Introducing digital fabrication into the architectural curriculum

Two Similar Experiences in Different Contexts

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Abstract. *The present paper describes two similar experiences in the setting up of digital fabrication laboratories in architectural schools and the introduction of such techniques in the schools curriculum, with the aim of answering the following questions: how long – and how much – does it take to incorporate these new technologies in a traditional architectural course? Both experiences were held in Portuguese-speaking countries, but within very different economic and cultural contexts (Europe and South-America).*
Keywords: *Rapid prototyping; digital fabrication; fabrication techniques for architecture; architectural curriculum.*

Introduction

The recent development of digital fabrication technologies is having an important impact on the architecture, engineering and construction (AEC) industry at two different levels: model-making and building construction.

On the one hand, after a period in which the advances in computer-graphics almost made physical scale models disappear from the architect's studio, rapid prototyping is bringing them back since the very early stages of the design process. On the other hand, the new construction methods opened up by digital fabrication techniques make it possible to build forms that would be unfeasible a few years ago. Therefore, these techniques should be kept in mind since the early design stages, modifying many design decisions at the very beginning of the planning process (Kalay, 2006; Chaszar, 2006).

For these reasons, the introduction of rapid prototyping and digital fabrication techniques in the design process is a fundamental issue today, and should be included in the education of the new generation of architects.

The present paper describes two similar experiences in the setting up of digital fabrication laboratories in architectural schools and the introduction of such techniques in the schools curricula, with the aim of answering the following questions: how long – and how much – does it take to incorporate these new technologies in a traditional architectural course? Both experiences were held in Portuguese-speaking countries, but within very different economic and cultural contexts (Europe and South-

America). One similarity, however, was the general skepticism of most of the faculty regarding the use of computers in the architectural profession, seen primarily as a representation, rather than a generative tool.

The experiences related described in this paper refer to ISTAR (the Architecture Research Laboratories of the School of Engineering of the Technical University of Lisbon, Portugal), and to LAPAC (the Automation and Prototyping for Architecture and Construction Laboratory of the School of Civil Engineering, Architecture and Urban Design of the University of Campinas, in Brazil).

One of the key factors to the success of the implementation of both laboratories was the scientific research approach along with a close relationship to the architectural practice. The first factor allowed both laboratories to keep rigorous methods of research and product development, while the second factor contributed to showing the direct applicability of the new technologies in the architectural profession, which was crucial to gain the support of even the most skeptical architects and professors.

Offering training workshops to the faculty members was another important strategy carried out in both laboratories, which resulted in the introduction of the new techniques in even more subjects than initially intended, not as an option, but in many cases as a mandatory technique. However, not all the studio instructors were able to see the digital fabrication techniques as an opportunity for trying new design strategies – most of them saw the laboratory simply as a state of the art model shop. The next challenge for both laboratories is to incorporate – both in terms of equipment and curriculum - the fabrication of full-scale prototypes with CNC equipment.

We expect that the experiences presented in this paper, along with the guidelines suggested, will help other schools to establish digital fabrication laboratories and to introduce these techniques in the curriculum, to allow the teaching of a seamless digital design process.

Laboratories´ history, objectives and funding

The ISTAR Labs were part of a larger strategy aimed at creating a set of curricular tools for supporting the teaching of architecture within the new undergraduate and graduate Program in Architecture at the IST, the Technical University of Lisbon School of Engineering. Such tools included several undergraduate and graduate courses, as well as a set of laboratorial facilities. The idea was to create an environment that provided students with state of the art design technology. On the one hand, the laboratories were partially inspired in William Mitchell and Woody Flowers's 'Design Studio of the Future' project (Duarte, Bento and Mitchell, 1999), which was aimed at studying how new technologies could be incorporated within architectural teaching and practice. On the other hand, the labs departed from knowledge, experience, and facilities already existing at IST, particularly in what virtual reality is concerned (Henriques and Sampaio, 2003).

The labs were funded by the Portuguese Science and technology Foundation (FCT-Fundação para a Ciência e a Tecnologia). One of the labs is the Computational Architecture Lab (LAC), which is the focus of the present article, and includes four modules: advanced geometric modeling, rapid prototyping, virtual reality, and remote collaboration, which shared the same basic space and provided the backbone of the electronic design studios.

