INTRODUCING DIGITAL FABRICATION LABORATORIES IN ARCHITECTURE SCHOOLS

Planning and operating

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Abstract. The present paper proposes a set of guidelines for the implementation of digital fabrication laboratories for education and research in architecture schools. These guidelines are based on the authors´ experiences in creating two of such laboratories, one in Brazil and another one in Portugal.

1. Introduction: Integrating digital fabrication into the architectural curriculum

Rapid prototyping and digital fabrication are respectively the automatic production of physical models and final objects directly from a computer model, with the use of computer-numeric controlled machines. The definitions and the different uses of these expressions in the literature have been discussed in Pupo, Celani, & Duarte (2009). During the past decade, digital fabrication laboratories have been installed in many architecture schools throughout the world. The establishment of such labs has been, in most of the cases, accompanied by structural changes in the curricula, in regards to the use of information technologies in the design proves. Some authors, such as Mark, Martens, & Oxman (2001), have presented proposals for integrating the new technologies into the curriculum. However, not much has been published about the operational and administrative aspects of these labs.

The present paper proposes a set of guidelines for the implementation of rapid prototyping (RP) and digital fabrication (DF) laboratories for education and research in architecture schools. These guidelines are based on the authors´ own experience in creating two of such laboratories, one in Brazil and another one in Portugal, and they are presented as a commented checklist of items that must be considered when planning a DF lab.

2. Context: similarities and differences between the labs

The authors of the present paper have been responsible for setting up labs at the School of Civil Engineering, Architecture and Urban Design (FEC) from the State University of Campinas (UNICAMP), in Brazil, and at the Higher Technical Institute (IST) from the Technical University of Lisbon (UTL), in Portugal. The former is called *Laboratory of Automation and Prototyping for Architecture and Construction* (LAPAC), and was established in 2007. The later is called *Architecture Research Laboratories* (ISTAR) and was established a bit earlier, in 2006.

In both cases the space in which the labs were installed was not originally designed specifically for a laboratory. At LAPAC the space used is the mezzanine of the school's model shop. At ISTAR the space was formerly a regular office space. Another similarity between the two labs is the fact that both targeted mainly architecture undergraduate students, but also graduate students, in a smaller number. Finally, both labs were created with the objective of developing research on the use of new information technologies in architecture and their introduction in the architectural curriculum.

The two labs also had some differences. While LAPAC's focus is just rapid prototyping and digital fabrication, ISTAR also includes other types of technologies, such as remote collaboration and virtual reality.

3. Checklist: points that must be given thought when setting up a new laboratory

After many years of continuous work at their labs, the authors were able to draw some conclusions related to their creation, administration, maintenance and use. These conclusions are summarized in the checklist below.

3.1. DEFINING THE TARGET PUBLIC

The target public must be defined according to the lab's objectives (researching new applications or just supporting model making), but also to its capacity in terms of the number of students that can use the facilities. It must take into account the number of machines available, the opening hours and the help offered by the staff.

When the labs are open to undergraduate students, their use tends to be concentrated in just two or three weeks during the academic semester, when the mid terms and the final presentations are due. Undergraduate students will often use these labs for producing regular architectural models, unless they engage a course in which they are encouraged to try out new production methods, such as parametric modeling and other generative strategies, which can be integrated to digital fabrication in a more meaningful way. When the lab is used by students from different classes it is important to talk to their instructors and make sure that their deadlines are not coincident, so there are available time slots for everyone.

The use of DF labs by graduate students, on the other hand, tends to be better distributed along the semester, because their research projects evolve at a more continuous pace. These students often develop series of experiments using the different technologies available, which optimizes their use.

3. 2. ESTABLISHING PARTNERSHIPS WITH EXISTING LABORATORIES AND OTHER RESEARCHERS IN THE FIELD

One of the most important decisions when setting up a new laboratory is to establish partnerships with experienced people from other similar labs, who can help out with tips about the machines and training for the staff. When LAPAC was created, a graduate student from UNICAMP was sent to ISTAR to learn about how to run a DF lab. At the same time, LAPAC also established a partnership with a federal government-run information technology center (CTI Renato Archer) in Campinas. The rapid prototyping lab from this center has been supporting LAPAC since then, by providing important information about the maintenance of our machines, and by producing models with technologies that we do not own, such as selective laser sinthering (SLS), whenever we need them.

3. 3. DEFINING RESEARCH TOPICS AND THE LABORATORY'S OBJECTIVES: SCALE MODELS X PROTOTYPES; REPRESENTATION X EXPLORATION, ETC.

In regards to the type of applications developed at each lab, they were a bit different. At LAPAC the main application was the making of architectural models, while at ISTAR the main application was the exploration of innovative ideas.

