MAKERSPACES IN ENGINEERING EDUCATION: A CASE STUDY

Lasse Skovgaard Jensen
PhD Student, Department of Mechanical Engineering, Technical University of Denmark
Kgs. Lyngby, Denmark

Ali Gürcan Özkil
Assistant Professor, Department of Mechanical Engineering, Technical University of Denmark
Kgs. Lyngby, Denmark

Krestine Mougaa
Project Manager, Office of Innovation & Sector services, DTU Skylab, Technical University of Denmark
Kgs. Lyngby, Denmark

ABSTRACT
The recent years have witnessed a new generation of Makers working with new ways of knowledge generation for creation and sharing of digital and physical products. While this development has started within collaborative and grass roots organised networks; educational institutions have also embraced it by opening makerspaces and adopting elements of the Maker Movement in their offerings. This paper investigates how university driven makerspaces can affect engineering design and product development education through a case study. We provide our findings based on interviews and data collected from educators, students the administrative and workshop staff of the makerspace. The findings are used to outline the challenges in incorporating the offerings of makerspaces. By discussing these challenges we identify opportunities for turning university makerspaces into innovation hubs and platforms that can support engineering design education.

INTRODUCTION
The recent years has witnessed the rise of the Maker Movement and Makerspaces, Hackerspaces and FabLabs. This new generation of Makers collaborate through loosely coupled networks and explore new ways of knowledge generation on creation and sharing of digital and physical products.

The concept of makerspaces stems from grassroots movements; they are usually community-driven, and they provide facilities and means for (mostly digital) manufacturing to individuals. Recently, a new class of ‘institutionalised’ makerspaces have also been emerging, which are established by the industry, municipalities, and educational institutions to be a part of their innovation ecosystem.

makerspaces provide alternative learning environments, and support project and problem based learning. Especially, universities offering technical programs have embraced the idea of opening makerspaces in their own facilities, to support project based courses and student innovation activities. Furthermore, there are strong correlations between the core elements of engineering design education and the offerings of makerspaces, such as rapid prototyping tools, multi-disciplinary approaches to knowledge generation and creativity.

A number of university makerspaces has opened in the past few years, with broad range of value propositions. While these places provide relevant offerings, and are being used -often indirectly- for design education, their effect on both educators and students are unknown. In this regard, this paper aims to better understand:

-Why have technical universities adapted the principle of FabLabs and Makerspaces as part of their educational offerings?
-How does the adoption of FabLabs and Makerspaces affect engineering education?
As a basis for this research we evaluate experiences from The Technical University of Denmark (DTU) makerspace – DTU Skylab, which is a 1550 m2 facility that offers prototyping workshops, office space and an auditorium. DTU Skylab is conceived as an asset in applying entrepreneurship and innovation education, which also shares relations to the paradigm of Conceive-Design-Implement-Operate (CDIO) [1] inspired teaching didactics. Our study cover perspectives and data collected from teachers, students and also the administrative and workshop staff.

The rest of the paper is organized as follows. In the next section, we provide an overview of the maker movement, makerspaces and how universities have adopted these concepts. In the following section, we present our methodology and the data that constitutes the basis for our findings. Next, we present these findings and discuss the how the offerings of a makerspace can be integrated in education. We find that the new and innovative teaching didactics supported by makerspaces can significantly benefit the students, but they also possess challenges to the involved actors. Finally, we conclude the paper by underlining that makerspace-oriented offerings can contribute to engineering curriculum e.g. by elevating the practical skillsets of future engineers.

THE MAKER MOVEMENT, MAKERSPACES AND UNIVERSITIES

Through the past few decades the western world has witnessed two digital revolutions; first with personal computers and then with the Internet. Currently, we are witnessing the next digital revolution, which disrupts the traditional means for manufacturing of physical goods. This movement have been coined ‘The Maker Movement’ [2], and it is characterized by the use of distributed networks of digital manufacturing tools, digital-first design mind-set, and the web model of sharing. Unlike the DIY culture, which has existed and also reshaped itself multiple times in the last 50 years, the Maker Movement appeal to ‘digital-born’ citizens, and it brings the Web’s culture of collaboration to the process of making physical things [3].

