fund the Capstone Design Course[20], where they work together with the students, and *Techshop* is cooperating with several industry partners such as non-profit organizations, the city of Chandler or *AutoDesk*.

Techshop as a for-profit organization is different from the other spaces, because it is the only space not funded directly by the university, which is the major source of funding for the other makerspaces. In contrast, it is relying more on the other sources of funding, predominately member fees for memberships and classes. However, *Techshop* is funded indirectly by the university, as they are providing the rooms and infrastructure for *Techshop* and agree to purchase a certain amount of memberships for students, who are taking classes in *Techshop*.

Staffing

The models of how the spaces are staffed vary in the amount, and in the positions of the staff working at the space. This includes an estimation of the average hours spent in the space per week, based on the input of the qualitative interviews with the program directors. Other tasks, beyond this scope of this study, may include repair, outreach or facility management, such as by faculty advisors. The positions of staff working in a makerspace can be summarized by four general types:

- *Director:* The *directors* manage and organize the space, and lead the other staff members. They generally have a strong technical background and can usually be compared to a head of a workshop in their task. However, they often take on additional activities, such as teaching.

The average hours in the shop per week for *directors* are estimated to be 40 hours.

- *Supervisor: Supervisors* are trained staff, who supervise the space and help the users in the space. They had a special training and are familiar with all machines in the space. In the cases of the *PRL* and *Hobby Shop*, the *supervisors* are students, working half-time in the space. At *Techshop,* they are employees, but at *ASU* a majority of the supervisors, called "*dream consultants*", are also students working part-time. Since in most cases the supervisors work part-time, the average hours in the shop for *supervisors* per week are estimated to be 20 hours.
- *Student supervisor: Student supervisors* are *Maker Club* members at the *Invention Studio*, who are supervising the space in exchange for 24/7 access. *Student supervisors* are generally not as well trained as regular supervisors, but have the distinct advantage of working voluntarily. Since staffing is generally the most expensive part of a space, this model is essential also in financial terms to how the *Invention Studio* functions and is able to exist. The average hours in the shop for *student supervisors* per week are estimated to be three hours per week, which is the policy for club members.
- *Instructor: Instructors* are working at *Techshop* and their job is to teach classes in safety and the handling of machines for users. The average hours in the shop for *instructors* per week are estimated to be six hours.

In each of the spaces the staff working in the space consists of a combination of the different staff positions Figure 2. The average total amount of staff hours spent by the entire staff per week for each space is displayed in Figure 3.