The objectives of ISTAR are:

1. to create a set of laboratories that support architectural teaching and research;
2. to design, implement, and maintain a comprehensive Web-based environment that supports the community of students, staff, faculty, alumni, and prospective applicants;
3. to investigate how computers and information technology can be integrated in the design process;
4. to create a research environment that supports creative and innovative design teaching and

Figure 1
ISTAR laboratory

practice;
5. to develop new expertise oriented towards new architectural and building solutions;
6. to provide technology-oriented consulting services to the AEC industry.

LAPAC is a pioneer in the use of digital fabrication techniques for architecture in Brazil. It was created in 2007 as part of a large research project about the use of new theories and technologies in the architectural design process. The economic resources for this project came from São Paulo state's official research funding agency, FAPESP. When this research project ends in 2010, the lab will be incorporated by the school of architecture. Just like ISTAR, LAPAC was also inspired by William Mitchell's introduction of Rapid Prototyping techniques at MIT in the late 90´s and early 2000´s.

Due to the type of funding used to create the laboratory, LAPAC is not intended for offering external services, but only for undergraduate and graduate academic research. However, some projects have been developed for external institutions, as an extension to the non-academic community. These projects have been selected based on their potential for generating situations in which research can also be developed.

Equipment

The four modules that compose the Computational Architecture Lab (LAC), at ISTAR, are (1) advanced geometric modelling, with computer programs such as AutoCAD, Revit and Rhino, besides software used to image processing and animation; (2) rapid prototyping, that which is equipped with a FDM Rapid Prototyping Machine (Stratasys Plus), a laser cutter (Universal Laser System X660), a Vinyl Cutter (Roland) and a Milling Machine (Roland), that also works as a 3D digitizer; (3) a virtual reality immersion system (EON) and (4) a remote collaboration system (RDIS videoconference system). LAC has also 24 desktop computers, an A3 flatbed scanner and an A4 laser printer (Figure 1).

LAPAC (Figure 2) is equipped with a 3D printer (ZCorp 130) and a laser cutter (Universal Laser Systems X660), and is currently acquiring a large format CNC router (a 1.80x2.80m MTC Robotics). While the 3D printer and the laser cutter are used for making scale models, the CNC router will allow new experiments with the production of actual size constructive elements. 3D scanning is done with David Laser Scanner, a computer program that allows acquiring 3D data without the need for special equipment (just a laser pointer and a web-cam).

Besides the digital fabrication equipment, LAPAC has also 2 tablets, 4 laptop computers, 6 desktop computers, an A3 deskjet printer and an A3 flatbed scanner. The laboratory is equipped with different computer programs, such as AutoCAD, Rhino, ParaClaoud and Pepakura, which allow preparing files for digital fabrication.

Figure 2
LAPAC laboratory

Research and projects under development

Among LAC productions, there are some deriving from an undergraduate course -DAC II, (Figures 3 to 4), where the approach is the programming and fabrication of complex architectural forms, using the rapid prototyping equipments available at the laboratory. Some others (Figures 5 and 6), are the finalists of the I Taxi Festival, sponsored by 'Institut pour la ville en mouvement' that rewarded six taxi stands designed by architecture and industrial design students from Portuguese universities in 2007.

Figure 5
Taxi Stand Prize, Lisbon, Portugal
Students: Ana Rita Antunes, Jona Rodrigues and Luís Ferreira.

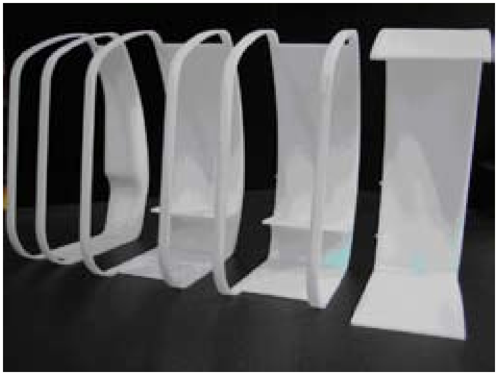

Figure 3
Scale model of a house generated by a computer program. Prototyped in a laser cutter. Students: António Góis e José Borges.

Figure 6
Taxi Stand Prize, Lisbon, Portugal, 2007 – First, Students: Andre Souza, Ana Rita Silva and Emanuel Moita.