The physical manifestations of the Maker Movement play a central role in knowledge sharing, and they are known as FabLabs [4], Hackerspaces [5] and Makerspaces [6]. Digital design and manufacturing tools – such as desktop 3d printers and laser cutters – are important assets in these places, and they are commonly used to produce physical things, which can be shared digitally with the other makers through local and online maker communities [7].

What is a Makerspace?

The term Makerspace is often used synonymously with FabLabs and Hackerspaces [8] [6]. FabLabs are generally focused on digital fabrication and specifically equipped with tools for that. The concept of FabLabs are defined by MIT’s Center for Bits and Atoms and described in detail in the ‘The FabLab charter’ [9]. Hackerspaces share characteristics with FabLabs but are oriented towards computers and technology, and are particularly attractive to makers focused on the digital domain. [8]. Based on his study of fabLabs, hackerspaces and various open peer production platforms, Moilanen defines the following characteristics of hackerspaces [5]:

1. It is owned and run by its members in a spirit of equality.
2. It is not for profit and open to the outside world.
3. People share tools, equipment and ideas without discrimination.
4. It has a strong emphasis on technology and invention.
5. It has a shared space (or is in the process of acquiring a space) as a centre of the community.
6. It has a strong spirit of invention and science, based on trial, error and freely sharing information.
We find that Hackerspaces are generally more loosely defined than FabLabs, and often they are more independent. Despite vague terminology, both FabLabs and Hackerspaces can be encapsulated in the term Makerspace, which is less regulated compared to FabLabs, and do not carry the negative connotations of the term hacker [10]. Similar to FabLabs, and Hackerspaces; Makerspaces are community-operated physical places, where people can meet and work on their ideas, projects or prototypes in a broad range of domains. These are ground-up initiatives for independent tinkerers, inventors and entrepreneurs, where individuals and groups can learn, explore and create together.

University Makerspaces

For many years, universities has incubated hobby clubs for maker-inclined students, such as radio clubs or woodworking workshops; but the university makerspaces are a very new phenomena. These educational makerspaces harness the same intellectual playground concept of the maker movement for the purpose of learning [11], and built upon the ‘learning by making’ principle of constructionism [12].

Due to the rather fuzzy definition of the term Makerspace, a wide range of implementations and value propositions can be found. On one hand, there are makerspaces such as Georgia Tech ‘Invention Studio’ that act as student run facilities with focus on self-initiated learning [13]. On the other hand places like Stanford University ‘Product Realization Lab’ act as an integrated part of the engineering curriculum and project oriented learning [14].

In general four varying aspects of university makerspaces are:

1. The number of users and degree of openness to community.
2. The size of the space and equipment available.
3. Opening hours and staffing.
4. Organisational structure, nature of funding and their mission.

University makerspaces has only been a subject of research in the past few years, and it is characteristically descriptive. Weinmann provides an in depth discussion on some of these above mentioned aspects through an analysis of five university makerspaces [15]. Another recent study by Barret et.al. [16] review the 127 top undergraduate institutions as ranked by US News & World Report, and they report 40 makerspaces in operation at 35 of these universities. Also Morocz et al. outline their plans to investigate the differences between students that are involved in makerspaces and ‘typical’ engineering students, and how the impact of makerspaces on students’ idea generation abilities and design-efficacy can be evaluated [17].

While the above studies provide an overview of university makerspaces and their approach to learning, this paper aims to provide an in-depth analysis over the use of makerspaces in engineering education, their perceived effects and the satisfaction of their users, through a case study.

| Table 1, Workshop Facilities in DTU Skylab (*To be opened in 2016) |
|------------------------|------------------------|
| Workshops | Primary equipment |
| Wood | Band saw, circular saw, various handheld tools |
| Electronics | Soldering stations, oscilloscopes, various components |
| Rapid Prototyping | Laser cutters, FDM 3d printers, 3d scanner |
| Machine Workshop | Manual and CNC machines (lathe, milling machine, plasma cutter etc.), welding equipment, sheet metal bender and cutter, sandblaster. |
| Design lab | For user testing and observations - video production equipment |
| Wet-lab* | For chemistry and microbiology |
| Food-lab* | For food processing and preparation |

