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Influential Pedagogies Using Digital Fabrication Laboratories onArchitectural Education

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Abstract

Innovation in advanced architectural design is imposing a revolution in ways to materialize contemporary buildings of geometrical complexities. In the professional field, such trend is demanding a constant update on the tools required to execute jobs. At the academic level, digital fabrication laboratories are becoming a place to fuse ideas with rationalized principles of construction in addition to helping students visualise the future challenges in the architectural practice. This paper tries to argue the influences on architectural education by the leading function of digital fabrication laboratories, with the prospect of presenting practical assessments of transforming digital information into analogue materiality, along with logical explorations to rationalize fabrication processes. A historical assessment of applied cases in architecture is included, in addition to a description of digital fabrication laboratories, and to an association between instructive approaches in digital fabrication and engineering laboratories. The impact of the introduction of such labs on architectural education is reflected in the conclusion.

Keywords

Architecture, Education, Technology, Digital Fabrication Laboratories

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ABSTRACT

Innovation in advanced architectural design is imposing a revolution in ways to materialize contemporary buildings of geometrical complexities. In the professional field, such trend is demanding a constant update on the tools required to execute jobs. At the academic level, digital fabrication laboratories are becoming a place to fuse ideas with rationalized principles of construction in addition to helping students visualise the future challenges in the architectural practice. This paper tries to argue the influences on architectural education by the leading function of digital fabrication laboratories, with the prospect of presenting practical assessments of transforming digital information into analogue materiality, along with logical explorations to rationalize fabrication processes. A historical assessment of applied cases in architecture is included, in addition to a description of digital fabrication laboratories, and to an association between instructive approaches in digital fabrication and engineering laboratories. The impact of the introduction of such labs on architectural education is reflected in the conclusion.

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1. INTRODUCTION

With the technological revolution advancing fast, many schools of architecture around the globe have been coping with providing students with tools, systems and environments to be in line with such trend. Since the late 1990s, investigational spaces for mainly rapid prototyping, and before being categorized as digital fabrication labs, were created in many prominent architectural faculties. But apart from digital technologies practice, the question of how such laboratories differ from the traditional model shops and the reason why they are not defined as workshops instead of laboratories must be raised. Such facilities also provide interrogations on whether to focus mainly on investigation, development or training. In addition, the fusion of these labs with pedagogical methods in an effort to integrate the architectural curriculum is put to test. The relation of these laboratories to other applied education spaces such as design studios and computer labs, in addition to their magnitudes in architecture schools should be explored.

In order to elaborate on such concerns, this paper presents an evaluation of applied instructions in architectural education through history. Considerations are taken on laboratory types and educational methods for practical teaching applied in the field of engineering. The main goal is to suggest a mode to integrate practical training in digital fabrication laboratories within the architectural academic curriculum, providing them a support to define their intentions with suitable pedagogical approaches in each stage of the education development. The paper also discusses the potential alterations that may affect the architectural professional practice with this educational approach.

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2. PRACTICAL EDUCATION IN ARCHITECTURE

The liberal arts, one of the diversely divided categories of arts in classical olden times, were considered as solely rational and were practiced by free citizens. All the other arts, which mainly involved manual labour, were performed by slaves. (Jaeger, 1986) For instance, and according to Aristotle, the "arts of necessity" were divided from the "arts of pleasure". In this sense, there were reflections neither from architecture nor from the symbolic arts within the superior arts, as they were merely considered arts of needs. Therefore, they used to be imparted as part of professional practices, and not inside the great philosophers' academies. However, this condition noticed changes as Vitruvius developed the first actions towards it. The establishment of a widely liberal architectural education notion would be simulated in The Ten Books on Architecture. (Vitruvius, 1914)

Classical Era	Middle Age	Renaissance	17th – 19th Century	20th Century	21st Century
Architecture is an art of utility, imparted in the professional environment.	Architecture is a mechanical art, imparted by the organisations.	Architecture is closer to liberal arts. Theory and drawing taught in the academy and with practical issues taught by organisations.	Theory and drawing taught in the academy. However, practical knowledge is acquired in autonomous studios and workshops.	Design studios and model workshops are part of the academy. Introduction to scientific content and to computer labs.	Digital fabrication Labs
Vitruvius	Alberti	Palladio	Beaux Arts	Bauhaus	Design Methods Movement

Table 1 Practical education transformation in architecture over time (table from author)

