Assessment of Digital Fabrication in Architectural Teaching

Rodrigo García Alvarado¹, Pedro Salcedo Lagos², Underlea Bruscato³

¹Universidad del Bio-Bio, ²Universidad de Concepción, ³Unisinos

Abstract:

This paper reviews several activities of digital fabrication in the teaching of architecture, in order to identify proper strategies and conditions to incorporate these technologies in professional education. It describes experiences carried out in Chile and Brazil, and a common evaluation through a virtual platform (developed in moodle), according to Problem-based Learning’s concepts and constructive subjects. Besides, in one case it reviews the educational performance of students and interviews with teachers and students. This review showed a positive appraisal of activities, in particular design exercises, although with some specific weaknesses. It also demonstrated the application of the virtual platform in order to evaluate activities and the impact of these technologies in working and teaching practices.

Key-words: Digital Fabrication, Architectural Teaching, Problem-based Learning.

1 Introduction

New digital manufacturing technologies allow the elaboration of physical objects directly from computer designs. To make test models or definitive elements for architectural and engineering projects. Thus, the education of these professionals should incorporate soon digital manufacturing technologies. However, the teaching of new tools requires proper integration in the regular processes and faces several combined factors (e.g. technical, aesthetic, functional). Diverse experimental activities have demonstrated the potentialities of digital manufacturing in the architectural work (Afify, 2007; Caldas and Duarte, 2005; Ficker and Zieta, 2006). These experiences show how digital fabrication gives a closer relationship of the design with the material condition, suggesting renewals of practice and new constructive possibilities. However, proper strategies to integrate these technologies in the teaching are not clear, nor are working conditions, which are crucial to its pedagogic involvement.

These technologies consist in machines that receive geometric information from computers to elaborate physical elements by subtractive or additive operations (Seely, 2004). The subtractive systems, known as computer-numeric-control machines (CNC), remove material by means of millings, knives, laser-beams or water-jets, in workbenches or robotic arms, to reduce volumes or to cut flat elements. Additive systems, known as rapid prototyping machines (RP) or 3D-printers, solidify material based on gases, liquids or dust, to elaborate complex shapes but normally in reduced sizes. These machines vary mostly in their work
sizes (from little desktop machines to big industrial facilities), as well as in the materials used, velocities of operation and finishing of the elements elaborated.

Digital manufacturing systems are being used extensively in the metal-mechanic industry, as well as in the elaboration of domestic products or building components. Professional firms and education institutions can use small size machines or external services to apply these technologies in projects. To collaborate in several quantitative and qualitative features. Manufactured elements can be more varied, precise and quickly elaborated. The development of real pieces or study models for can support the material understanding of design allowing the revision of properties of weight, volume, finishing, lightning and appearance. They also allow the revision of structural, physical, environmental and constructive behaviours according the conditions of elaboration and tests available. In particular cutting machines can make cladding or structural elements, with processes of finishing and assembly. Digital fabrication requires defining execution conditions of the pieces (sizes, appearance, fixtures), as well as procedures (graphic conventions, assemblies, repetitions). These requirements incorporate in the design process a more physical and constructive detailing than usual, and awareness of temporality and material responsibility, that is related with environmental conscience. In this way, digital fabrication promotes an important renewal of building processes, with new production strategies focused on customized massification.

The constructive potentialities of digital fabrication have promoted its incorporation in teaching mostly through experimental projects, based on architectural education is strongly targeted to design processes. This orientation is related to the theory of Problem-based-Learning (PBL). The problem resolution through technological media allows students the construction of their own knowledges and promote theirs creativity. In this way it is expected to educate professionals with capabilities to develop complex tasks like research, evaluate and resolve problems (Barros and Kelson, 1996). Problem-based learning is a pedagogic method...

