Strengthening Capacities of an Academic Network of Digital Fabrication Laboratories and the Role of International Collaboration in Times of COVID-19

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Abstract. Technologies based on 3D printing are revolutionizing academia and public health. The objective of the article is to describe the activities of the Academic Network of Digital Fabrication Laboratories (Fab Lab) at Universidad Continental (Peru) in the context of COVID-19 pandemic. During period April-June 2020 more than 500 kits that included face shields were developed and distributed to public and private institutions nationwide. In addition, 3D-printed respirator valves for respirators were donated to public hospitals in Peru in order to keep COVID-19 patients who required oxygen alive. Moreover, Universidad Continental implemented seven multidisciplinary virtual learning courses on digital fabrication during the first semester of 2020. 91 students were trained on digital fabrication concepts and developed 13 research projects related to tackling the COVID-19 pandemic. Finally, the role of international academic collaborative networks to share resources and lessons learned is discussed during the COVID-19 crisis.

Keywords: Education, University, Digital Fabrication, Peru, Spain, SARS-CoV-2, COVID-19.

1 Introduction

The COVID-19 pandemic was a challenge for higher education worldwide. Social distancing and other control measures established during the COVID-19 pandemic generated a sudden change in the provision of education for students in higher education institutions worldwide [1,2]. Asian countries and Eastern Europe, being the first affected, had a short adaptation time to switch to digital learning education; while in Hong Kong the universities adapted well due to a previous history of implementing virtual classrooms [3]. However, many universities, especially in resource-constraint settings around the world, had serious problems due to lack of technological resources, infrastructure and sociocultural issues, so those countries took a long time to adapt to digital learning education [4,5]. A significant challenge for many low- and middle-income countries that university digital fabrication labs were lockdown [6] yet the

gradual adoption of digital education with its wide range of digital resources and stimulation self-learning enabled them to overcome these challenges [7,8].

Due to the critical shortage or lack of personal protective equipment (PPE) in the context of the COVID-19 pandemic, digital fabrication laboratories around the world used their technological capacity to massively manufacture personal protective equipment and supplies necessary for the containment of the COVID-19 pandemic [9,10]. In Peru, the Fab Lab National Network (Fab Lab Peru) called for a collaboration of all the digital fabrication laboratories in the country to be able to produce face shields for healthcare workers during the pandemic [11,12]. This article describes the activities of the Academic Network of Digital Fabrication Laboratories (Fab Lab) at Universidad Continental (Peru) in the context of the COVID-19 pandemic. In addition, the role of the national and international academic collaborative networks to share lessons learned is discussed during the COVID-19 crisis.

2 Activities of the Academic Network of Digital Fabrication Laboratories (Fab Lab) at Universidad Continental (Peru) in the context of the COVID-19 pandemic

Peru, as many countries in the world, suffered from a critical shortage or lack of PPE for healthcare workers and people that provided services to the citizens, specially at the beginning of the pandemic [13] The Academic Network of Digital Fabrication Laboratories (Fab Lab) at Universidad Continental in Peru is comprised of four digital fabrication laboratories located in the following campuses: Huancayo, Lima, Arequipa and Cuzco. In the context of COVID-19, this effort was initiated during the last week of March 2020 after it was realized that digital fabrication could have a significant role to the PPE shortage for healthcare frontline workers [14].

Face shields production kits. Since April 2020, Universidad Continental began to manufacture protective face shields and three stages were developed: 1). Acquisition of 3D files; 2) Validation and adjustment of parameters; and 3) 3D printing.

For the 3D file acquisition stage, a file entitled "Easy 3D printed face shield"(15) was downloaded from the "Thingiverse" website in STL file, which loads the geometry of the three-dimensional file. Regarding 3D modeling for size validation and parameter adjustment, different specialized graphic computer programs, such as Inventor and Autocad, were tested to redesign the 3D modeling of the protective visor for adaptation to the Peruvian biotype. In addition, the Ultimaker Cura program was used for the validation of the 3D printing parameters and export them in Standard Triangle Language (STL) files. Regarding the 3D printing stage, it was decided initially to produce the face shields with the printers: Colido X3045 and Ultimaker 2+. The face shields took initially about 2 hours 30 minutes to manufacture. However, it was later decided to develop kiwi-type face shields using transparent polycarbonate sheets manufactured with laser cutters, since they were produced in less time (compared to 3D printing) and due to the feasibility of mass production.

During April to June 2020, more than 500 face shields production kit donations were made, which included a face shield, a disinfection manual and a zero-contact clamp, which were distributed from the four laboratories of the Network of Digital Fabrication Laboratories at Universidad Continental to diverse public and private institutions in Peru, including: Regional Medical College of Physicians of Junin, Continental Clinic in Huancayo, Regional Medical College of Physicians of Arequipa, Ate Vitarte Emergency Hospital, and Condorcanqui District Municipality. Face shields were evaluated before their production by medical doctors who worked in hospitals in Lima (José Casimiro Ulloa Emergency Hospital, Ate Vitarte Emergency Hospital) and Ramiro Prialé Hospital in Huancayo.