In the first academic institutions of the Middle Ages, subjects such as grammar, geometry, music and astronomy were imparted in the lower division of the seven liberal arts. According to John Scotus Eriugena, mechanical arts such as architecture, medicine, agriculture, and even hunting, were defining the arts of needs. Labeled by then as arts, professional associations instructed these majors with scientific tutoring. Defined as organizations, construction sites, and guilds (Fig. 1), such fields of education offered no link to scientific, philosophical, or higher art matters. (Walton, 2003)


Fig. 1 The contrast between the practical teaching in a high medieval construction site and the design studio of Josef Albers with students of the preliminary course in 1928 in a critique at the Bauhaus in Dessau illustrating the progressive changes in history (photos from Maciejowski Bible and Otto Umbehr)

The architectural status, still far from what it is today, began changing during the Renaissance period. Between the sixteenth and the seventeenth centuries, architecture became closer to figurative arts including painting and sculpture, and at the same time, standing in the middle of the mechanical and the liberal arts. It was possible by then to appreciate architecture somehow approaching to science and literature, while distancing from crafts. Professional personalities of the field such as Alberti and Leonardo played major roles in this transitional process. For instance, Alberti defines architecture in De Re Aedificatoria as a product of design, providing the practice with intellectual and rational scopes.

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Architects noticed to have increased their control over building constructions after the adaptation of tools such as the perspective and the scale models. Alberti and Palladio also defined strong architectural discourses that contributed to the freedom of the practice from the guilds' masters. Architecture, as a result, would become a generalizable science with its own language and principles.

The architectural academy was not developed in order to ultimately replace the internship system. Rather, intentions were based on the fair introduction of innovations in the theoretical argument about architecture and arts. In addition, the strength of drawing had to become a consistent communication mode in order to describe buildings. Still, practical education was provided by private workshops and specialised associations during a long period. For instance, studios would only be incorporated at the École de Beaux Arts after the 1950s.

The Bauhaus was one of the most successful examples of the 20th century that combined architectural academic education with professional workshop skills. Instructions were imparted in the traditional educational system, and simultaneously proposing integration between aesthetic and technical issues through intense labour in workshops (Fig. 1). The unity between artistic design and material production was appreciated with the crafts work. (Dewey, 2005) In each workshop, there were two tutors with different tasks. The first one was responsible for the artistic and aesthetic aspects of the design work, while the second was responsible for the technicalities of the project, translating to students the craftsman skills and abilities to build.

László Moholy-Nagy set up a methodology between 1923 and 1928 that is reflected today as the spirit of the Bauhaus. A clear architectural path was set up with the integration of science, arts, and technology. Originating aesthetic values from innovative industrial manufacturing methods by appreciating the qualities of materials was one of his motives. Later published in1929, it would become a vital reference for the modern design process. He described an educational method where teachers and students would work in close collaboration to innovate when dealing with materials, thus merging design, theory and practice. (Moholy-Nagy, 1938: 5) Such process would lead to the possibility of working with machines and tools in unprecedented ways at the academic level.

The Bauhaus was a predominant model of architectural education after World War II. At the same time, and to attain reputation, many specialised institutes were being merged into universities in order to introduce more technical and scientific material. (Simon, 1998: 111) For instance, in the engineering field of education, subjects such as science and mathematics were progressively supplemented to its programs. Quickly, more theoretical and scientific matters related to the academia started to become imposing over the traditional issues taught at engineering laboratories. (Feisel and Rosa, 2005: 122)

Through the addition of scientific content, architectural curriculums were gradually reshaped in a similar way of the engineering. They were gradually being detached from their traditionally practical approaches of education. With the Design Methods Movement of the 1960s, this progression climaxed with the architectural design process widely studied in an academic manner. Contemporary scientific means of design were being developed and experienced in the architectural faculties in a main response to the programs of high complexities. Developments in the areas of computer technology, operational investigation, and artificial intelligence influenced the movement. One of their main objectives was to design in better ways by consistently indulging the design process and externalizing it by allowing large teams to collaborate. In addition, it would also be possible to tackle issues such as mass production by automated means. (Gregory, 1971)

Thus, the architectural academy was considered to have introduced a new type of practical education. Basically defined as the science laboratory, this facility has been categorized as a place for scientific research and development, conducting studies using a number of tools and procedures that would involve architectural conditions of interest such as measurements, calculations, and precision in the presentation of results.

With the Computer Aided Design (CAD) skill courses introduced in the architectural curriculum in the 1970s, computer labs caused a great impact in the architectural academy. During the next decade, computers started serving architectural design studios for 3D modeling. In a very short timeframe, and as a fast move towards technological issues applied to architecture such as tridimensional visualization, basic digital tools became common in design studios. (Mitchell, 1990) The popularization of 3D modeling and rendering caused an impact in the design proposals, being taken to higher levels of complexity in many schools.