Fig. 1. Digital Manufacturing Equipment (from up-left to bottom-right): Industrial Plasma-Cutter, Timber-boards router, Milling machine and Laser cutter.
featured by the development of challenges similar to real world, established like contexts where the students develop their critical capacity and problem-solution, as well as essential concepts of one specific realm. Using BPL the students get skills for whole life, like capacity to find and use proper resources (Sola, 2005 and Álvarez, et al, 2004).

These features are also related to team-work learning, in a collaborative way, where each person participate in all parts of the project or problem, as well as cooperative, where each member has an specific duty in the project or problem. In both ways it’s required work distribution and relationships to develop the whole. Cooperation and collaboration are highlighted when are applied in rich-material and tool environments, such are provide by computer technologies (Cataldi and Lage, 2001). Then collaboration can be defined like a participative process in knowledge’s communities, taking advantage of the possibilities given by the material surrounding in order to facilitate common review and understanding. Computers allow a wide variety of links and shared references. According Crook (1998) there are three interaction’s features crucial to productive collaboration; confidence between participants, availability of external resources and history of previous mutual activities.

This paper (part of research project FONDECYT 1080328) review several activities to integrate digital fabrication in the teaching of architecture, in order to identify proper strategies and conditions. It describes some experiences and a common evaluation developed through a collaborative e-learning platform. The evaluation review features of problem-based learning like educational framework, and the understanding of constructive subjects, due contributions suggested in this realm. Besides it reviews the works done in the activities, and in one case, the education performance of students and interviews. Following sections make a brief of the activities, as well as results of the review and conclusions carried out.

2 Experiences

Six educational experiences that incorporate digital fabrication in architectural teaching were recorded. The experiences were activities in courses or full courses, mostly related to design studios. The design studio is the main course in the architectural curricula, and they are devoted to teach design processes through practical exercises with manual and digital media. The activities recorded involve different subjects, durations and equipments. In different institutions and academic levels. All the cases includes practical works executed by the students like part of design assignment, such regards study of problem, exposition of examples, use of machines and software, reviews of developments and final presentation of the works done.

The more extensive experience was “Taller Ensamble Digital”, carried out in the School of Architecture in Pontificia Universidad Católica de Chile, in four times (first and second semester of 2007, first and second semester of 2008), with around 15 students each time. Students can take this course in fourth or fifth year, and it is devoted to exercise architectural design with several teaching options. In this case, the studio promoted to study prefabrication systems and digital manufacturing. It develops different subjects each semester; a constructive system, a residential enlargement, a minimum house and a mountain refugee. They were carried out individually with classes two times per week more personal work (around 240 hrs. in total). They did an analysis of references, digital design and model, and development of prototypes with 3D printers, laser cutter and routers.

Also it was recorded an exercise in the course “Realidad Virtual” of the school of architecture of Universidad del Bio-Bio, carried out the second semester of 2008 with 25 students. This course for fifth year students is devoted to an optional learning of advanced digital media. In
this opportunity the students design, model, elaborate and evaluate a panel of shadow-lattice in couples of students, using a laser cutter and solar bench for natural illumination tests. With one class per week more personal work (around 80 hrs. in total).

A special course carried out at December 2008 in the school of architecture of Universidad de Vale do Rio Sinos, Brazil, was also recorded. The course, called “Workshop de Arquitectura y Fabricación Digital”, had 20 participants from freshmen to graduate students. With a duration of 20 hrs. in three days. The first two days in the computer lab of the school and last day in a furniture factory. They develop the design, modelling and elaboration of a wall-furniture in real scale with timber-boards cutters and routers, beginning in couples and ending in 5 person groups.

Besides, it recorded an exercise about high-rise buildings carried out at middle 2008 in the fourth-year design studio in the school of architecture of U.Bio-Bio. The activity involved 25 students during two weeks (around 20 hrs. in total) with the elaboration of building models evaluated in wind tunnel and solar test bed. A technician in a milling machine, according basic shapes and models of real buildings of the city, elaborated the models. The students know the fabrication process, and study alternatives with the models making several tests.