CASE STUDY: DTU SKYLAB

Our case study is based on DTU Skylab, which is an on-campus makerspace for student innovation and entrepreneurship at DTU (Figure 1). It was opened in September 2014 with a mission to create a space where students can “feel free to experiment, create, prototype, test ideas, fail and try again, and do this in a place where they are not being judged” [18]. The space has an open door policy but in order to use the prototyping facilities or get access to entrepreneurship programs DTU studentship is required. Use of the prototyping facilities is slightly more restricted that the remaining facilities, as they are mainly reserved for use within the focus areas described in the following sections.

DTU Skylab includes an open workspace including a kitchen, an auditorium, conference rooms for teaching and events, labs and different workshops as presented in table 1. The meeting rooms and the open space can be accessed 24 hours, while workshops and labs are open during normal office hours. DTU Skylab has six administrative staff for the daily management of the facilities, four technical staff for the workshops and six part-time student assistants.
As a university makerspace, DTU Skylab aims to be the student innovation hub, and it has three focus areas:

**Academic courses:** The in-house auditorium and conference rooms are hosting a number of courses that are focused around innovation and entrepreneurship pedagogics. A number of courses also use the workshops as an integral part of teaching and learning activities. (Figure 2)

**Industrial collaboration projects:** In collaboration with industrial partners, DTU Skylab facilitates case competitions, hackatons and innovation challenges. It also acts as a matchmaker for students whom would like to do their bachelors and masters projects in collaboration with an SME or a start-up.

**Student entrepreneurship:** By providing access to the prototyping facilities, open office space, informal mentoring, legal advice and web services; DTU Skylab acts as a pre-incubator for student entrepreneurs.

**METHODOLODY AND DATA ANALYSIS**

In order to analyse the effect of DTU Skylab on engineering design education, we have aggregated data from three different resources:

- **Data collected by the administration:** DTU Skylab administration collects data, such as number of daily visits, number of student start-up’s and number of courses thought and events hosted in collaboration with industry.

- **Workshop registration forms:** In order to use the workshops Skylab users register their projects by filling out a simple form. The forms provide basic information on the projects such as project members and affiliated courses. 228 forms collected throughout 2015 have been analysed for the purpose of this study.

- **Teachers using the facilities:** There are a number of courses that are taught at DTU Skylab, and we have contacted 25 educators whom use the facilities and collected data on their use, satisfaction and perception over the effect of DTU Skylab on their teaching activities and outcomes.

- **Survey with Students:** We have contacted 243 students whom took courses at DTU Skylab or used the facilities for project work in 2015. Through a survey, we have collected information from 43 of these on their use, perception and satisfaction over the offerings of DTU Skylab.

**General user data**

Throughout 2015, DTU Skylab had 56,156 visitors whom were detected by an electronic people counter at the entrance. In addition to courses and regular use, 75 different events were hosted, and 9 ‘hackatons’ and case competitions were held in collaboration with the industrial partners.

DTU Skylab offers teaching facilities, and 14 courses (from 8 different departments, figure 2) were hosted. Additionally 4
courses used the facility on an ad hoc basis for single events or exams.

Throughout 2015, 112 student start-ups and ‘pre-start-ups’ (students working on a project with the intention to start a company) used the facilities. Out of these, 27 student start-ups were registered as official companies with VAT numbers.

Workshop use data

In 2015, the workshops supported students with the production of 214 different prototypes and 228 different projects. Figure 2 shows the affiliation of these students, and the purpose of their workshop use.

%93 of the workshop users are students whereas the remaining %7 are researchers, alumni and students from other educational institutions. Group work is common for the courses being thought at DTU Skylab, and %45 workshop users mentioned that they were working in groups.

![Which resources are used the most?](Image)

**Figure 3:** Skylab offers a number of tools and workshops that are used by the students (individually) or used by the teachers as a part of their courses.