The beginning of the 21st century has witnessed workstations and laptops become integrated tools in the model workshops. Since the late 1990s, and in the same way that computers were becoming part of design studios, some schools introduced rapid prototyping and computer-controlled machines. This would modify the meaning of the traditional model workshop in such a way that they were transformed to digital fabrication laboratories, primarily including basic rapid prototyping machines, such as laser cutters, for fabricating scaled components for models automatically from CAD files. Soon, after the potential seen in such machines to concretize what the designers conceptualize, an interest in innovative means of construction of full scale prototypes was born.

3. THE ROLE OF DIGITAL FABRICATION LABS IN THE ARCHITECTURAL ACADEMY

The implementation of digital fabrication technologies in the architectural academy is a relatively new feature. Fabrication labs in education are today ordinary active spaces. (Oxman, 2010) In the professional field, and in the early 1990s, the first traces of digital fabrication of architectural components are clearly appreciated in the works of Antoni Gaudí at the Basilica of the Sagrada Família in Barcelona, and of Frank Gehry at the American Center in Paris respectively.

The first practices in the use of digital fabrication for creating models and prototypes at architectural schools were performed in association with mechanical engineering laboratories. Such facilities and procedures were already present there for the use of advanced techniques. (Mitchell and McCullough, 1994) Soon, the potential in the use of digital fabrication tools such as rapid prototyping and computer numerical control (CNC) fabrication for building models and parts was somehow perceived. The translation of data from the digital to the physical environments was increasingly feasible. Digital fabrication was seen as a strategy not only to directly transform CAD data into an automated fabrication of items (Fig. 2), but also to produce components such as moulds needed to reproduce objects in multiple copies or in mass.

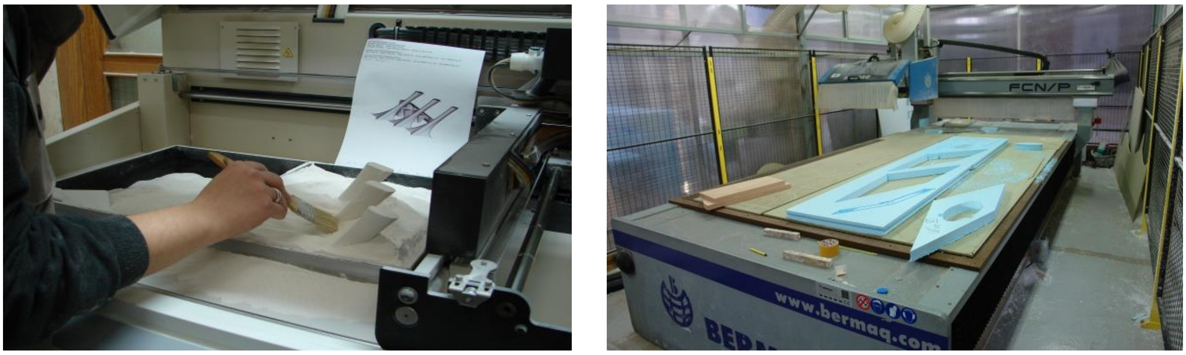

Fig. 2 Examples of tools commonly used at digital fabrication labs such as 3D printers, and computer numerical control (CNC) machines in order to produce prototypes and components and parts (photos from author)

The spirit of a laboratory is in the scientific methodology to investigate, not just in the acquisition of advanced tools. For instance, digital tools are becoming increasingly popular and affordable to the level that it is believable that in the near future this technology could be available even at ordinary homes. (Wittbrodt et al., 2013) However, it is necessary to embrace in such facilities the use of systematization, parameters of variable mechanisms, estimations, and thorough process documentation in order to fulfill the rationalization and optimization of the work. By exploring such essences, and in the late 1990s, Professor William Mitchell was able to set up at MIT one of the first digital fabrication laboratories in an architectural school. One of the first tools acquired for the laboratory was a laser cutter in order to produce models for students of advanced academic levels. The tool was mainly used for exploring the potential of automated techniques of production in architecture. As a next step for the increase of tools in the lab, CNC machines and water jet cutters were purchased for both the architectural and mechanical engineering faculties. A larger number of students started using these tools with

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procedures and restrictions progressively integrated. As more machines were acquired, the facility was transformed into the Digital Design Fabrication Group (DDF). Nowadays, a series of pioneering courses in the field of architecture and technology are imparted in addition to the conduction of advanced research projects.

