FAB THESIS: A UNIVERSITY MASTER'S PROGRAMME

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ABSTRACT
Fab Labs are educating people in digital fabrication relevant to many areas of life. Often, education in Fab Lab context is non-formal. The existing examples of the formal educational programmes of the Academany educational initiative, such as the Fab Academy distributed educational programme, are provided through Fab Labs for people to learn the possibilities of digital fabrication, with Fab Academy being recognized in several universities around the globe. There is a need for continuum for this education within Fab Lab network, as well as it would support the appreciation of this continuum throughout the world if it would be possible to recognize it even partly in any university. Here, we study pilot "Grow with Fab", run in the network and propose a model of formal education for digital fabrication, Fab Thesis, and a possible method of sharing it to the network as well. This is a methodological development that bridges the Fab Lab educational paradigm with academic education. Findings of the Grow with Fab pilot contribute to the framework presented in this paper, for Fab City created prosumers in higher education. There is an educational path utilizing digital fabrication from pre-school to elementary school, high school, and university in Oulu area. In Fab City Oulu, we connected sustainability goals to this education. We will produce new kinds of prosumers to working life with new needs and values to empower their productivity. Still, we do not currently have a master's programme for these people with future skills and future values. This paper contributes to this goal.

Keywords: Fab Lab; higher and education; recognition of non-formal education, Fab City

1 INTRODUCTION
Fab Lab is a small-scale digital fabrication and innovation platform, derived from MIT [1]. Fab Labs are defined by four rules: public access to the Fab Lab is essential, Fab Labs subscribe to the Fab Lab charter [2], Fab Labs share a common set of tools and processes, and Fab Labs must participate in the larger, global Fab Lab network [3]. Common core tools are a laser cutter, a sign cutter, a precision CNC-milling machine, a large-scale router type milling machine, a 3D-printer, an electronics workstation, and communication devices for video conferences. Common processes utilize also for example composites, casting, programmeming, etc. Having common processes is a tool for developing distributed manufacturing and enabling knowledge sharing network. There are over two thousand Fab Labs in the world. The contribution of this paper is towards the definition of form and purpose of Fab Labs [4]. One of the most important focus areas of the Fab Lab network is education [5]. The biggest programme, Fab Academy [6], is a six-month distributed learning process for the principles and practices of digital fabrication, based on MIT's 18 study credit point course "How to Make (almost) Anything". Fab labs need to have an educated instructor and a full inventory to participate in this programme. The diploma is granted by Fab Foundation. It recognizes skills to work and found a Fab Lab and ability to integrate those skills into a functional prototype presented for a final project. There is no global academic recognition for Fab Academy. However, many universities recognize the Fab Academy at some level.
Fab Labs' role in education is of high importance [7]–[9]; For instance, the Fab Lab approach is significant for students to effectively bridge the gap between product design and electronics in an accessible way [9]. University teaching, along any education and digitalization, is in a change. Some universities are planning to sell the courses on the web and some, more than 250 institutions including MIT, share their materials for free [10]. Still, there is no distributed, master's level education for the

digital fabrication. Nor there is a programme for digital fabrication and rapid prototyping in Finnish universities. In this paper, we propose a partial solution for this problem.

1.1 Fab Thesis Pilot

Fab Thesis was piloted under a name "Grow with Fab". It was a nine-month education programme pilot, started in October 2017, and followed Fab Academy completion. Fab Thesis was open for registration in 14 Fab Labs. It further developed the distinct role of Fab Academy within education [11]. It was designed to be a project incubation programme and the next step after Fab Academy or Bio Academy [12] ("How to Grow Almost Anything", a programmeme on the intersection of biology, biotechnology, and digital fabrication). Bio Academy used the latest personal digital fabrication processes to enable biological experiments outside expensive high-level laboratories. Additionally, Textile Academy [13] (a programmeme on the intersection of textiles, fashion, and digital fabrication technology) was piloted, to tackle issues of fast fashion with personal digital fabrication, at the time. The student applying to the Fab Thesis was recommended to have one or preferably two of the Fab educations. The student proposed a project. It would have been beneficial to continue the final project of Fab Academy if the funding (15 000 €) were achievable. This pilot blended elements of design challenge addressing a specific design problem, an acceleration programme (that helps early-stage startups grow and scale), engineering, design, and digital fabrication. Fab Academy is a programme of weekly workshops and a short final project to present the skills gained during the weekly workshops. This leads to a situation where numerous innovative projects are prototyped but remain unfinished. Fab Thesis aims to help these projects to reach a productive state [14]. There are already commercial or otherwise successful projects continued after Academany educational initiative offering distributed educational programmes focused on digital fabrication (e.g., Aquapioneers [11], Smart Citizen Kit [14], Open Source Beehive [15]). Cherry picking the best projects to the pilot would also help labs to keep talented people around. Especially if they would get a partial grant for working in the lab part-time during the Fab Thesis. In the larger scale, Fab Lab networks promise a positive impact on society, fostering innovations and new product development.