Interviews and surveys with Teachers and Students

Figure 3 illustrates how the workshop facilities has been utilized by the users. The laser cutters (%69 of users) and 3D printers (%55 of users) are the most frequently used tools by students. These digital manufacturing technologies provide a ‘low floor, high ceiling’ [12] design and prototyping environment: While they are easy to use, relatively fast and require minimal/no tooling, they are still advanced technologies that can be used for realizing complicated designs. In contrast, most teachers use ‘paper prototyping kits’ that consist of a range of stationary items that are used for low fidelity prototyping in their courses. It should be also noted that, a small number of the teachers and students only use the meeting rooms and auditoriums, without using any of the other facilities.

**New ways of teaching and learning**

According to our survey, teachers have generally changed their teaching material or teaching methods because they have starting using the makerspace (Figure 4). This can be accredited to the focus on innovation and entrepreneurship at Skylab and corresponding demand of the industry for more capable engineers [1].

Even more positively, students generally report new ways of learning as a consequence of their exposure to DTU Skylab (Figure 4). While this is a natural consequence of the new teaching methods introduced by the teachers, we believe that the focus on project based learning [19] and informal learning [20] through building prototypes in the workshops also contributes to the positive experiences.

Better prototyping and learning

One of the main offerings of a university makerspace is the prototyping facilities. In order to better understand the perceived effects these prototyping facilities, we have asked the teachers and students to evaluate if they/ their students come up with better designs, if they make better or more frequent prototypes, and how the maker space affect their teaching and learning activities? (Figure 4)

There is a general correlation and agreement on the positive effects of the makerspace among teachers and students. While the higher frequency of prototyping activities can be attributed to the availability of the new makerspace facilities, we believe that teaching methods that are adopted to the DTU Skylab’s offerings correlate with students’ perception on producing better designs and prototypes.

The highest overall effect is observed on collaboration and group work. The facility is designed as an open environment with a focus on group work and easy access to workshop-facilities, and this result verifies the intended use of the facilities.

**Satisfaction about the offerings**

Similar to the perceived effects, there is a similar pattern between teachers and students, in terms of satisfaction parameters. There is an overall tendency that teachers evaluate DTU Skylab slightly higher than the students, but the differences are not statistically significant (Figure 4).

Both students and the teachers are very satisfied with the support they receive from the staff. While still slightly above the average; the electronics workshop the least satisfactory facility whereas the machine workshop the most.
The electronics workshop is a rather small facility with limited space for equipment and it is proven to be difficult for DTU Skylab to keep a full range of components - which we believe one of the main reasons for relatively low level of satisfaction. On the other hand, the machine workshop is a manned workshop with more focus on directly supporting the users due to safety reasons. This also with the result that the machine workshop provides the strongest support in using the array of manufacturing tools and providing inventory of standard components.

In addition to the questions regarding satisfaction, we have also conducted the standardized ‘Net promoter Score’ (NPS) questionnaire with teachers and students [21]. NPS poses a single question: “Would you recommend Skylab to another peer / college?”. On an 11-point scale (0-10) both students and the teachers would very highly promote the Skylab to their peers (9.24 +/- 0.46 for students and 9.73 +/- 0.31 for teachers; .95 CI)

Figure 4, The summary of results from surveys with students and teachers. Both teachers and students perceive the effects of the makerspace on their teaching and learning activities very positively. Survey results show no statistically significant different between the perception and satisfaction of teachers and students.
DISCUSSION

How can the offerings be improved?
Based on the NPS and the satisfaction variables, we have conducted a key driver analysis which is shown in Figure 5. The only disparity between teachers and students is on the teaching facilities; which are perceived as significantly more important by the teachers. Strongly indicated by the students, but also by teachers, the electronics workshop is in need of attention from the staff, and the future improvements will potentially increase the overall satisfaction.

More diverse user base
The current users of the makerspace are focused around engineering disciplines that have focus on the use of workshop facilities, such as mechanical engineering and electrical engineering. DTU Skylab is a part of the central administration of the university and it is for all students, therefore it is important to broaden the offerings to include knowledge domains that are not within the scope of traditional workshop facilities. To address this, DTU Skylab aims to open a food- and a wet-lab in 2016, with the intention of attracting users from different departments, and supporting cross collaboration among a more diverse user base.