As the application methodologies developed by pioneering digital fabrication labs, such as the one at MIT, became feasible, other schools started to implement their own labs. In addition, with the decrease in the price of such technologies, more affordable tools became available, thus allowing architecture schools to deploy their own digital fabrication laboratories. Motivational power has been present in the globalized world, and these new resources could be clearly seen as tools to assist the exploration of new manners to reach architectural creativity, allowing a deeper immersion into subjects related to architectural design. With the prospective for optimization of time and cost, new ideas related to more non-standard architectural designs could become a potential contemporary trend. Solutions would be experienced and quickly altered in the virtual and real means. (Mark, Martens and Oxman, 2001: 210)

The ideal computer curriculum would include, at the advanced academic level, a Computer Aided Manufacturing (CAM) and a Robotics course. (Mark, Martens and Oxman, 2003: 170) They would incorporate opportunities from numerical control processing to rapid prototyping and building component manufacturing. The program would also include discussions on different strategies for introducing new contents related to technology in the architectural curriculum such as digital design themes being integrated in existing courses, and a deeper integration of topics in specific mandatory courses. However, the first strategy has been noticed to potentially be more effective since architectural education had still to focus on issues such as building and place.

Nevertheless, and due to the rapidly progressing and increasing implications of technology, it is essential to provide guidelines for students concerning these advanced tools, be them hardware or software. In addition, it is important to deal with digital fabrication concepts related to procedures related to materialities in ways of production such as the additive and subtractive ones. (Lennings, 1997) Such issues for instance have a potential to influence decisions in the design process as they may lead to the need of implementing digital fabrication means. Therefore, advanced fabrication strategies using digital technologies could be dealt with in the first levels of the architectural curriculum, and progressively integrated digital design and fabrication methodologies applied in more advanced levels.

4. DIGITAL LABORATORIES FOR EDUCATION, RESEARCH AND DEVELOPMENT

Nowadays, a vast and diversified number of laboratories are available at both academic and some professional practices of divergent fields. In the area of engineering, they can be categorized according to their different objectives. Among these types, the great majority falls in the categories of education, research, and development. (Feisel and Rosa, 2005) For instance, and accordingly, in research laboratories, investigations are conducted in order to try to find a wider comprehensive knowledge able to be generalized and structured for professional acquaintance. Digital fabrication tasks may be often combined with other science laboratories in research projects and generate a multidisciplinary interaction as a result. (Avram et al., 2013)

Such type of research is found as an example at the Basilica of the Sagrada Família in Barcelona, done in 2005. In order to study the different formal variations that a series of geometrical combinations positioned in a tridimensional space could provide, an experiment using parametric software was used in order to generate the central tower of the temple conceptualized by Antoni Gaudí. However, the amount of historical data available was not enough to generate the final product. Therefore, and after creating a series of geometrical relations that would provide a wide number of different proposals, a limited number of possibilities were chosen and produced at the scale 1/50 using a 3D printer (Fig. 3).

Such tool would first show precisely the geometrical articulation needed in order to be validated, in addition to a subsequent structural analysis using the same virtual model. By merging the architectural aesthetics and structural conditions, the adequate materials were able to be chosen in order to preserve the identity of the project, especially since the tower ended at the height of 172 meters and the surface articulations were to be appreciated from the ground level. There would also be the process of construction to be implemented by the production of moulds for parts that would be repeatedly produced and the robotic fabrication of the non-standard ones. Such a process could help other projects of formal complexities to be studied.

Fig. 3 Three proposals for the central tower of the Basilica of the Sagrada Família in Barcelona made in 2005 showing the formal variations that a parametrically designed object could provide and translated to the physical condition (photo from the archive of the Basilica of the Sagrada Família)

Attaining information to assess professionals in the design development stages is one of the objectives found in development laboratories. In such facilities, specific measurements of performance are gathered in order to determine and test the intended performance of the design. (Feisel and Rosa, 2005: 121) In 1992, Frank Gehry was one of the first architects to use digital fabrication tools to develop building components. For the fish sculpture built for the 1992 Summer Olympics in Barcelona, the design team digitally fabricated models for testing articulations using a laser cutter. The project defined a key moment in the architectural digital revolution due to the establishment of the process of fast and efficient translation of digital data to physical means. (Shelden, 2002)

Since then, a series of developments have been carried out by labs in order to serve architectural purposes. A series of building systems and materials have since been developed in many digital fabrication laboratories. For instance, parametrically defined aluminum foam applied according to the areas that are more and less subject to stress was developed by Russell Loveridge in 2011.

