Technology transfer in digital prototyping by means of research laboratories: two case studies in architecture schools

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ABSTRACT: Based on the authors' experiences implementing research laboratories in undergraduate architecture schools in Brazil and in Portugal, this paper proposes some guidelines for creating digital prototyping labs for producing architectural scale models. Questions such as selecting techniques and machines, defining the laboratory layout, training and monitoring students and professors, developing work protocols, establishing partnerships with other laboratories and institutions, organizing events, defining operational and security rules, proposing relevant research topics and developing meaningful extension projects are addressed. The objective of the paper is to contribute with other architecture schools that plan to establish similar laboratories.

1 INTRODUCTION

Rapid prototyping and computer numeric control (CNC) machines started being incorporated in the architectural practice in the 1990's, for three main applications: the production of (1) architectural scale models, (2) the production of full scale prototypes of construction parts, and (3) the fabrication of non-standard construction parts. The present paper will focus on the first application and its incorporation in the architectural curriculum.

Architectural scale models are a special type of prototypes. They can be categorized in different typologies according to production methods - mass, surface and linear elements; theme - geography, landscape, garden, urban setting, building, structure, interior, construction detail, furniture and object design; purpose - design exploration, analysis, communication of ideas, presentation to the client and exhibition); and level of elaboration (Knoll & Hechinger 1992).

Rapid prototyping machines can build prototypes layer-by-layer in an automated way, from a 3D digital model. They were originally developed for product design development. CNC machines, on the other hand, are computer-operated lathes, mills and other types of machines, which were originally developed for industrial use. However, some authors include CNC machines under the term "rapid prototyping". Lennings (1997), for example, has proposed that rapid prototyping is "a process that automatically creates a physical prototype from a 3D CAD-model, in a short period of time." Other authors, such as Sass & Oxman (2006) use the term "digital fabrication" to refer to both additive (layer-based) and subtractive (CNC) techniques.

Since the focus of this paper is the use of computer-controlled machines – including additive and subtractive techniques – for producing scale models, we will use the term "digital prototyping" to refer to both technologies at the same time. The term rapid prototyping will be used in the classic way, to refer to layer-by-layer production techniques.

Digital prototyping techniques can substitute traditional model shop techniques with many advantages: precision, safety and integration with the media in which designs are currently developed (CAD software). Based on current descriptions of digital prototyping applications in architecture schools, it is also possible to say that these techniques encourage architecture students to build models and test their ideas more often and more efficiently during the design process. However, it is important to develop strategies for integrating these techniques in the architectural curriculum.

The present paper presents guidelines for implementing digital prototyping research laboratories in architecture schools, based on the authors´ experiences in Portugal and in Brazil. Specific details of the authors´ experiences have already been published in Pupo, Duarte & Celani (2008). Critical issues in the processes of planning, setting up and running such laboratories are presented.

2 PLANNING THE LABORATORY

2.1 *Selecting machines*

The process of planning a digital prototyping laboratory for an architecture school starts with the selection of machines. According to Burns (1993), there are three main types of digital prototyping machines: additive (also known as rapid prototyping), subtractive and formative. The subtractive group includes milling and cutting. Formative machines are still not commercially available (Lennings 00).

From a pedagogical point of view it is interesting to include at least one of each category in a digital prototyping laboratory. Besides, the production of most models requires the combination of different techniques. When this is not possible, due to limited budget, space, logistics or other constraints, it is important to establish partnerships with other laboratories or institutions that can provide access to a whole variety of technologies.

2.1.1 *Additive technologies*

Among the available additive technologies, 3D printing (3DP) and fusion deposition modeling (FDM) are the most suitable for architectural applications.

3DP models made of plaster-like materials are not very strong and do not allow constant manipulation, which is not an issue for visual evaluation purposes. This kind of model does not have a very high resolution in comparison to other techniques, but in architectural model-making there is usually no need for screwing or snapping parts together. The lack of precision can actually be positive in the early phases of the design process, in which some features of the building are still not very detailed. On the other hand, the 3DP technique is relatively cheap in terms of initial investment and supplies, which is crucial for the economic viability of the laboratory.

Another additive technique that can be used for architectural applications is FDM. The difference between both technologies relies in the type of geometry that can be produced with each of them. Certain geometries, such as truss structures, require too much support material for their construction, which can be hard or even impossible to remove.

Although the 3DP technique is relatively less expensive than the FDM technique, both are in the same cost range. Both techniques present the inconvenience that they need post-processing. 3DP models need to be sealed with a special resin, and FDM models need to have the supporting material removed. For architectural representation purposes, however, 3DP models are often just sprayed with acrylic paint.

Other additive techniques can also be used for making architectural models, but they present some inconveniences, such as high cost of machine and/or supplies (e.g. Selective Laser Sintering) or limited envelope size (e.g. Desktop Factory, which can build parts of up to 5'x5'x5'). In some cases, however, it is possible to use underutilized machines and second-hand material from a partner laboratory at a reasonable price.

The 3D files that are used for rapid-prototyping can be produced in regular architectural CAD software and exported as an STL file. It must then be imported into the machine´s proprietary software, which automatically performs the layering process.

2.1.2 *Subtractive technologies*

Subtractive machines can be divided in two main types, according to the type of data they use. Sculpting machines typically use 3D models, while cutting machines typically work with 2D digital drawings. In comparison to additive technologies, they present the advantage of not requiring special supplies, which makes their use much less expensive.

