Teaching Digital Fabrication in the Post-Industrial Era

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Abstract. *The creation process of a product is a work of immersion and concentration, and is, seldom linear. A primary concept most likely will undergo modifications during the process. In what concerns teaching, a great number of Brazilian higher education institutions act exclusively on the formation of students as specialists in the creation of primary concepts. As for the process of refining an idea, as in prototype production and observation, this phase will only be learned and understood on the job market. Nowadays, new methodologies for digital fabrication put into evidence other strategies resulting from post-industrial production.*

Keywords*. Digital fabrication, digital modeling, prototyping, education*

Introduction

Little investment is required to start off with digital fabrication in Design, but the creation process and methodologies of teaching, related directly to machines and automation, produces a big change in education. Today's industry is able to adapt to local demands, due to the facility of the reduction of product development cycles. We are producing more and better with less energy and lower cost, due to the possibility of parameterization and new methods of digital design of a product, for simultaneous markets and evolving requirements, ability coined as Glocal (global+ local issues) Design.

Brazilian automotive and aerospace industries have had positive returns in spite of international financial crisis, thanks to advances like these, in plant layout design and the use of the so called emerging technologies. On the other hand, several Design schools focus exclusively on the creation of primary concepts. Physical models are not always produced, fabricated manually, or even when computerized, do not add any value to the design process, other than providing a better (three-dimensional, look and feel) view of the intended product.

In the Brazilian automobile industry, the adaptation and customization began in the 1970's, with the Volkswagen beetle, aimed for the middle and lower income families, without the luxuries of import models, their powerful engines and chromed parts. This market segment gave origin to the so called Flex cars (running on petrol, ethanol and/or natural gas), nowadays more comfortable, even when powered by 1,000 cm3 engines. Foreign designed models produced in Brazil and exported to other countries, only because of lower labour costs, where at first customized for local environment and cultural requirements. Nowadays, products, designed locally, originally for domestic use, have found their way into the global markets. These include both the cars and the ethanol fuel (Silva, 2009).

As a newcomer in the design industry, Brazilian achievements where not, and still aren't easy, but are the result of fiscal incentives (Federal Law 10.973/04) and partnerships between industry and higher education schools, with the creation of regional research and diffusion centres. The name Design, beyond invention and innovation, now carries and extra added value of sustainability. The design professional, perceived as highly valued, but not yet (and most likely never) a diploma required competence in Brazil, faces enormous market pressures to save businesses from economical recession due to global market financial crisis.

This context of expectation and doubt requires a critique of the technologies and methodologies of Industrial Design. This text is focused on such matters, when analysing aspects of digital modelling and fabrication and rapid prototyping in teaching Design.

Local government incentives and the academic community

Several initiatives for new Design courses and instruction and research centres have been put forward in Brazil, in the last years. The São Paulo state government has recently created the São Paulo Design Programme (São Paulo, 2009). Among the projects proposed, is the construction of a Prototyping Centre to offer to micro, small and middle sized companies the benefit of an environment based on the above cited technological binomial, i.e.: teams of professionals trained in the use of computational tools and modern techniques in design and manufacturing; management methodologies that enable the integration and cooperation of the several activities that cover the cycle of product development.

In order to attain the proposed objective, the São Paulo Design Programme states three goals, as follows:

- Constitute a team of designers, engineers and technicians, highly skilled in the use of modern tools and methodologies in design and manufacturing;
- Produce of educational material necessary for teaching advanced design and manufacturing technologies, to be offered to the industrial community;
- Build and integrated environment for design and manufacturing, based on principles of simultaneous engineering, i.e., cooperative work among professionals of different disciplines during the whole product development cycle

The São Paulo Design site on the Internet names some partners, SEBRAE/SP, IPT and FIESP/CIESP (two civil associations for business and industrial development and a research institute), and refers to others such as micro, small and medium sized companies and the academic community.

Regarding the academic community, at least until the writing of this text, listing of education institutions on the above Website remains a broken link. There are, and we have visited several higher education and research institutes, with laboratories, human and other resources, dedicated to the study of digital fabrication, including the so called rapid prototyping.