3. 4. SPECIFYING APPROPRIATE TECHNIQUES AND MACHINES

By clearly establishing the objectives of the laboratory it is also possible to specify the rapid prototyping and digital fabrication machines. Both at LAPAC and at ISTAR the main objective was to acquire machines that could illustrate different fabrication strategies: cutting, adding and subtracting material. For this reason the laboratories own similar machines: a laser cutter, a layer-based rapid prototyping machine, and a CNC router. The machines are made by different firms and have different sizes, but they explain the very same concepts.

3. 5. SPECIFYING APPROPRIATE SOFTWARE

The specification of CAD software in a RP/DF laboratory can have a great impact in the outcomes. For example, by offering students the possibility to use CAD software that can handle freeform easily, there are greater chances that they will better explore the capabilities of a 3D printer to produce these forms. Also, by providing them with software that automates the unfolding or the slicing of polyhedrons, they are more likely to produce complex shapes with the use of the laser cutter.

3. 6. SPECIFYING REQUIRED TRADITIONAL TOOLS IF NECESSARY (BOTH MECHANICAL, SUCH AS ROTARY AND SANDING TOOLS, AND MANUAL, SUCH AS SCREWDRIVERS, HAMMERS, ETC.)

Since LAPAC was set up at the mezzanine of the school of architecture's existing model shop, it was possible to borrow drills, sanding machines and other tools for finishing the models produced with the computer-controlled equipment. The model shop staff was always ready to cut boards in the size required for the laser cutter, as well as to help out students in the finishing process. When creating a new laboratory that is not connected to a model shop it may be necessary to specify traditional tools for these operations.

3. 7. RAISING FUNDS FOR BUYING EQUIPMENT AND SOFTWARE

Fund-raising is probably the most difficult part of the planning of a new lab, because these machines are very expensive and in most countries they need to be imported and shipped from far away. In a budgetary proposal it is important to include the costs of replacement parts, basic training and a minimum amount of supplies to start running the machines.

3. 8. DIMENSIONING AND QUALIFYING THE REQUIRED STAFF

The number and training of the people who will work at the lab is directly related to the target-public that will use the lab, the lab's objectives, the type of service that will be offered to the community, if these services will be charged or not, and so on. At ISTAR there was simply no staff at all. As a result, the lab had to be kept closed for most of the time. At LAPAC the staff was composed by two people without any training in IT, who could hardly help. In both cases the solutions was to hire students as monitors. Although these students could learn very quickly, they often had to quit, making it necessary to train new monitors at the beginning of every scholar year.

3. 9. DEFINING THE LABORATORY'S SPACE LAYOUT

The greatest problems in a RP/DF lab are related to environmental quality. Laser cutters produce strong – often poisonous - smells, 3D printers and routers produce dust, and all of them produce irritable noises. It is often necessary to build sound-proof partitions, and to establish rigid rules for both the staff and the students regarding the use of safety equipment, such as masks and ear protectors.

3. 10. CHECKING OUT SAFETY ISSUES

To avoid the breathing of harmful gases and dust, some RP/DF equipment need special exhaust systems. The spaces also need to have good natural or forced ventilation. Air-conditioning may be dangerous if there is no air renovation. Besides, there are issues related to fire safety, especially when the lab has a laser cuter and a CNC router. These machines may never be left unattended, and the staff must be trained to use specific electric-fire extinguishers.

3. 11. DEVELOPING WORK PROTOCOLS AND ESTABLISHING USE AND SAFETY RULES

All users of the labs must be aware of the work protocols and safety rules, no matter if they belong to the faculty, to the staff or if they are students. It helps a lot to post signs explaining such protocols and rules on the labs walls.

3. 12. TESTING MATERIALS AND PRODUCING A LIBRARY OF SAMPLES

To avoid "re-inventing the wheel" every time a new project is started, it is very useful to produce a library of samples that show the results of the use of different parameters in each machine. At LAPAC, for example, a student has developed a sampler for the laser cutter, which shows the results of different combinations of power and speed on different types of materials with different widths, such as cardboard, paper, acrylic, MDF, balsa wood, etc.

3. 13. DEVELOPING PRODUCTION METHODS

It is also important to provide detailed descriptions of production methods to students, based on other students' experiences. This can contribute to improve the quality of the work developed and reduce the need for offering training. It is also important that this literature is made easily available, for example through publication in the lab's website, such as the manuals available at www.fec.unicamp.br/~lapac. They were produced by undergraduate students who developed research projects at UNICAMP.

3. 14. DEVELOPING EQUIPMENT AND SOFTWARE TUTORIALS

In the same way that the manuals described above can help students plan their production methods, manuals for using the equipment can reduce their dependence on the staff, who can then just supervise their work.

3. 15. ESTABLISHING THE SCHEDULING SYSTEM AND RULES

Scheduling of equipment can be a source of fights between students, especially when deadlines are approaching. At LAPAC an online scheduling system is being tested to avoid such problems. However, these systems are not completely error-proof and require constant attention to avoid scheduling on holydays and for rescheduling appointments when the machines are out of order or the monitors are absent.