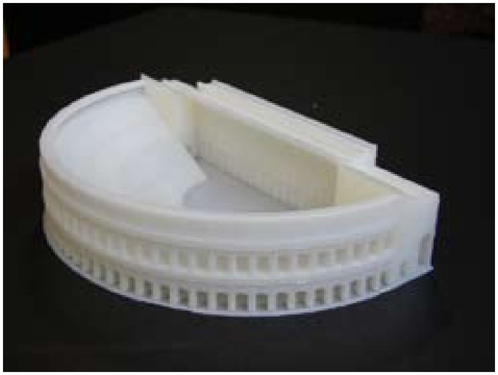

Figure 4
Roman theater scale model generated by a computer program. Prototyped in a FDM printer.
Students: Duarte Pape e Tiago Sousa.

Considering that the courses LAC was supposed to support used other lab facilities to accomplish their goals, it is reasonable to consider that LAC started its activities even before its own equipment were installed in 2005. In these circumstances, we may set its birth date back to 2001, when the classes were in place and the initial research proposal was submitted for funding to FCT. In this time 7 year time frame, (2001-07) LAC has significantly contributed for about 11 bachelor thesis or graduating design projects, 14 pre-Bologna master theses, 7 Ph.D. theses, 12 international research papers, 1 international design and 1 academic awards, 8 national patents, 1 commercialized product, and 1 startup.

Figure 7
Undergraduate research project: Production of tactile scale models for space orientation of the blind and visually impaired with rapid prototyping techniques.
Student: Luís Fernando Milan

Figure 8
Master degree research project: An exploratory study about the use of fabrication and rapid prototyping techniques during the design process.
Student: Érica Pinheiro Vieira

Figure 9
PhD research project: Rapid prototyping and digital fabrication as a new challenge in architecture learning process.
Student: Regiane Pupo

LAPAC has also been productive, although much younger than ISTAR. Thirteen undergraduate, eight master degree, and one doctorate research projects have been developed at LAPAC since the laboratory opened in 2007. Besides, three extension projects are also being developed at the laboratory. Figures 7 to 10 show some of these projects. As a result, twenty five research papers have been published in conferences and scientific journals.

Courses and training

In the peak of its use in 2006, LAC was used by 110 students enrolled in the three mandatory undergraduate classes (CAD I, CAD II, and CAAD Studio), plus by a few graduate students. In addition, the former head of the lab has moved to the school of architecture and was substituted. The number of users decreased since then, mainly due to the re-organization of the undergraduate program to match the European Bologna agreement, which led to the cancellation of the CAAD Studio and to the sliding of the other two classes to later years (2nd and 3rd). In addition, the former head of the lab has moved to the school of architecture and was substituted by other instructors who are less familiar with the technology. The number of users is expected to rise again in the coming years as the new instructors become more familiar with the technology and succeed in inserting its use in their classes.

At the moment, ISTAR does not have monitors in charge of its surveillance and maintenance. These have been guaranteed by a pool of professors, including its former head. However, there are proposals under way that aim at securing the support of two lab monitors seven hours a day, five days a week. In turn, they organize similar courses on a regular basis to instruct other students and professors on the use of the equipment. The idea is to guarantee that there is a group of people knowledgeable of the use of the equipment always around, so that the lab does not suffer from the lack of monitors when they have to stop working at the lab or graduate.

Figure 10
Extension Project: Production of a 1:25 scale model of a museum with rapid prototyping techniques, with planning purposes. Students: Ana Emilia Claudino, Evelin Bottesini and Joyce Carvalho.

In regards to its public, LAPAC´s situation is very different in comparison to ISTAR. Due to its nature and type of funding, it is not intended for supporting undergraduate courses. However, the laboratory offers crash courses and workshops for studio instructors and senior students of UNICAMP´s architecture school. This year, nearly 50 senior undergraduate students have attended workshops at LAPAC. These students are now developing their final graduate projects with the support of the laboratory's infrastructure. Architectural design instructors have also participated at these workshops to better advise their students on the use of the available machines.

Through UNICAMP´s student's financial aid program, it was possible to hire three monitors for LAPAC. These monitors work in the extension activities, help other students, and schedule the use of the machines in the laboratory. Although the monitors are junior civil engineering students with no prior experience in digital fabrication, they were able to learn how to use the machines very quickly and have been very helpful.

Challenges

There are two major challenges faced by ISTAR Labs and LAPAC in particular today, one related to their purpose and the other one to their operation. The first is to overcome the suspicion on the behalf of the instructors who are less familiar with the use of the computational means in architecture. There are two steps in this regard. First, is to lead the new CAD instructors to use the lab in their classes, thereby recovering some of the teaching and research framework. This should raise enthusiasm on the behalf of the students. The second step is to make the other instructors more familiar with the lab and involve them in decisions concerning the lab at an early stage. This could be accomplished by organizing more crash courses and by discussing with them ways of using the lab that benefit their classes.