1.2 Open Questions

While there are differences as well, Fab Academy and Fab Thesis pilot both share common elements with formal education. Class, professor, teaching assistant and evaluation, all have their equivalents in both settings. It is of high importance to recognize key differences and similarities, to take advantage of agile development of non-formal education programmes in the Fab Lab network in formal setting. The proposal of Fab Thesis in the context of higher education rises the questions of its recognition as a part of higher education. In particular, the main issues are: (1) How to integrate the elements of Fab Thesis into the higher education degree, and (2) How to preserve the inherent characteristics of making and learning processes in Fab Lab in the context of such integration. In this paper, we discuss the example solutions of these issues.

2 METHOD

The Fab Thesis students built the next version of their project or given subject for approximately nine months. The schedule started with defining the nodes and the committee in April 2017. Application was launched for students June 29th with the deadline of July 31st. Projects were selected by the committee and local labs in August at FAB13 conference. The study programme started at October 16th. The progress was reviewed in December and mid-term review was in March. Thesis presentations were in July followed by project exhibition or presenting a paper at FAB14 conference.

The project had to be documented weekly. The programme offered top-tier, globally acclaimed lectures held by CEOs of leading companies or known scientists. Table 1 presents information about Fab Labs that took part in the Fab Thesis Pilot programme, including Fab Labs' names, locations, students starting in the programme, the subjects of their thesis, and their mentors. Two students accepted to the programme did not start. Students are considered as the primary authors in the Fab Thesis, providing approximately 10-page conference papers. The authorship is shared between local labs and Academany. The cost is predicted to be shared by students, labs, and/or companies. Utilization of the project is determined on a case-by-case basis. One of the targets of the pilot year was to develop a business model for each Fab Thesis. Labs offering the programme must have sufficient expertise to guide students' daily activities and the capability to grant access to the machines for 20 hours per week. The Academany

coordination provides global supervision and guidance for the students through a group of experts from both within and outside of the Fab Lab network. Students' progress is documented and shared online. Finally, certification is granted to the students by the evaluation committee. To graduate, two primary objectives should be met: (1) a conference paper of ten pages presented in the FAB conference, and (2) a landing page. The landing page is a web page set in a dedicated domain to present the design project. It serves the purpose of rapidly presenting the idea or product to external parties, such as companies or external visiting mentors with subject-specific expertise.
The research and project development for producing a conference paper are documented in the GitLab repository. These documentations are useful for instructors and supervisors to follow the development of the project. An instructor is equivalent to a teaching assistant and a supervisor to a professor in formal education. Communications and feedback happen through issues and milestones set in the GitLab repository. Furthermore, attending midterm presentations is compulsory for the students to remain in the programme. The final presentations of the pilot took place at FAB14 conference, with the alternative option of presenting via video. The certificate of completion was granted by Academany.