Some models of the final degree project were also recorded in the same school, involving 12 students of sixth year. These models were developed with laser cutter; making a constructive interpretation, design of pieces, elaboration and assembly of full models, during three to four weeks (around 80 hrs. in total each one).

At the end, it recorded an activity in the first semester of 2009 carried out in the design studio of third year in the school of architecture of U. Bio-Bio. This activity involved the elaboration of models for rodeo stadiums (called “medialunas”) with 21 students in four groups. They made a photographic review and drawings of four existing stadiums, then new design with a prefabricated constructive system, drawing of pieces, cutting and assembly. Working two times per week during three months (around 120 hr. in total).

<table>
<thead>
<tr>
<th>Experiences (Course, Institution)</th>
<th>Level (year)</th>
<th>Duration (classes + work)</th>
<th>Modality</th>
<th>Technologie(s) used</th>
<th>Organization</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Taller Ensamble Digital (Talleres de Profundización, PUC)</td>
<td>4th and 5th</td>
<td>240 hrs.</td>
<td>Two sessions per web, during four months</td>
<td>Laser cutter, Router, 3D Printer</td>
<td>Couples and Individual</td>
<td>Constructive system, Enlagement of house, Minimun house, Mountain shelter</td>
</tr>
<tr>
<td>2. Exercise of High-rise buildings (Taller 4, UBB)</td>
<td>4th</td>
<td>40 hrs.</td>
<td>Three sessions per week during two weeks</td>
<td>Milling machines</td>
<td>5-person group</td>
<td>Enviromental evaluation of Hig-rise buildings</td>
</tr>
<tr>
<td>3. Exercise of shadows panel (Realidad Virtual, UBB)</td>
<td>5th</td>
<td>60 hrs.</td>
<td>One session per week during three months</td>
<td>Laser Cutter</td>
<td>Couples and 6-person group</td>
<td>Design and test of shadow panels</td>
</tr>
<tr>
<td>4. Workshop Arquitectura y Fabricación Digital (Unisinos)</td>
<td>1st to 5th</td>
<td>20 hrs.</td>
<td>Three days continue</td>
<td>Timber-boards cutter, Router</td>
<td>Couples and 6-person group</td>
<td>Design of a furniture-wall</td>
</tr>
<tr>
<td>5. Models of final degree projects</td>
<td>6th</td>
<td>80 hrs.</td>
<td>Two weeks</td>
<td>Laser-cutter</td>
<td>Individual</td>
<td>Houses or Service</td>
</tr>
</tbody>
</table>
Table 1. Experiences Recorded

For the record and evaluation of experiences it set up a virtual platform developed with the open-source software “moodle” in the internet site www.fabricacion_digital_arquitectura.com. It defines different work groups in courses and some cases the platform was used to support regular development of the course (“Realidad Virtual” and high-rise buildings exercise), and the others were used only to apply a questionnaire.

The moodle platform has several capacities for educational cooperative work by internet, like definition of units and participants, schedule of activities, upload of documents, graphic material, videos, chat, portfolios, evaluations and subdivision of groups. For these courses were used some capabilities targeted to problem-based learning, such implies to adjust the regular work system. The units were defined in relations to the students’ activities, by advancement of the design, with assignments to upload images of the development. With an initial unit for the teachers can upload a selection of images and comment results and achievements. Also additional units were used to provide technical documentation and movies of work with the machines. Using chat to discuss advancement of the works and calcification by alternatives to adjust the technique of rubrics used in problem-based learning approach. Besides it was necessary to adapt the subdivision in groups and control of students’ participation to visualize and interact in different collaborative ways, due in the design work usually there are tasks that combine devotion, like a cooperative work.

Fig.2. Configuration of Virtual Platform with Moodle.