Another challenge is related to operational issues. Currently, LAC lab is in a catch 22 situation. Without monitors it has a limited use, particularly on the behalf of external commissioners. Without these, it is difficult to raise the funds to support itself. This means that it needs some internal support before it reaches a 'cruise speed.' Another possibility is to look into external sources of funding, such as private and institutional sponsors.

LAPAC, on the other hand, can count on monitors through UNICAMP´s student financial aid program, but lacks financial resources for buying supplies, such as binder and powder for the 3D Printer, which need to be imported from the United States at a high currency exchange rate.

Collaboration between both labs

The collaboration between ISTAR and LAPAC was the result of the following facts:

1. Both laboratories are (or at least were, when created) pioneers in the area of automation and digital fabrication for architecture in their countries. Therefore, the possibility of exchanging experiences with another laboratory with similar conditions was fundamental for acquiring self-confidence in terms of getting funding, choosing and maintaining the equipment, defining research topics, and, above all, justifying the whole project.
2. Both laboratories were created with similar pur-

poses, because their idealizers had had their first contact with digital design media at the same institute of technology in the United States (MIT), with the same adviser (William Mitchell). For this reason, their agenda included the use of digital fabrication techniques not simply as representation tool, but within a whole digital process of design, rooted on a solid computational theory of design.
3. Although both laboratories were created in new architecture schools, which were supposed to be open-minded towards the use of new technologies, it turned out that digital design media was still seen exclusively as a representation tool in both cases. Therefore, both laboratories faced the challenge of modifying the attitude of other professors towards the new techniques that were being introduced.

The collaborative work between the two laboratories has been including the following activities:

- Developing joint experiments, in order to evaluate the advantages and disadvantages of the equipment in each laboratory;
- Exchanging graduate students for internships;
- Participating in graduate research projects;
- Visiting the laboratories;

The laboratories are currently formalizing an official protocol that will allow students from each of the schools to take courses for credit in the other one. However, it takes time and proper justification to approve this type of document. The laboratories also plan to organize joint seminars and conferences in the near future, but again funding may be an issue, so the first step is to start looking for funding programs that support international collaboration between Brazil and Portugal.

Results

Despite the human and funding difficulties faced by ISTAR and LAPAC today and in the past, the results achieved so far are very promising.

The main intangible result has been the acquisition of competences by students to develop innovative architectural design projects with to the use of state of the art design technologies. Other important results were to gain a good understanding of how new technologies can be incorporated with success in the design process, and to provide the architecture, engineering and construction industry (AEC) with consulting services in terms of design technology.

The tangible results include:

1. direct application of the techniques (the work developed by the students within the context of classes that used the laboratories and the work developed in extension projects);
2. the development of methods for producing scale models and for using digitally fabricated models during the design process;
3. the development of pedagogical methods and proposals for the introduction of digital fabrication in the architectural curriculum (based on the observation of the use of the laboratories by students);
4. master and Ph.D. theses, research papers, academic and design awards, patents, and startups.

In summary, the results expected when both laboratories were created were, to a certain extent, achieved. The technology has been integrated in the architecture programs and the use of skills that students acquired in the supported courses has extended to other courses, despite some resistance on the behalf of other instructors. The courses and the labs have served as the basis for developing several master and doctorate theses. The work of students has led to innovative and creative approaches with recognized results. For instance, one student from IST won the FEIDAD Award in 2005 and a student from FEC won the best paper award at SIGRADI

2007. In addition, several patents were obtained by ISTAR, some of which have yielded new products for the construction industry that are now being commercialized. This, in turn, has prompted the industry to take the initiative to commission new projects. Finally, the courses and the labs have contributed for increasing the students' employability.

Conclusions

ISTAR and LAPAC labs represent a new strategy for professional education in general and architectural design programs in particular – a strategy that employs educational technology to build upon the established strength of the studio method, and the design community experience with it. The strength of the studio method was its problem-oriented focus by engaging students in complex ill-defined problems that require creativity and cross-disciplinary work. The proposed strategy was to create a robust research environment that complements and improves the traditional studio.

Acknowledgements

The authors would like to thank the funding agencies that have been supporting ISTAR (FCT, Portuguese Science and Technology Foundation) and LAPAC (FAPESP, CAPEs, CNPq and SAE-UNICAMP).

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