It is clear that throughout the architectural revolution, the objectives of digital fabrication laboratories are following a consistently progressive track. However, the goals of educational laboratories need to be enhanced with properly defined learning objectives, and which is also conceivable to state to digital fabrication labs. Besides the rarely explicit learning objectives, the actual cost of digital fabrication tools limits many architectural schools to acquire and maintain such equipment. Therefore, digital fabrication labs should simultaneously serve education, research and development. In addition, even ordinary design studios take advantage of such labs in order to fabricate scale models, producing an overlap of intentions in these facilities. As a result, a vast majority of fabrication labs in architectural schools are not classified as a laboratory of specific type.

In an effort to merge education with an effective professional practice willing or in need to deal with high tech tools, many digital fabrication laboratories pertaining to architectural academies and industries developed a kind of partnership in order to carry out development of design projects on an instruction basis with students, using scientific methods of research to develop advanced knowledge. Such strategy has provided the possibility of developing, enhancing and economically supporting these laboratories.

In 2009, Maria Vogiatzaki-Spiridonidis has generated an association for digital fabrication between architectural faculties and small companies active in such field, establishing exchanges of knowledge, data, and proficiency in the contemporary architectural trends. The idea was to mainly tackle the difficulties of design and construction methodologies facing the academic and professional practices. (Vogiatzaki-Spiridonidis, 2009: 5) The constant diffusion of data in the cooperation process would provide possibilities for students to get acquainted with real challenges facing production processes, and

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with industries also getting direct and first hand outcomes from researches conducted at the academic institutions. This was a feasible possibility to integrate education, research and development of ideas in the professional field.

5. PEDAGOGICAL APPROACHES IN DIGITAL FABRICATION LABORATORIES

Pedagogical methods used are some of the most important issues concerning laboratory instruction. During the first decades of the twentieth century, John Dewey suggested the introduction of experimental approach to transform education. Defined as from children's to adult's learning, he emphasized his suggestion based on scientific methods in order to try to encourage educators to go back to the intellectual approaches previous to the scientific method.

However, and due to the contemporary societal conditions, another alternative was proposed based on a systematic use of scientific methods for developing intelligence according to potentialities essential in practice. (Dewey, 1997) The emphasis on scientific method, according to Dewey, provides a working arrangement for experimentations. In such track, educators are requested to adequately adjust criteria according to diverse conditions, focusing on students' maturity levels. The experience by then would be made effectively educative.

A clear classification related to the purposes of the educational laboratory is another significant concern in experimental education. (Feisel and Peterson 2002) Some of the issues to deal within the procedures concern the use tools, model work, and education on safety during experiments, development of psychomotor skills and sensory responsiveness, data collection and analysis, design and assembly systems, creativity development, teamwork practice, and communication skills.

While mapping the criteria concerning the objectives that a laboratory should meet, it is noted that most of them are fulfilled during courses imparted in digital fabrication labs. From students' work with CNC machines and 3D printers, to the model making strategies and presentation of their projects for review are reflected as examples. Even though such facilities are exciting environments for students who have potential to provide good results, the scientific methods used in the design process are not clear in laboratories.

A theme of an interesting debate among educators and psychologists is the diverse teaching styles in science laboratories. Assumptions made by Jean Dickey and Robert Kosinski sustain the lack of effectiveness of the traditional laboratory for education due to its similarity to methods applied in traditional classrooms, which mainly centred on diffusing data. In contrast, inquiry labs accommodating students to define strategies to implement their own experimentations in a systematic manner instead of just following guidelines was proposed to solve the problem. Their role in the provision of future scholars is based on the argument that the practical based discipline defines science. The incapability of students to appreciate scientific method is a fact. In addition, this is supported by the essences of scientific investigation based on possibilities to obtain and analyse direct data. (Sweeney and Paradis, 2004: 195)

Nevertheless, such method may not be the most effective strategy at all levels. Guided education is also essential, established on the alterations between the data that can be grasped by expert and new students. (Kirschner et al., 2006) Controlled experimentations can be partial and may not essentially stimulate creativity. However, they are a requirement in beginner's courses. Guided approaches of minimal guidelines, such as for example the problem based learning strategy, are more effective when applied to intermediate and advanced students.

In an engineering learning study approach, Sheri Sheppard proposed in 2009 the classification of a laboratory education system of three levels (fig. 4). When contextualizing ideas at the level concerning new students, laboratories should be normally used to gather information linked to indications targeting physical conditions. Students at this level strictly follow gradual guidelines offered by the instructor in order to reach the anticipated outcomes, determining an idea or a concept. In general science courses, such as physics or chemistry, lectures of theoretical norms are typically presented and proven. Subsequently, students apply the explained principles in order to recognise the rationality of the idea. Finally, the development of simulations in the lab is performed in order to illustrate the idea. Students can then validate these controlled experiments by testing and confirming the explained concepts with a diverse series of conditions and parameters.