For the general evaluation of the experiences was apply a similar questionnaire to all the students after to end each activity. The questionnaire had questions with different approval values (similar to Likert scale) according features of problem-based learning and constructive
conditions of design. It regards problem-based learning like conceptual framework to measure the general educational process, and the constructive conditions like the specific knowledge involved in the activities according the references studied. Then, it included 18 questions asking to students if they learnt in the activity subjects like materiality, structures, constructive specification, environmental behaviour, execution, costs, maintenance, innovation, prefabrication, etc. And it included 11 questions about if the activity promoted subjects like motivation, teamwork, integration of previous knowledges, own ways to work, autonomy, etc. At the end of questionnaire it included an open comment. Besides it collected and reviewed some works made in the activities.

In the more extensive experience (taller de ensamble digital) it carried out also a review of the curricular performance of students involved, according they final marks in the different courses, and group interviews with teachers and students to discuss in details the subjects included in the questionnaire.

3 Analysis

3.1 Questionnaires

The questionnaire had 29 questions, the first about constructive subjects (from more specific to general), and last one about features of problem-based learning, like the following:

1. ¿Este ejercicio con modelos de fabricación digital le ha otorgado mayor interés al desarrollo del proyecto?
2. ¿Este ejercicio con modelos de fabricación digital le ha motivado a usar posteriormente estas tecnologías en el desarrollo de proyectos?
3. ¿Este ejercicio con modelos de fabricación digital le ha permitido aplicar conocimientos previos de otras asignaturas o talleres en el proyecto?
4. ¿Este ejercicio con modelos de fabricación digital le ha permitido comprender mejor su propia manera de desarrollar el proyecto?
5. ¿Este ejercicio con modelos de fabricación digital le ha permitido comprender más cabalmente como se desarrolla profesionalmente un proyecto?
6. ¿Este ejercicio con modelos de fabricación digital le ha permitido comprender más ampliamente el desarrollo del proyecto?
7. ¿Este ejercicio con modelos de fabricación digital le ha permitido integrar diferentes aspectos arquitectónicos en el proyecto?
8. ¿Este ejercicio con modelos de fabricación digital le ha permitido alcanzar habilidades que se aplicaran posteriormente en su carrera o desempeño laboral?
9. ¿Este ejercicio con modelos de fabricación digital le ha permitido desarrollar más autonomía de trabajo?
10. ¿Este ejercicio con modelos de fabricación digital le ha permitido comprender mayormente sus capacidades de proyecto?
11. ¿Este ejercicio con modelos de fabricación digital le ha permitido comprender mejor interacción con otros colaboradores y el trabajo en equipo del proyecto?

The results, showed in the graph 1, expose the high assesment given by the students to the BPL features in the experiences evaluated. In particular related to use of technologies (probably the new tools used), like motivation, that could be linked to theris personal involvement in the works. The projection in future skilss and use of previous knowledges looks also high assesment, but more reduced in the understanding of general profesional
development. Maybe technological novelty is regarded by students far away from labor practice. The results are regular in the different experiences, except teamwork in the title work, due they are individual and they also related with operators and comparison to partners. The „taller ensamble digital“ looks more positive result, probably due extension and equipment, and the high-rise exercise the lowest, such have the more reduced duration and less design involvement. Then results demonstrated a positive assessment of experience in relationship to problem-based learning (an average value of +1.48 between –2 to+2), remarking the duration, elaboration and technologies available like main factors.

![Graph 1. Results of questions about BPL features.](image)

The graph 2 shows the responses to questions related to assessment of understanding constructive subjects. This evaluation also looks a positive average (+1.48), remarking the learning of material reality, constructive development, possibilities of prefabrication and basic structural conditions. Results shows weakness in costs, maintenance and energy performance, all related to building behaviours. That looks similar between the different experiences, with a positive understanding but irregular in some conditions, that should be supplemented. The high-rise exercise is the lowest (an average of +0.39), due apparently this activity doesn’t provide learning of constructive issues. The exercise of shadow panels and graduate projects are quite positive (+1.14 y +1,26), but higher values are found in “taller ensamble digital”, “workshop” and “medialunas” (with averages of +1,48, +1,58 y +1,48). This three experiences are strongly different in duration and technologies used (from 20 to 240 hrs. and diverse equipment). Also the institutions, levels and subjects were different, then these conditions are apparently irrelevant for this learning achievements. But they match with the development of a full design using the equipment, that wasn’t in the other experiences. This result suggest that practical work is an important condition to integrate digital manufacturing technologies in the architectural education, getting a high understanding of constructive issues and problem-based learning.
3.2 Works