Table 1. Fab Labs and students accepted into the Fab Thesis Pilot programme

Location	Student	Subject	Mentors
Peru, Lima, Fab Lab TECSUP	Jose Lazarte, Website: https://growwithfab2018.fabcloud.io/JoseLazarte	Cocoa fermenter	Local mentor: Roberto Delgado Supervisor: Francisco Camacho
Ecuador, Quito, Fab Lab ZOI and Yachay	Roberto Gallo, Website: https://growwithfab2018.fabcloud.io/RobertoGallo/	Bits and Atoms Pen	Local mentor: Isaac Robles Supervisor: Jani Ylioja Advisor from the network: Fiore Basile
Finland, Oulu: Fab Lab Oulu	Jari Pakarinen, Website: https://jarifablaboulu.wixsite.com/modular	PCB THP Automation	Local mentor: Jani Ylioja Advisor outside the network: Adj. Professor Georgi Georgiev
Spain: Fab Lab Barcelona	Student N.N., Website: no longer available.	Ecotron	Local mentor: Santiago Fuentemilla Supervisor: Tomás Diez
Switzerland, Geneva	Student N.N., Website: https://www.fabkit.org/	fabkit	Local mentor: independent Supervisor: Jani Ylioja

2.1 Impact of the pilot

Three out of the seven applicants completed the programme, and two of them received certificates upon graduation. The third applicant, who completed the programme, missed the deadline for the conference paper, although the manuscript was almost ready. Cocoa fermenter project (see Table 1) was continued after the graduation and is currently patented. Figure 1 presents the PCB THT Automation, which was a study project and never meant to be continued after the graduation. It enabled the automation of a machine with labour-intensive two-hour process, freeing the operator for other tasks and reducing their workload. Bits and Atoms pen was continued after the pilot and mass manufacturing was designed in collaboration with a Chinese producer. Unfortunately, there was no follow up on the concept as a Kickstarter project and marketed solution.

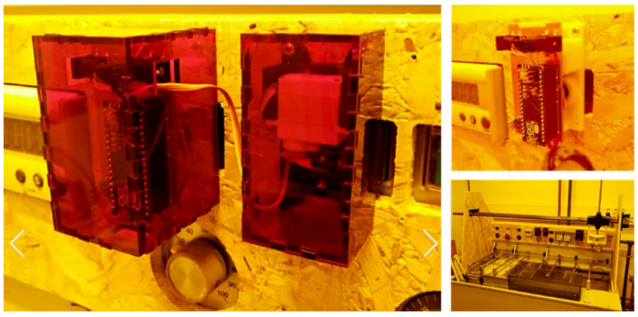

Figure 1. Left: a pushbutton on the left and a rocker switch on the right automated with modules. Up right: a button pusher module uncovered. Down right: A printed circuit board through hole plating machine automated with the modules. The entire automation system can be removed from the machine in one piece

2.2 Findings from the pilot

One of the aims of the pilot was to start a network capable of offering distributed education based on the Fab Thesis pilot. However, only one graduate in Peru was available to serve as a node since the student in Finland left the Fab Lab for an industrial position. In this initial pilot, the roles were reversed: while normally students come to teacher(s), we sent a teacher to each student for a week to address the most challenging aspects in design/creativity, engineering, and hardware acceleration/impact. Data was collected through close observation of students' progress during week-long visits to each student, facilitating discussions on the subject matter and obtaining feedback. While the outcome and impact of the pilot are obvious, we do not consider it to be in alignment with the required resources. Initiating the programme locally and subsequently sharing the suitable parts for the network appears to be more feasible.

We identified essential elements for impacting formal education, such as integrating creativity practices to fight the design fixation, emphasis on processes, and engineering, as well as active searching for impact in the hardware acceleration process. These elements address a major challenge in formal education, where students struggle to design and prototype fully functional devices quickly.

3 PROPOSED COMBINATIONS

The Fab Thesis contributes by bridging Fab Labs as alternative educational and innovation platforms [16] to a form of education that complements conventional methods. In this paper, we outline the recognition of Fab Thesis elements and compare them with the last year of ITEE (the Faculty of Information Technology and Electrical Engineering) study guide's master's programme for a bottom-up approach. As for a top-down model, we develop a framework for a master's programme in a university to be shared to the Fab Lab network later.

3.1 Master's programmeme in study guide for computer science at the University of N.

In the University of Oulu's ITEE faculty, the fourth academic year entails courses totalling 60 ECTS (European Credit Transfer and Accumulation System; 1 ECTS is approximately equivalent to 27 hours of effective work) credits in 2024. The fifth academic year is divided into two parts. The first part consists of regular courses, and complementary and supplementary studies, as well as 5 ECTS credits of practical internship in the field of student's major studies. The 5 ECTS credits could be gained for two months of training and report submission. The first part is worth of 30 ECTS credits. The second part involves completing the master's thesis for 30 ECTS credits.