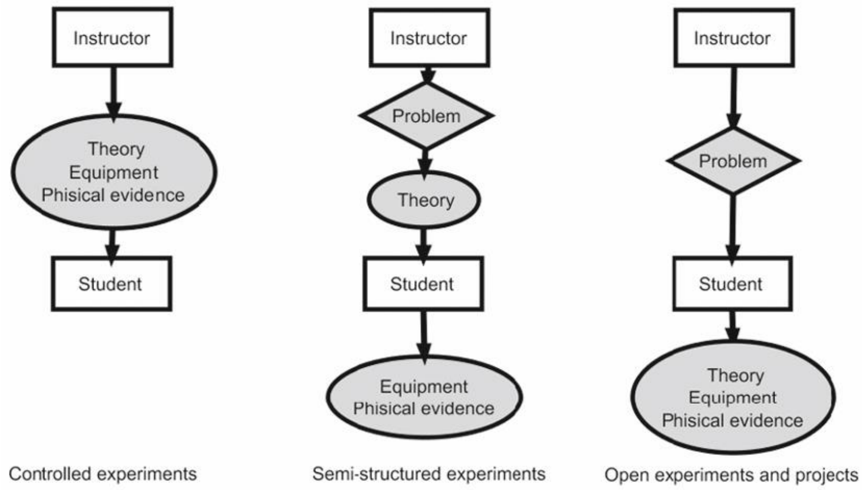

Fig. 4 Examples of three laboratory instruction models based on a diverse way of proposing experiments (Sheppard et al. 2009)

It is not very common to use a guided education methodology in digital fabrication labs. Even in general architectural education, such methodologies are hard to apply. This could be the reason for the difficulty found by students to develop their design experiments, often recurred to trial and error instead of a more rational scientific manner.

The basic knowledge of the different automated construction methods present in digital fabrication laboratories can be imparted as preparatory workshops. Students are requested to create simple models with the intention of exploring tool capabilities. (Stevens, Boden & Rekowsky, 2013) For instance, an exercise has been developed in a digital modeling course intended to introduce students to the themes of precise and optimized 3D printing. Students were asked to generate a basic cube of 10 x 10 x 10 cm to be topologically distorted using controlled data on the original form. As a next step, they were requested to explore ways to transform their objects into solids to be sent to a 3D printer, but with the intention of getting the smoothest surface and consuming the least amount of material possible (Fig. 5). Ingenuity in the use of parametric principles, previsualization of the final product, and optimization of time, cost and quality were covered in the exercise. Students also gained confidence and motivation while witnessing the transformation of a virtual idea created and simulated by them into an additive automated process of construction.

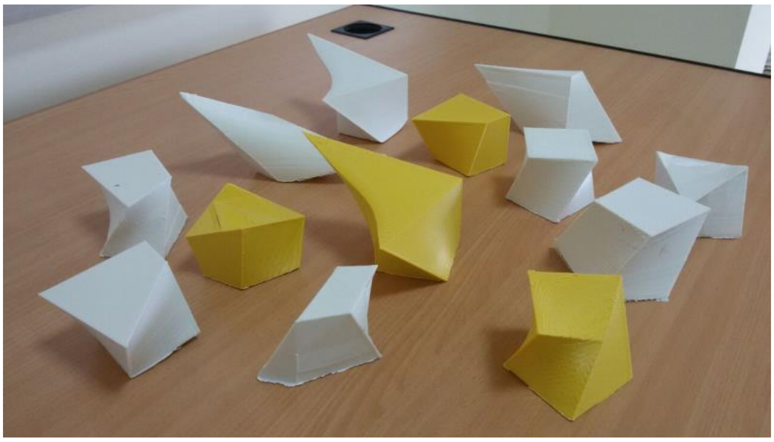

Fig. 5 3D printer experiment showing a series of topologically distorted cubes created by students and fabricated using time and cost optimization principles (photo from author)

Providing students with an environment to solve practical problems is the next procedure to take into consideration in laboratory instruction. Students are in this case requested to critically assess the

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ideal digital and physical tools to be used in order to perform the job according to a given concept. Defined as a semi-structured experiment, the concepts and goals are a given, while the procedures to execute the job are to be suggested by students. These types of experimentations provide a more challenging and motivating scenario to students than the controlled experiments, involving problem solving approaches which require intellectual convictions. Even though it requires better knowledge on the potentials and restrictions of the fabrication tools and materials to be used in the process, semi-structured experiments create a greater sense of pro-action and confidence in students when dealing with advanced technology. (Sheppard et al. 2009)

In a digital fabrication lab, the work at this level requires students to develop complex shapes and articulations that would be evaluated compared to the ideal tools to be used for later fabrication. For instance, students could be requested to define the most appropriate method to digitally fabricate a model of spatial structural tridimensional complexities requiring innovative or non-standard solutions. Within results presented by students, whether they are reasonable or not, interesting arguments could be generated.