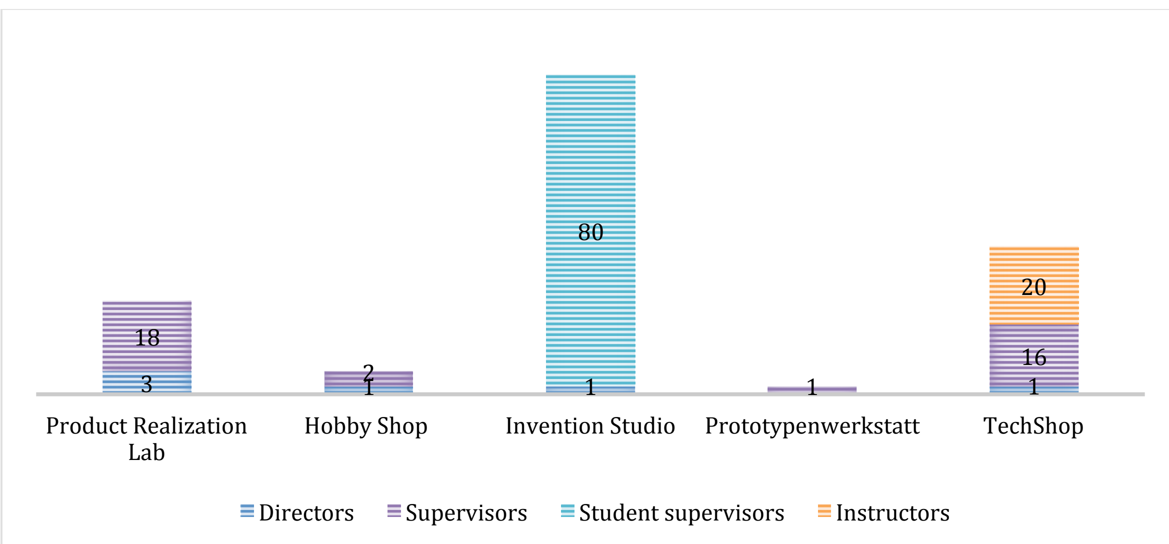

Figure 2. Number of staff members by category

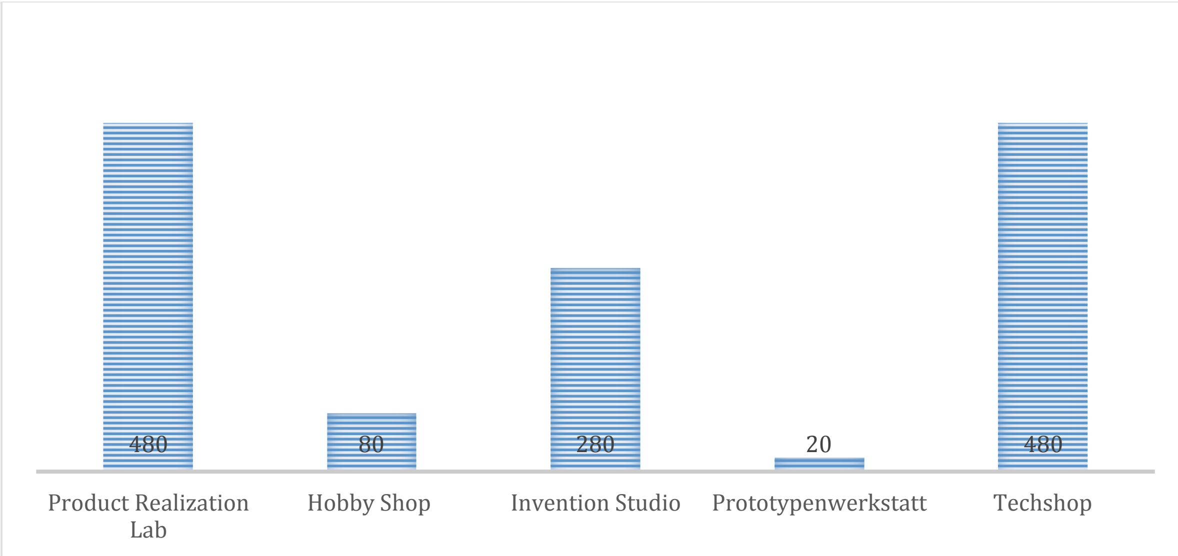

Figure 3. Estimated average total number of hours per week spent by their entire staff