3.2 Building a master's programmeme on findings of the Fab Thesis pilot

For a bottom-up model, we suggest aligning the first part of the academic year with five or six subdivided diary-style project documents for the Fab Thesis. Each document would receive accreditation for approximately 5 points. Accreditation can also be extended to the landing page and internship in the Fab Lab. The Fab Academany Thesis paper would be extended to master's thesis.

If the programme adopted the top-down approach, resembling a master's programmeme, then it would be crucial to initially have Fab Academy or 5 university courses, which are equivalent to Fab Academy. This would enable students to fully utilize the capabilities and resources of a Fab Lab as a learning environment, amounting to 25 ECTS credits. Next, students would have the option to choose two modules from a range of established courses offered by the university from fields such as computer science, information technology, or environmental subjects. Each module would contribute 25 ECTS credits towards the programme. The field of computer science encompasses design and creativity. A special course designed to teach students on Super Fab Lab processes (Fab Labs capable of making Fab Labs), along with a seminar series covering a range of topics would be developed, each contributing 5 ECTS credits. Subjects for the seminar series would be Super Fab Labs, Fab City (a network of cities empowering their inhabitants to circular economy via Fab Labs), sustainability, safety, value creation (Merriam-Webster, value added: "of, relating to, or being a product, whose value has been increased

especially by special manufacturing, marketing, or processing "), and impact. Internship would provide 5 ECTS credits. Master's thesis would be 30 ECTS credits. Areas to investigate in master's thesis would include a product developed beyond the proof of concept, enhancing its functionalities through Super Fab Lab processes, and considering frugal approaches to production.

4 RESULTS, DISCUSSION, AND IMPLICATIONS

In this paper, we acknowledge the similarities between the status of the pilot's programme and the potential for the academic accreditation at the University of Oulu. [17]. From our empirical observations of the Fab Thesis pilot two findings emerged. Firstly, while effective hardware acceleration and product-to-market process would benefit from expertise in design, engineering, and marketing, mastering all these areas or even maintaining interest in all of them was not easily achievable for an individual. While boundaries between subjects overlap and engineering shares similarities with design processes, students faced difficulty in mastering subjects outside their personal backgrounds. [18], [19] Secondly, the students who completed the course were in countries, where it is not customary for students to pay the necessary fees for the business model to be viable. In Finland, education is free, while in Peru and Ecuador, the cost of Fab thesis at a large scale exceeds the standard of living.

Several design educations have taken advantage of Fab Labs [20], [21]. Mosted-Van Der Sar & al. utilized a specific course developed to be executed within Fab Labs to explore design education in such an environment. [9] They acknowledged the shift in skill sets and design practices required after the third industrial revolution. Similar to our pilot, they noted that students were empowered in rapid prototyping and participatory design. Moreover, aligned with our findings, they observed their Fab Lab transforming into an interface to the city, thereby impacting their environment using educational elements. Also, in their course, the students' backgrounds determined whether they found certain subjects irrelevant or complex. These observations resulted in alternations to the course. Informed by our empirical experience and research findings, we refined our educational framework. While the bottom-up approach to integrate the Fab Thesis into the formal education would preserve the characteristics of the Fab Thesis, it was too different to local educational norms to gain local acceptance and lacked financial sustainability.

During the development and execution of this programme, the primary focus was on addressing the needs of the Fab Lab network. Due to the distinct business model and Fab City Oulu initiative, which aims to attract digital fabricators to study at the university, there is a need and opportunity to establish a local master's programme. The suitable components of this programme could be shared with the Fab Lab network through a top-down approach. We consider this a more feasible approach to link Fab Thesis with a master's programme. The method for documentation resembles the one used in Fab Academy. In addition, the processes utilized are often derived from Fab Academy. It will connect novel educational processes crafted for digital fabrication into academic setting. Our proposed framework will enable the recognition of the content and the learning goals of Fab Thesis to align closely with master's degree studies according to the Bologna process [22]. The framework will serve to bridge the cutting-edge research in the new field to both local and global economy and environment. The framework presented in this paper is expected to lead to a new degree programme focusing on emerging digital fabrication techniques.

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