Earl Mark describes as an example of semi-structured instruction the idea that in a studio, an instruction was given to students regarding how to write numerical control programming, such as g-codes for job executions and m-codes for milling procedures, for generating tool paths in order to be sent to a CNC machine. (Mark, 2003: 339) As a next step, students were requested to use different methods using CAD commands in order to create geometries for the production of models, and later to generate toolpaths in an automatic way using ordinary CAM software. In order to optimize objectives, such task required a trial and error process of testing. By using the appropriate digital platforms, students were able to control forms and to foresee the fabrication through simulation. The exercise of programming the CNC toolpaths as a part of the design process usually provides the possibility of a greater understanding of the digital to analogue process and allows greater control of forms and materials merge during the fabrication process.

Open experiments is a procedure structured to instruct advanced students, providing the possibility to use much more open techniques than in controlled and semi-structured experiments. Experimentations in this laboratory instruction can help demonstrate the dealing process with problems of considerable complexities. A brief description of the problem given is one of the main base guidelines in open experiments. Therefore, students start by defining the goals of their experimentations and the intended means to achieve them. Most important, tutors would not present new concepts, but rather, students would be responsible of searching and proposing them, or even abiding by approaches using interdisciplinary knowledge. (Sheppard et al. 2009) Once students are familiar with the diverse potentials and restrictions provided by automated fabrication tools, and not found in ordinary design studios, it is then possible to integrate this acquired knowledge in order to become then the part of the design process. This is an issue that shows the development of their sense of scientific process systematization, which should assist them in reaching greater efficiency during design considerations.

In 2016, a workshop regarding digital tools and robotics in architecture was conducted with seventy architecture students from third to fifth levels. The aim of the workshop was to expose students to some of the most advanced digital design and fabrication processes in order to help in the development and construction of architectural projects of formal complexities. Students were requested to develop a small design experiment to be robotically fabricated at real scale. The application of automated technology in architecture relied on the drastic expansion of formal possibilities that allows a non-standard mode of production, from the scale of the building component to the building shape itself.

Among the many categories of experimentations, one group of students started their design approach by capturing some geometric motifs from the city such as building patterns, landscape, street tiling, and building details. In the class, the students would analyze the data acquired and select one of the motifs to perform a series of geometric manipulations in the development of the design project. This phase of the experiment served to strengthen the engagement of the students with integrating certain characteristics of the city.

The students decided to deal with the milling fabrication process using a robotic arm, one of the most attractive trends in fabrication assisted by computer in architecture. Basically, the machine had a milling end-effector in order to carve EPS blocks, forming a 120x200 cm wall, with a maximum width of 50 cm. Since milling is a fabrication procedure suitable for the creation of freeform surfaces and textures, the students decided to develop an expressive 3D surface inspired by ideas previously encountered in the city. Rhinoceros, Grasshopper and KUKA|prc were the digital platforms used as the design tools to produce the parametric tridimensional geometries and simulations of the robotic arm for later fabrication.

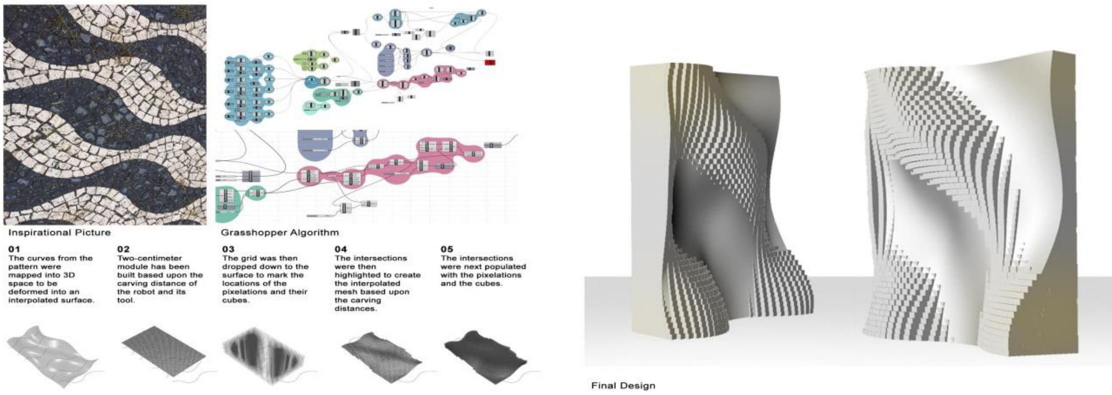

Fig. 6 Students created a parametric system to be applied on a surface in order to provide a feeling of fusion between surface and pixels. (Image from Nemr Nabbouh, Nour Rmadan, and Rami Sabbagh)

The final result produced was based on the curvilinear arrangements of the pavements of the city, transforming the curved lines into a tridimensional configuration. An extrusion of the pavement square tiles on a surface representing the hills made the pixels vanish as they go downward, creating a sense of rough ups and smooth downs, and defining the topographical imagination of the city merged with the pavements on its roads (Fig.6).