Sculpting

Among the available 3D subtractive technologies, CNC routers and hot wires are the most suitable for producing architectural models.

CNC routers can have three, four or more axes, and one or more router spindles. Three axes routers can move in the X, Y and Z directions; four axes routers also have one axis of rotation of the router spindle, and so on. The more axes a router has, the more expensive it is, but the greater freedom is has in terms of geometries that can be sculpted. Routers can sculpt different types of materials, such as wood, MDF, acrylic and foam. If a layer-based production technique is available, usually a three-axe CNC router is enough for architectural model applications.

Hot wire CNC machines can sculpt foam blocks based on 3D digital models. This method has more limitations than the CNC routers in terms of geometry, but is faster and less expensive.

Although the 3D models can be made in any architectural CAD system, these types of subtractive machines require special software for planning the production process, which may involve tool change and the automated arrangement of parts for optimization.

Cutting

The most popular machine in digital prototyping laboratories of architecture schools nowadays is the laser cutter. Laser cutters can cut different types of thin sheet material, such as paper, cardboard, corrugated cardboard, acrylic, bass wood, and MDF, from 2D CAD files. It is possible to associate different power levels and speeds to each of the drawing colors, so the machine can be used for cutting, scoring and making light folding marks.

Blade cutters, also known as vinyl cutters, are a cheaper alternative to laser cutters. Originally used for cutting vinyl signs, they can cut different types of thin, flexible material, such as plastic and paper.

Cutting machines don´t require special software. They can be used like a printer from a regular architectural CAD software. In certain CAD programs it is possible to automatically planify 3D volumes for flat cutting, which makes the 3D-2D-3D worksflow much easier.

CNC routers and hot wires can also be used with 2D files for profiling.

2.2 *Other expenses*

Besides the initial investment in machines, it is necessary to plan ahead a minimum stipend for running the lab, which must include replacement parts, supplies, safety equipment (masks, gloves, ear plugs, etc.), maintenance and insurance.

When making a digital prototyping laboratory budget, it is also important to include other equipment, such as a good camera, computers, and an exhaust system, as well as specific software, such as milling, planification, etc.

3 SETTING UP THE LABORATORY

Once the machines are chosen and the funds are raised, it is important to establish a functional layout for the laboratory. It is also important to set up a training program for faculty, staff and students, and to develop a protocol of use and safety rules.

3.1 *Laboratory layout*

Safety is the most important issue when planning the layout of any teaching laboratory. In the case of a digital prototyping laboratory there are three main types of potential risks: fire, intoxication and hearing loss. Laser cutters present these three types of risks simultaneously and need to be used very carefully and under permanent surveillance. It is important to plan a fire escape, to leave a fire extinguisher at hand, to install a good exhaust system and to provide natural ventilation in the room. When buying a laser cutter, it is possible to specify an optional compressed-air system that reduces the risk of fire, especially when cutting very inflammable material, such as corrugated cardboard.

CNC routers also potentially present the three types of risk, although fire is less common. It is possible to adapt a vacuum cleaner to the CNC router head, so that the milled powder will not fly away in the room. Depending on the rotation of the router and the material being milled, a CNC can be extremely noisy. For reducing the noise it is possible to use an acrylic cover or walls around it. It is important that the walls are transparent because this type of machine also needs permanent surveillance.

3D printers exhale a very thin powder that stays suspended in the air and shouldn´t be breathed. This powder can be also harmful for computers and other machines in the room. If the machine is used frequently, it may be necessary to install it in a separate room. This type of machine usually does not need surveillance.

Blade cutters are probably the less potentially harmful among the machines described above.

The laboratory layout should include tables for assembly and post-production of the models, open shelves for storing work in progress, and cabinets for storing expensive equipment and supplies.

3.2 *Training*

It is very important that faculty, staff and students are trained before using a digital prototyping laboratory. The training should include general knowledge about digital prototyping techniques, a methodology for making architectural models with digital techniques, safety rules and operational rules.

The laboratory´s safety and usage rules and emergency contacts must be available for any person at any time, on the laboratory´s web site and on its walls. Operational rules must include not only time schedules, but also cleaning and storage rules.

The methodology for making architectural models with digital techniques must include directions for choosing production processes and materials, preparing CAD files, using the machines and post-processing the models. Tutorials for using specific software must be available in all the laboratory computers.

4 RUNNING THE LABORATORY

Once the laboratory is set up, it needs to be monitored for safety, ideally by permanent staff. When staff is not available, advanced students can take turns as monitors and teaching assistants.

It is important to offer training workshops regularly for new students and faculty, and to organize special events, such as invited lectures and exhibitions. It is also important to develop interesting research projects and meaningful extension projects. Finally, the laboratory must be integrated in the curriculum through systematic use by curricular subjects.

It is important to keep a website with updated information about the machines, events, schedules and planned workshops. The website should also include self-explanatory tutorials and downloadable templates.

5 DISCUSSION

In this paper some guidelines for setting up a digital prototyping laboratory for producing scale models in an architecture school have been presented. There are still many questions to ask, such as "how many machines should be planned per student?", "how much does it cost to maintain a digital prototyping laboratory?" and "how long do these machines last"?

Even though, we expect that this paper can help establishing a protocol for setting up new laboratories in architecture schools.

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