The three experiences with highest results made designs and physical models, in some cases, in real sizes. In “taller de ensamble digital” the subjects were diverse and requires a review of constructive possibilities, to develop a personal architectural proposal according to a particular request, to detail the design and execute a model with rapid prototyping or laser-cutter, sometimes in real size with routers and timber-boards. In “workshop” the designs of furniture-wall were elaborated in couple and real-size executed in groups thorough routers and timebr-boards. In the exercise “medialunas” the work was done in groups based on an existing design but changing to a new modular system, making pieces and a total model with laser-cutter and timber boards.

The three cases looks similar material (timber boards), assemblies tasks and formal conditions according the machinery available. The design are usually different from conventional solutions, with new alternatives and details, taking advantage of the technical capabilities and the functional requests. Technical innovations suggest also some weakness in the support and maintenance of work without a proper solution. The design evolves from the initial concepts to the execution, and these changes probably motivated the higher learnings. Designs looks proper and creativity, although not all efficacy requested, encouraging formal and constructive exploration, than integrity and practical proyection, due the experimental technologies used.

They looks an architectural process differnt to conventional taks. The formal conception in highly influenced by constructive issues, and it is developed as whole and detail simultaneously. Regarding massification but that is not properly analyzed. Design systems
more than unique objects. The functional and aesthetic features are regarded, although light than traditional process, remarking technical innovations. They shows high material definition, with novelty constructive solutions and suggesting productive improvements, that also has repercussions in the labor organization of construction.

![Fig.3. Examples of works done in the „Workshop Arquitectura y Fabricacion Digital“ (Unisinos), „Taller Ensamble Digital“(PUC) and „Medialunas“ (UBB).](image)

### 3.3 Curricular Performance

In order to review the development of the experiences in relation to the general performance of the students, it collects final marks of courses carried out by all the students on „taller ensamble digital“ (42). Like this course is at the end of carrera, the marks express their previous performance. It analyzed relationship of this course to other design studio, and also to the courses devoted to constructive issues (structures and building sciences).

The correlation between the course with digital fabrication and the construction courses is almost nule (0.06). The correlation with the other studios is 0.41, that is low, but traditionally this courses has strong variation in performance of the students, then this value express a significat relationship. This result suggest that development and learning of the experiences are more based in the capabilities learnt in design studio than technical knowledge. That express the potential of this technologies to integrate capacities, but also a lack of relationship to technical courses. Also express the link of this strategy with the design teaching and exploration of architectural possibilities. That verified verified a positive relationship with the general development of carrera.
3.4 Interviews

In the more long experience (taller ensamble digital) several groups interviews were carried out in June 2008 and April 2009, some of them recorded in audio and video. It develops open conversations guided by the subjects asked in the questionnaire (learning of constructive features and problem-based concepts), and other issues. Usual comments were the following:

Students:

- After the studio they got high motivation in this field, and most of them are searching new courses, pos-graduate programmes or developing final graduate projects related to these technologies. More than a third of the students involved in the studio are continuing in the Master programme of the university, such have a line in this subject.

- They think there are not relationship between the knowledges acquired in this studio and other courses, but they feel an application of previous courses due in this studio.
they need to resolve practical problems. They agree this studio is mostly practice with less than 20% related to theory.

Teachers

- They feel high motivation by the students’ interest, expressed in the continuity of the subject in the Master programme.

- They observes the collaborative work carried out in the studio, looking for common solutions, going after that to more individual work when they set-up the solution. The students collaborate in the learning of others students. Some of them begin to use the machines and after that they teach to theirs partners.