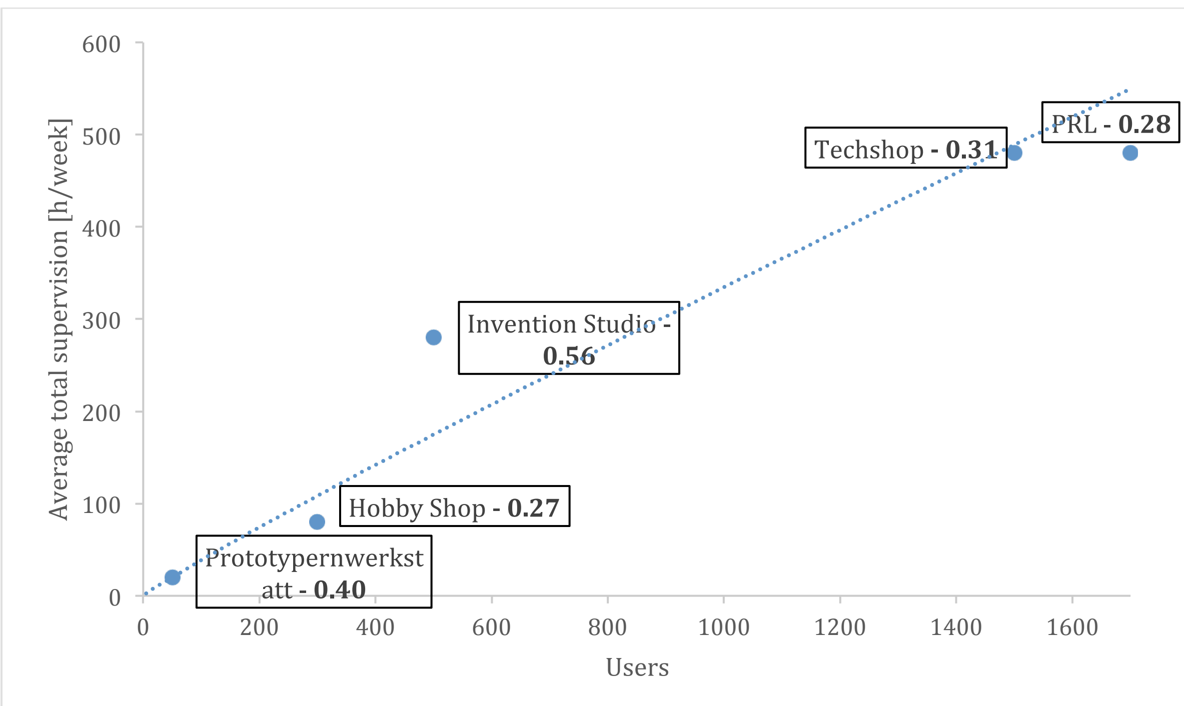

Figure 4. Staff hours of supervision (h/wk) vs. number of users currently registered to access the space, ratio of supervision hours to user indicated

Based on these results, the ratio of hours of supervision per week by the staff available per user was calculated, and the trend is demonstrated in *Figure 4*. This shows how much supervision hours the staff is investing per user in a given week.

The values range from 0.27 weekly hours per user in supervision for the *Hobby Shop* and 0.28

weekly hours per user for the *PRL* to 0.56 weekly hours per user for the *Invention Studio*, which is about twice as much. This range can serve as a benchmark for planning staffing needs for increasing facility size, or number of users currently registered to access the space, or planning a new space. One of the reasons, why the *PRL* and *Hobby Shop* are investing less hours per user, could be, because in comparison to the other examples they have been around for a long time and might be more efficient with their supervision. While the *Invention Studio* is putting in a lot of supervision hours in total, the staff consisting of student volunteers is not as well-trained and a larger staff may result in a loss of efficiency. There does not appear to be a significant correlation between the ratio of supervision per users to size of the space.

Conclusion

We surveyed five makerspaces at large, research-oriented universities—specifically their foci, size, accessibility, intellectual property policies, funding and staffing. This small sample size does not enable generalization or statistical measures across the broad spectrum of dozen or hundreds of university makerspaces, but it does introduce some figures of merit, or metrics, for the quantitative measurement of makerspaces as well as present an initial dataset for makerspaces at a few large, research-oriented institutions.

Amongst those surveyed, the focus of a makerspace has a large influence on the other factors. While larger makerspaces affect a great portion of the student population, smaller spaces appear to focus more on a specific user group, such as entrepreneurs, student clubs or hobby tinkerers. Amongst the five surveyed, makerspaces focused only on education might limit access to students, while other makerspaces open their doors to a larger group of stakeholders, such as alumni, entrepreneurs or even the general public. Most of these makerspaces have single foci,either education, community, or entrepreneurship, with some emerging models of multiple foci.

There are wide ranging successful models for the set-up among these five makerspaces, especially the accessibility, funding and staffing. Total staffing hours per makerspace range from 20/week to 480/week, or on a per use basis 0.27-0.56 hours/supervised user. Accessibility and funding vary widely and should be evaluated based on goals and environment. Space varied from 0.5-1.7 monthly users/m^2. The results further indicate, that the key aspects to implement a good makerspace is to form a great community and to encourage and support the users through classes and supervision. Having expensive equipment for high precision work seems not to be as important as motivating and empowering members of the university community to build a culture.

Makerspaces increasingly enter educational institutions and in the process are transforming university education. The implementation of makerspaces in universities is a growing trend, both in the USA and internationally. While a comprehensive review of makerspaces would be extremely valuable to the engineering education community, this limited survey and analysis of only five large, research-oriented universities provides an initial dataset and statistics for large, research-oriented institutions and a benchmark for relevant metrics.

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