Feedback provided in the student’s survey also points to two aspects where we see room for diversifying the user base. A need for introductory courses and activities in innovation and entrepreneurship is mentioned by a number of survey participants. Another common desire is to be able to freely tinker with projects that are not always related to courses in entrepreneurship or industrial projects. This group of students desire a more open attitude towards utilizing prototyping facilities for personal use, as the classical makerspaces offer. Both groups can potentially become future entrepreneurs and innovative thinkers. A stronger focus on inclusion can provide inspiration to other users and at the same time orient the tinkerers to innovation and entrepreneurship related activities.

Group rooms vs. open space
The comments provided by students on open space and group rooms are slightly contradictory; on one hand, 17 of 36 respondents specifically provide positive feedback about the open environment of the facility. Students highlight the possibility of listening to the talks and lectures, see what others are doing, interact to share knowledge (across disciplines) and do small talk in the kitchen.

On the other hand, 11 respondents specifically suggest access to and availability of more private group rooms as a potential for improvement. This contradiction aligns well with the findings of Haynes et.al. [22]: Their evaluation of open office environments reveals that higher levels of interaction is perceived as the most positive effect on productivity whereas distractions result from these are perceived mostly negative.

Top down vs. bottom up
Troxler et.al. argue that is crucial to nurture an innovative ecosystem around spaces such as FabLabs, and makerspaces by supporting openness [23]. While it is easy for student-driven university makerspaces to embrace this philosophy and operate...
as a grass-roots organisation, staff-driven university makerspaces can have difficulties to provide the same levels of openness. Depending on the objectives of the makerspace, both approaches can have benefits and limitations.

Universities are traditionally organized as top-down hierarchies, and the knowledge is dispersed from the experts to learners. University makerspaces, on the other hand, can provide alternative and hybrid means for learning, that is learner driven rather than teacher driven. [11].

When it comes to formal engineering education; there is not yet enough empirical data to evaluate the influences of university makerspaces on the constructive alignment [24] of curriculum, teaching activities and assessment methods. While informal learning helps students to retain content better than traditional learning [20], it is also more difficult to assess. In this regard, one of the concrete challenges is the evaluation of informal learning from the activities taking place in a makerspace, where the process is mostly learner driven.

![Graph](image)

**Figure 6.** There is a high demand for more prototyping in engineering education, our survey (n=15) with newly appointed assistant professors reveal that they would like to implement prototyping in their courses.

**Occupancy and the environment**

DTU Skylab strives to be an innovation hub, with activities ranging from teaching to case competitions. Due to the semester structures, and various events; the level of student activity level can vary even over shorter periods. Despite efforts to implement online booking systems, users can still have a hard time figuring out when the space and machines are available. An academic course demanding access to specific machines at a certain period of the semester can easily result in a backlog for the regular flow of users. A few survey respondents mentioned this as an issue; and a solution would be a more transparent online activity calendar and booking system.

**Are teachers prepared to teach at DTU Skylab?**

In general, teachers who are currently not using the makerspace offerings in their courses are curious about how they can start to do so (Figure 6). On the other hand, most of them also mention that they are not currently confident about implementing prototyping related activities. Dym et.al argues that there is a clear need to expand the number of faculty members interested in and capable of teaching design, and to create the facilities—such as design studios and associated shops—needed for modern, project-based design courses [25], and our survey also supports the desire of the teachers to be supported in this way.

**CONCLUSION**

University makerspaces are new offerings in the higher education ecosystems. This paper outlines how these new initiatives are inspired from the grass-roots maker movement. Through our case study, we present our findings on how a university makerspace affects engineering education. We find that both teachers and students evaluate the facilities and the activities taking place very positively. Along different parameters, such as the effect on collaboration and group work, we assess that the integrated workshops and open-work environments have a significant impact on the satisfaction of the users. Students claim to experience new teaching methods and ways of learning, and teachers’ mention adopting their methods to the makerspace.

We believe that the number of university makerspaces will increase significantly in the near future, and with proper integration of these spaces into the engineering curricula, the outcomes of project-based-learning can be harvested to elevate the practical competencies of future engineers.

**REFERENCES**