- The work done in the studio has only a partial relationship to professional practice. The studio promotes experimentation that is not usual in the real work. These technologies allow this experimental spirit with lower costs than other equipment.

4 Conclusions

This paper exposes a variety of experiences devoted to integrate digital manufacturing in the teaching of architecture is demonstrated. The activities were carried out in different institutions and educational levels, developing practical exercises, in groups or individually, mostly related to design studios. The activities worked on different subjects with diverse equipment; milling machines, laser-cutters, routers benches or rapid-prototyping machines.

The activities were analysed through questionnaires set-up in a virtual platform, besides review of works, curricular performance and interviews. The evaluation showed in general a good appraisal of the strategies developed, according to Problem-based Learning (PBL) and construction features. The results of questionnaires and works demonstrated in all the experiences to reach most of PBL’s strengths. Besides they showed a positive appraisal in the understanding of constructive subjects. Although they showed also some weakness, mostly related to professional projection and understanding of building behaviours, such must be complemented. Moreover, it is observed the practical activities don’t develop a complete theoretical description of technologies and applications, making emphasis in to make creative proposals.

The activities devoted to complete design tasks experiences showed more positive evaluations. The experiences that carried out full design process demonstrated higher results, although they had different duration, level or technologies used. These features seems not to affect the learning substantially. Then, it can suggest that an effective integration of digital fabrication in architecture can be realized with diverse activities involving design tasks and using any available technology, with a strong recognition of creativity, teamwork and constructive learning. However, according the weakness detected, it recommends also supplementing labour application and technical behaviours.

These experiences also demonstrated the application of a collaborative virtual platform to review and integrate the learning of new technologies in higher education. That allows verifying and sharing the utilization of machinery in the teaching process and suggesting potentialities of these technologies for education and labour future of architects. Incorporation of digital manufacturing through practical activities, demonstrated a positive contribution in the general learning and in particular to constructive development of designs, according the overall educational performance and supporting the implementation of equipment to adopt these technologies. Although it must regard safety issues and real application in professional
practice, that should be regulated in the future. The experimental approach applied in these
initial activities allows exploration of possibilities, but they can go far from labour realities.
Then, next researches can adjust the technical contributions of the diverse technologies and
exercises. Also, some possibilities explored in the experiences can be applied in the buildings
promoting diversity and industrialization, and diffusing the potential of academic realm to
develop practical innovations.

References:

(CAM) in Architecture. Third International Conference of The Arab Society for Computer Aided
Experiencias de aprendizaje orientado a la solución de problemas con soporte tecnológico. 3er
Congrés Internacional de Docència Universitaria i Innovació, Girona, 1-3 July 2004.
newsletter of the Australian Problem-Based Learning Network, 26, 8-9
Contemporary Context. Education in Computer Aided Architectural Design in Europe 23, Lisbon,
21-23 September 2005
modelos cooperativos-colaborativos aplicada a la algoritmia usando nuevas tecnologías de
comunicación. I Congreso Internacional de Matemática Aplicada a la Ingeniería y Enseñanza de
la Matemática en Ingeniería, Buenos Aires, 6-7 September 2001
Architectural Design in Europe 24, Volo, 6-9 September 2006.
Institute of Technology.

Authors:

Dr. Rodrigo García Alvarado
Universidad del Bio-Bio, Depto. de Diseño y Teoría de la Arquitectura.
Avda. Collao 1202
Concepción, Chile
rgarcia@ubiobio.cl

Dr. Pedro Salcedo Lagos
Universidad de Concepción, Depto. de Metodologías de Investigación e Informática
Educativa
Campus Universitario
Concepción, Chile
psalcedo@udec.cl

Dra. Underlea Bruscato
Unisinos, Curso de Arquitectura y Urbanismo
Sao Leopoldo, RS
Brasil
bruscatop@unisinos.br

FONDECYT 1080320