3D-printed respirator valves for respirators. The team made the following 3D printed respirator for respirators: Charlotte and PEEP (positive end-expiratory pressure) [16]. Those valves were used for non-invasive ventilation systems and were donated to public hospitals in Huancayo (Junin) in order to keep COVID-19 patients who required oxygen alive.

2.1 Strengthening capacities through Fab Lab multidisciplinary virtual learning courses

On August 2019, the Academic Network of Digital Fabrication Laboratories (Fab Lab) at Universidad Continental (available at: https://fablab.ucontinental.edu.pe/) began the design of an academic curriculum with a multidisciplinary faculty group that incorporates digital fabrication technologies in academic programs. On September 2019, our proposal was piloted in the following three in-person courses at the Arequipa campus: Design of Mechanical Systems, Architectural Projects IV and Design of Industrial Plants.

Module 1 provided: the basic concepts on digital fabrication, information retrieval (searching databases such as: SCOPUS, Web of Science and SciELO, web page design using the following resources: Nicepage and Github platform. Finally, students were instructed to use 2D Design and 3D Freeware online tools to start designing their projects.

Module 2 provided the basics of laser cutter, 3D printing, CNC machining, vinyl cutting plotter. Project deliverables included: web page, reports, infographics and videos.

Module 3 provided the following topics: project repositories related to courses, rapid prototyping tools, project management. During the field testing, the prototype interacts with clients and/or end users. All three modules were developed throughout weeks 1 to 15 (Table 1).
In general, 85% satisfaction rate was rated among students in the three courses involving 50 students.

Table 1. Modules of the Digital Fabrication Curriculum at Universidad Continental.

Module 1 (Week 1 - 5)	Module 2 (Week 6 - 10)	Module 3 (Week 11 – 15)
Introduction to Fabrication Digital	Laser Cutter	Project Repositories
Databases and Information Retrieval: SCOPUS, Web of Science SciELO	3D Printing	Rapid Prototyping Tools
Management Project	CNC Machining	Field Testing
Web Page Design	Vinyl Cutting plotter	Project Deliverable
2D / 3D Design		

2.2 Digital Fabrication Curriculum during the COVID-19 Pandemic

In March 2020, due to the COVID-19 pandemic, seven multidisciplinary virtual learning courses on digital fabrication were adapted and implemented (Table 2). 91 students from there campus (Huancayo, Lima, Arequipa) were trained on digital fabrication concepts and developed 13 research projects related to tackling the COVID-19 pandemic.

Table 2. List of virtual learning courses on digital fabrication (March-July 2020)

Courses	Academic program	Semester	N° Students
Mechanical Systems Design	Mechanical Engineering	VIII	17
Biomechanics, Ergonomics and Occupational Health	Medical Technology	VI	21
Innovation and Technological Management	Industrial Engineering	VIII	24
Industrial Design	Industrial Engineering	VII	13
Digital Representation I	Architecture	III	1
Architectural Projects III	Architecture	III	1
Architectural Projects IV	Architecture	IV	14
Total			91

2.3 Satisfaction survey

The following four criteria for the satisfaction survey were considered: Support for the prototyping phase, where one member of the technical team (Fabber Tech) printed the student design and then, the prototype was delivered to students home address in order to complete their final projects; Teaching materials (included: presentations, guidelines and multimedia resources), the methodology during virtual classes (flipped classroom, and problem based learning); and finally the Fabber Tech who provided support to the students (Table 3). An overall satisfaction rate of 87.57% were achieved among students.

	Mechanical Systems Design	Biomechanics, Ergonomics and Occupational Health	Innovation and Technological Management	Industrial Design	Digital Representation I	Architectural Projects III	Architectural Projects IV
Support for the prototyping phase	90 %	90 %	78.88 %	74.81 %	100 %	100 %	80.90 %
Teaching materials	84 %	88 %	80.83 %	70.37 %	73.3 %	73.3 %	81.90 %
Methodology	87 %	85 %	83.61 %	68.14 %	100 %	100 %	81.90 %
Fabber Tech	95 %	93 %	84.41 %	81.41 %	100 %	100 %	80.95 %
General	87 %	89 %	81.93 %	73.68 %	100 %	100 %	81.41 %

Table 3. Result of period 2020-10 satisfaction survey.

2.4 IX Engineering Project Fair (July 2020)

Engineering students had the opportunity to present their digital fabrication projects at the IX Engineering Project Fair (July 2020) entitled: “Towards finding engineering solutions to tackle COVID-19”, held on July 24, 2020. The keynote lecture was given by one of the authors (CL) who shared the experience of digital fabrication applied to architecture and engineering at the Fab Lab Madrid CEU (Spain).