Fig. 7 Meeting with students at the fabrication lab for explanation of the restrictions between design and production (left) and stage of fabrication process with a robotic arm (right). (Photos from author)

During fabrication, the pixels would align themselves with the original material module, and with the final component resulting in a fusion between rough pixels and smooth parts of a surface. Students also integrated the series of restrictions set by the machine, taking into consideration such constraints as factors throughout the design process (Fig.7).

During the project, students presented very strong conceptual methodologies, using imaginative ideas for a varied series of outcomes. Once rationalized, conceptual and design phases were able to be presented and produced at a small scale with the use of 3D printers. The final outcome for fabrication also provided a balance among ideas, design processes, and fabrication in a satisfactory manner.

In this open experiment, Students were able experiment a variety of parametrically controlled formal variations in order to balance it with their ideas, in addition to associating their intentions with advanced automated fabrication. Since ideas, processes and fabrication links require a more dynamic

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way of thinking from the traditional one, targets and programs were set in more complex ways. This experiment was an opportunity to also increase their design cultural background, where creativity was open to possibilities that were first taken to extreme levels, and later balanced with constraints for further concretization.

6. CONCLUSIONS

In a review of the influence of practical teaching throughout the history of architectural education, the notion of reaching to a reputable science from the practical evolution was able to be noticed. Progressively converted from a minor art, architecture became a theoretical discipline of reputable impact in discourse over history. From a practical view, the architectural design practice became a prescriptive movement. Tools such as drawings and models became rigid means of communication foreseeing reality, with all aspects of the building being able to be determined before the construction process.

Practical instruction in architectural education disappeared at some point in history before being reintroduced in the twentieth century. As a support for this reestablishment, scientific methods were hosted the architectural discipline, expanding its boundaries to a larger scope. The characteristics of digital fabrication labs have been described in order to understand not just to figure out the proper way to introduce it to the academic curriculum, but also to foresee ways to provide a progressively positive performance and integration to it. Definitely, there are clear pedagogical ways of implementing experiments in order to provide dynamism in digital fabrication labs to effectively perform as scientific laboratories and to simultaneously host innovative explorations.

One of the primary implications in architectural education for setting up digital fabrication laboratories was merely to increase the number of physical models produced by students. This is due to the probable introduction of digital fabrication in particular courses instead being integrated in the architectural curriculum. Familiarizing students with all types of digital tools is vital since the early stages of their academic education in order to help them comprehend the way to deal with the different digital fabrication strategies and their complexities. During the senior academic stage, digital fabrication methodologies and architectural design studios should be merged. In addition, they should be combined with other technologies already available in many architectural academic programs such as digital modelling, parametric design, scripting, and programming. It is also essential to create conditions in order to use equipment from other science laboratories, as for example computational analysis tools or light simulators.

As the popularity of digital fabrication laboratories in schools of architecture increases and as they become more embraced by design tutors, it is possible to promote technological advances in architectural education. It also becomes easier to provide environments that allow students to control automated production processes in order to have a better control over complex building challenges. Being aware of the values of technology and realising what can be done in digital fabrication laboratories nowadays was one of the main goals of the experiments carried on during research. The results attained assisted students to analyze design strategies and construction principles of advanced spatial complex forms and to appreciate in a broader perspective the use of advanced fabrication principles for building connected to concepts, design processes and building strategies.

The awareness in digital fabrication applied to architecture is associated with a cultural shift defining contemporary trends in the practice. Therefore, it is essential to integrate digital technologies within the base knowledge of the architect, unavoidably embracing digital skills, and accepting digital fabrication laboratories to play its role in education. Fabrication cannot be merely considered as a part of a modeling procedure, but rather a revolution in architecture.

Digital fabrication laboratories are environments of great potential for promoting architecture with scientific methodologies and innovative approaches, the essences of the practice in contemporary architecture that should unequivocally be stimulated. With such motive, digital fabrication laboratories will not be merely considered as digital fabrication workshops.

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