In Campinas, 100km from São Paulo, at the Faculty of Civil Engineering (FEC), of the State University of Campinas (UNICAMP), is LAPAC - Automation and prototyping for architecture and construction laboratory, with whom we have a cooperation agreement in research. UNICAMP, which does not have a course on Design, has been experimenting with digital fabrication in Architecture. LAPAC started off using equipment from the nearby CenPRA – Renato Archer Research Centre (www.cti.gov.br). LAPAC has acquired a laser cutter from Universal Laser Systems (www.ulsinc.com), a 3D printer from ZCorp (www.zcorp.com), and more recently, a large Router, from MTC (www.roboticas.com.br). Use of such equipment is restricted to students with research projects on the subject (www.fec.unicamp.br/~lapac/index.htm).

In Santa Bárbara do Oeste, 140 km from São Paulo, is SCPM – Computational systems for design and manufacturing laboratory, of the Faculty of Engineering, Architecture and Urbanism (FEAU) of the Methodist University of Piracicaba (UNIMEP). SCPM has a partnership agreement with Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik (IPK) of Berlim and ROMI, one of Brazil's leading machining manufacturer. SCPM uses a heavy duty, Siemens controlled, milling high speed cutter, from ROMI. Students have access to this machine and leading CAD/CAE/CAM software (www.unimep.br/feau/scpm).

In São Paulo, at SENAC University, is SENC – Workshop of the course on Design. Bureau type equipment has been set aside and students now operate heavy duty CNC machining. SENC is itself operated like an industrial plant and students follow rigorous training as in daily operations (www.sp.senac.br).

In São Carlos, 240 km, from São Paulo, at the School of Engineering (EESC), of the University of São Paulo (USP), is NUMA – Advanced manufacturing centre (est. 1988). NUMA aggregates researchers from several universities in the state of São Paulo, USP, UNICAMP, UNIMEP, cited above, Federal University of São Carlos - UFSCar, and also from Aachen, Germany (www.numa.org.br).

SENAC and UNIMEP are private owned, global job market oriented, schools. For this matter, they have opted for the kind of equipment, that students will likely use in the industry, such as Datron (www.datron.de), Romi (www.romi.com.br), Tecnodrill (www.tecnodrill.com), and Veker (www.bener.com.br). Initial investment, per unit, ranges from fifty thousand to more than one hundred thousand US dollars, and expected lifetimes range from fifteen to twenty five years.

Other schools have adopted another approach, towards smaller, cheaper, assemble it yourself kits or bureau type machines. The latter are intended for use on design offices enabling them fabricate their own models, usually mock-ups. Lack of robustness is counterbalanced by price, smaller footprints and extra axes, necessary for producing more complex forms, such as jewellery or hulls. An alternative to machining (Fonseca et al., 2006), are the so called rapid prototyping (RP), additive technologies (Volpato, 2007).

Schools with legacy equipment, such as milling cutters and lathes, can benefit from CNC retrofitting, specially if capable of handling tough metals (an expensive requirement for new machinery), as illustrated in Figure 1.

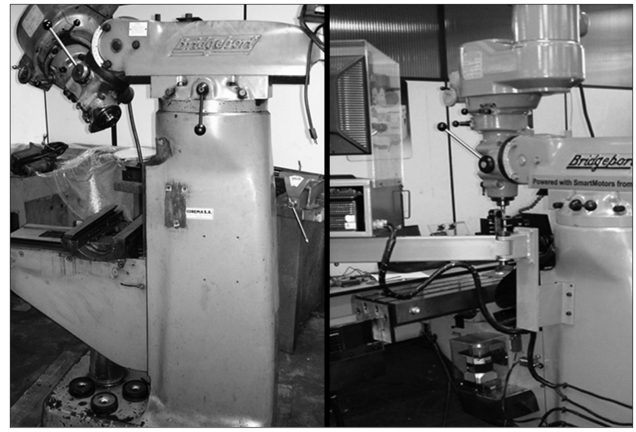

Figure 1. Retrofitting of a legacy machine.

Figure 2. Synthetic cork for gasified beverages.