3 The role of international academic collaborative networks to share resources and lessons learned during the COVID-19 crisis.

Among the most outstanding international academic initiatives among Fab Labs globally, it is worth highlighting the work developed by the Center for Bits and Atoms (CBA) of the Massachusetts Institute of Technology (MIT) [17] focused not only on the design and manufacture of equipment and devices to support the fight against COVID-19, but also to support the Fab Labs community, fostering collaboration, sharing through their institutional repository standards related to materials, protocols, among other resources [18].

Also, it is important to point out the collaboration between the Fab Labs of Stanford University, Brown University and the University of Utah that involved more than 120 students in the design and manufacture of a respirator [19] that is in phase of validation in India, Kenya and Nepal, where they will be manufactured on a large scale. Those universities have incorporated simulation tools in their classes so that students can view their models (Cornell Tech's Maker Lab), others have used augmented reality technologies (Fab Lab Madrid CEU), some broadcasted their classes by videoconference using Go-pro cameras, which allowed students to visualize the operation of the machines by the lab instructor (Rice University's Oshman Engineering Design Kitchen). Other universities decided to mail kits of electronics materials and tools to their students (UCLA Samueli Makerspace Engineering School) and some even chose to design machines and provide students with materials so that they could manufacture them in their homes (IAAC, Fab Lab Barcelona).

A report prepared by the Fab Foundation [20] based on information collected from more than sixty Fab Labs distributed around the world and carried out in May 2020 reveals the impact that Fab Labs have had on their local communities during the crisis due to the COVID-19 pandemic. The conclusions of the Fab Foundation report show that, although the lockdown, 61.9% of the Fab Labs that responded to the survey, found a way to remain open or partially opened and got involved in the manufacture and distribution of PPE and medical devices for healthcare personnel distributed locally to hospitals, health centers, and those who needed the most, and most of which were donated for free, sharing the designs based on open source licenses.

It should be noted that local initiatives were developed in the United States, such as the one that joined the Chicago Fab Lab (The Wanger Family Fab Lab) [21] with the city's Makerspaces network to create a virtual community, the Illinois PPE Network (22), organizing the production and distribution of 6,500 daily face screens that were distributed for free to more than 100 hospitals in the Chicago area.

In Europe, the collaboration between Fab Lab Madrid CEU and the Coronavirus Makers Madrid [23], produced more than 300,000 PPE (Fig. 1) that were distributed among hospitals and health centers. With more than 20,000 volunteers throughout the country, the Coronavirus Makers initiative [24] managed to manufacture more than 1.5 million personal protective equipment nationwide.

Figure 1. Personal protective equipment manufactured at Fab Lab Madrid CEU (left) and Coronavirus Makers face screen model validated by the authorities (right).
Image source: Covadonga Lorenzo.

In Italy, the Fab Lab Western Sicily, in collaboration with the Italian maker network, focused on the manufacture of thousands of Ventury and Charlotte valves for respirators, which were in short supply during the early phases of the pandemic, which made possible to connect diving masks with a respirator, to help the most seriously ill patients [25].

On the African continent, Fab Lab Rwanda [26] and Fab Lab Nairobi [27] worked in collaboration with the Fab Lab Network and local authorities in the design, manufacture and validation of respirators, oximeters and protective equipment for local hospitals.

Finally, in Asia, it is worth highlighting the work of laboratories such as Fab Lab DhakaFab Lab Vigyan Ashram or BSDU Fab Lab, which manufactured masks, facial protection screens and other medical equipment since the beginning of the pandemic, and were manufactured only in India, more than 2 million open source equipment's [28,29].

4 Final remarks

The crisis caused by the COVID-19 pandemic has demonstrated the important role for digital fabrication regarding the design, prototyping and validation processes of prototypes when manufacturing medical devices and PPE using 3D printing and laser cutter technologies, and even on a large scale when working collaboratively with local communities [10,30]. Local and international collaboration have been a key issue for digital fabrication, as well as for other topics such as digital health [31,32]. In addition, we presented the case of Universidad Continental that implemented seven multidisciplinary virtual learning courses on digital fabrication during the first semester of 2020. We continue currently accompanying 211 students are participating in 07 multidisciplinary courses on digital fabrication. Therefore, more than 300 students were trained on digital fabrication concepts and developed innovative research projects related to tackling the COVID-19 pandemic during 2020.

We also present the important role of collaboration to establish links between laboratories, universities, companies and local institutions, in order to support the communities most in need during the toughest phases of the pandemic. This paper shows the potential of fabrication digital technologies and the importance as live spaces that promote co-creation, but also as spaces for social innovation and to build capacity for a next generation of interdisciplinary students.

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