3. 16. ESTABLISHING A CALENDAR FOR BUYING SUPPLIES AND REPLACEMENT PARTS MAINTAIN EQUIPMENT

One common error at labs is to wait until the supplies are about to finish to start thinking about how to buy new materials. Usually when that happens it is already too late to order and the machine will have to stop working. For this reason it is very important to keep track of the amount of material that is used for each machine, and to keep a strategic reserve of replacement parts. Establishing partnerships with suppliers can also help. It is also important to do the maintenance procedures required for each machine, which are specified in their manuals.

3. 17. DEFINING THE REQUIRED ANNUAL BUDGET AND DEFINING SERVICE FEES; DEFINING STRATEGIES FOR ASSURING THE LAB'S BUDGET

In most universities it is possible to charge students for the use of RP and DF machines. However, it is very difficult to establish a fair value for these services, so that students will still be encouraged to use the machines, but the lab will have enough funds for buying new supplies. An exact value is always difficult to obtain, but can be established based on a statistical study after a few months of use of the machines. Although in some universities labs need to support themselves, students cannot be expected to be the sole supporters of a RP/DF lab. In order to generate budget, labs can develop services for the outside community, as long as it does not interfere in the use of the lab by the students. For example, these works can be done at times when the labs are less used by the students, such as during vacations.

3. 18. CREATING A WEBSITE AND DEFINING ITS UPDATING FREQUENCY

Just creating a beautiful website is not enough. It is important to keep the lab's website constantly updated, as a way of communicating with students and other users.

3. 19. DEFINING A CALENDAR OF EVENTS, FOR THE TARGET PUBLIC

In order to make people feel like they belong to the lab's community, it is very important to offer activities at a regular basis. These activities can be communicated through the lab's web site and they can include introductory and advanced technical workshops for both students and faculty, invited lectures, and exhibitions of work developed in the school and elsewhere.

3. 20. PROPOSING EXTENSION PROJECTS FOR THE COMMUNITY OUTSIDE OF THE UNIVERSITY

At LAPAC a partnership with a public museum resulted in a 2x3m scale model for helping curators plan new exhibitions. The model has magnetic walls, on which the curators can stick scaled reproductions of the museum's paintings. Students enjoyed developing this project because they could see its impact to the community outside of the university.

3. 21. ASSESSING THE WORK DEVELOPED AND FEEDING-BACK

Finally, it is important to assess the quality of the products developed, the quality of the services provided, and the impact of the lab on architectural education, and to survey the need to acquire new machines, software and technologies. The results must be used to feed back the laboratory's rules and protocols.

3. 22. ESTABLISHING PARTNERSHIPS WITH THE LOCAL INDUSTRY AND DEVELOPING JOINT PROJECTS WITH THEM

In 2005, ISTAR labs developed a studio experiment with the aim of exploring the design and fabrication of innovative roof systems based on ceramic tiles using digital technologies. It included a collaborative teaching experiment involving the university, a professional research center and a factory. One of the aims of the project was to develop a novel learning environment where students would be in close contact with the Technological Centre for Ceramics and Glass, with industry partners, and with factories, in order to develop technically feasible products that could also be easily fabricated using the existing industrial projects. The collaborative process involved physical visits to factories, review panels including industry partners, and participation of the Laboratory of Advanced Production Techniques for prototype production. The final solutions are particularly elegant outcomes of this process. The fact that they led to five patent requests also shows that they have commercial value. In the end, it shows that innovation pays-off and that it could help ceramics factories to expand their business.

Besides the items described above, other ideas still need to be tested both at LAPAC and ISTAR, such as offering expert-consulting and training in digital fabrication-related skills, such as parametric modeling and scripting to the target public and the outside community.

4. Discussion and future work

It is important to say that the issues above do not need to be necessarily considered in the same order as they have been presented, and that they can evolve over time. Depending on the nature of the funding available to start the laboratory, it may be possible or not to dimension it according to the desirable objectives and to the expected target public. If the initial budget is too limited it may be necessary to restrict the public and the lab's objectives in the beginning, and start thinking about financial strategies to allow buying more machines and hiring staff. After this initial stage, the objectives and public can be progressively redefined, in order to reach the desirable state.

The authors have also been visiting digital fabrication labs throughout the world and interviewing their coordinators for collecting more important information to contribute to this work in progress. The final outcome of this research will include more examples of equipment, achieved results, and cost estimations, and is expected to help architecture schools plan new facilities.

The impact of the digital fabrication laboratories created by the authors on education and research in their respective schools will soon be published (Duarte, Celani & Pupo, 2010). In both cases, it is possible to say that students have become more involved in the design process and more creative. They have become enthusiasts of making models and prototypes, and their projects have benefited from the feedback given by their physical experiments.

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