Teaching digital fabrication in Design

The first CAD software, Sketchpad, was developed in MIT (Massachusetts Institute of Technology) in 1961, by Ivan Sutherland. With the advent of personal computers, CAD use flourished in the 1980's, and were gradually inserted into school programmes.

The dispute over teaching with software in undergraduate courses is a long one, but it's noteworthy to observe how Forti (2005) analyses some Design schools in Rio de Janeiro, where professors have contradictory opinions, arguing over if a faculty is the appropriate place for offering software classes. Such quarrel is meaningless. CAD applications have evolved to full CAD/CAE/CAM systems, and are completely taking over the drawing board, mostly because of their analytic tools, rather than their drawing capabilities.

The creation process of a product is a work of immersion and concentration, and is, seldom linear. A primary concept most likely will undergo modifications during the process. In what concerns teaching, a great number of Brazilian higher education institutions act exclusively on the formation of students as specialists in the creation of primary concepts. As for the process of refining an idea, as in prototype production and observation, this phase will only be learned and understood on the job market.

The concept of idea refinement, at school, must include a series of observation and testing exercises, and reasoning, which empowers students in solving problems not evident in primary ideas or digital models (Lara et al., 2008). The solutions applied to study models (up to prototypes), throughout revisions, is the correct path towards such refinement. Students will understand the laws of physics governing product functionality. This knowledge can only be acquired through practice.

An illustration of such process is described as follows. Initial concept is of a synthetic cork with a lever, for ease of opening of gasified beverages, improving a former product, from problems identified, through market research (Lara et al., 2008). Figure 2 consists of three photographs of intermediary and final results. Top right is of an early study model. Bottom right is of a prototype being tested on a bottle. Left photo shows the machining produced injection cast, to be used in final production.

When the first cork prototype was tested, gas leakage and problems operating the lever where observed, identified and corrected.

Conclusions

Several schools in Brazil traditionally teach craftwork design in Architecture, through manual tools and machinery. Education has ultimately focused in developing creative initial concept solutions. In Architecture and Urbanism, drawings are not only technical but are themselves considered works of art. Since the introduction of Design courses in Architecture schools, the importance of physical modelling has been renewed. In Industrial Design, technical drawing is minimalist, dictated by mechanical drawing standards. On the other hand, in the product development cycle, time spent on model evaluation and testing can be (and usually is) much higher than what is spent on the initial concept design.

We conclude that, for that matter, digital fabrication technology must be gradually introduced, in the following order:

- Start with low cost milling cutters or routers and laser cutters. These should have sufficient X, Y and Z yields to handle bulky low cost materials such as foam, wood and cardboard;
- Existing subtractive heavy duty machines, capable of handling tough metals can be retrofitted with CNC, also enabling cast production, for use on small injection moulding machines. Retrofitting of machinery render their usage only for CNC. Existing technical staff must undergo training on equivalent equipment before such change is implemented. Acquisition of injection moulding machines is optional, because of their high cost (consider outsourcing);
- Acquire heavy duty lathes, milling cutters (new or retrofitted) or machining centres. Prioritize safety, large Z yield, automatic tool change, number of axes, high speed cutting and precision, in this order;
- Acquire 3D laser scanners and robust additive (RP) machinery, whose process and materials provide precise, stable and resistant study models.

The approach towards computer and software acquisition accompanies investment in machinery. CAD/CAE/CAM software must be compatible with the intended fabrication processes. Professors, instructors and students must undergo prior theoretical education on the subject, not only training in the specifics of an application. Software must be acquired, learned and used (e.g. in simulations) in advance of the corresponding machinery.

After full implementation of the above phases, with proper education and training, students should be capable of building physical study models, mock-ups and prototypes. We emphasize that the first three phases cited above should prioritize the acquisition of domestic technology, designed for use in schools, and where absolute precision is of secondary importance.

Until, and even after, all the above phases are reached, ongoing courses must benefit from knowledge gained in other schools and research centres, that can be achieved through cooperation and exchange of information.

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Credit

Figure 1: Choice of equipment, software and workshop layout design must be determined through careful planning, based on intended student professional profile (Avedaño, 2005), and consistent with school curriculum, course programmes and class activities.

Credit Figure 2: credit: photo by Everson Navarro