DESIGN PEDAGOGY IN THE 4TH INDUSTRIAL REVOLUTION
PROTOTYPING IN ARCHITECTURAL EDUCATION

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ABSTRACT

This paper addresses as a case study the use of digital fabrication, focusing on rapid prototyping in architecture, as a potential element for the design pedagogy in the fourth industrial revolution. The study reports on the findings of a benchmarking study and is enriched by the authors’ observations on the case of the Fabrication Lab of the Department of Architecture of the University of Patras. As such, it analyzes the impact that these technologies might have in the learning process and in practice, narrating therefore, on the importance of their consideration in the academic curriculum of architectural schools. Following this objective, the study identified that the applicability of rapid prototyping can be governed by a series of critical processes and application specific issues. Specifically, several changes are presented that occur with the application of this technology in: the structure of the pedagogical program; the context and object of teaching; the mentality of users and the new skills that emerge because of their use and their capability in entering easier at work markets. The results of the study lead the authors to argue that in this instance of transformation, the meaning and value of the technological education becomes apparent and invokes changes in Design Culture.

KEYWORDS: Design pedagogy, fabrication lab, prototyping, smart manufacturing

INTRODUCTION

The Fourth Industrial Revolution, based on the Third Revolution of digitization, is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres (Schwab, 2016, paragraph 2). Its velocity, scope and systems’ impact are evolving at an exponential pace, affecting entire systems of production, management and governance (Schwab, 2016, paragraph 3). For instance, in business, companies shift their attention to innovation that depends on combining technologies for better performance. The technological foundation of these methods consists of cyber-physical systems, the internet of things, cloud computing, cognitive computing, artificial intelligence, robotics, 3D printing, nano-technology, biotechnology, materials science and energy storage. When these technologies are combined, the companies profit by new possibilities for mass customization, flexible manufacturing, lean manufacturing, and others (Hermann et al, 2016).

One of the areas of greatest influence is smart manufacturing, a subset of manufacturing that employs computer controls of adaptability in the multi-phase process of creating a product out of raw materials (Shipp, 2012). The term smart is not that new but the original establishment of the term its synonyms (e.g. intelligent), was used to explain how advancements in technology might develop the ability to acquire and exchange data for improved efficiency on levels such
As automation, analysis and maintenance within various industries (Shipp, 2012). In the specific field, the term defines an “intensified application of advanced intelligence systems that enable rapid manufacturing of new products and real-time optimization of manufacturing production and supply-chain networks” (SMLC, 2011).

If we look at architecture, rapid prototyping is clearly one of the sectors directly linked with smart manufacture that might affect the discipline in many ways. In fact, since the beginning of the 1980, prototyping has been considered as a sector where innovation emerged quite rapidly. At that time, the manufacturing industry began developing what has evolved into rapid prototype and three-dimensional (3D) printing technology, a technology that provided the ability for designers and engineers to create 3D physical models from 3D computer models. This process involved either the removal of material (machining) or the addition of material (printing) (Shipp, 2012).

Currently, many world famous architecture firms use rapid prototyping and many architecture schools have begun experimenting with these technologies (Dimitrov et al, 2006). For example, Foster, Partners have fully integrated rapid prototyping within their design process since 2008 considering it as a “fundamental phase in the design process”. UN Studio (Berkel, Bos 2006), OMA (Koolhaas, 2004), Greg Lynn (Lynn and Rapolt, 2008), take into consideration dynamics of rapid prototyping to generate the logic of design (Achten, Kopriva, 2010). Zaha Hadid Architects’ director, Patrick Schumacher, in collaboration with DRL (Design research Lab) of Architectural Association, uses the AA digital Prototyping Workshop Lab, creating a revolution in the field of parametric design. Lastly, major corporations and international firms use BIM and rapid prototyping in the design and implementation process, affecting in depth the manufacture process of materials and built forms (Schumacher et al, 2010). Generally, the common argument behind using prototyping in practice and in education is that they can interconnect design, engineering, product creation and advanced technologies, being therefore attractive (Achten et al, 2010). In fact, the creation of printed parts, not just models, reduced the costs and time in the product development, allowed to architects the possibility to create almost every shape, and maximized human interaction with machines. That means that with rapid prototyping, scientists and students can rapidly build and analyze models for theoretical comprehension and studies.

However, today rapid prototyping has not been universally adopted as a necessary educational tool. Therefore is not recognized yet as a field able to generate useful professional skills for the industry in the schools of architecture. It is obvious that the issues briefly described above are but a small fraction of the plethora of challenges that new technologies bring to design education for the Fourth Industrial Revolution. These challenges have given rise to the need redesigning instructional frameworks in order to increase technological literacy and to aid in the professional development of those educated (Hemsath et al, 2009). Moreover, holistic frameworks for design education are necessary in pursuance of pedagogy for the Fourth Industrial Revolution. For this reason, we would like to argue that a focus on educational frameworks that might include the potentialities, challenges and specificities of rapid prototyping might be of interest in the academic world. For instance, the common concern between teaching and praxis might be overcome when bridging together all the above-mentioned sectors. Following this premise, this article aims at highlighting the issues concerning this discourse and offers a suggestion of the possible key sectors to examine. These sectors are categories of interest that have the ability to attract market stakeholders and help young professionals to acquire better employment possibilities.
DESCRIPTION OF THE PROJECT

We base our research on the fact that there are not many studies that evaluate the insertion of rapid prototyping in the educational curricula due to concerns that surround the cost of technology, which includes not only a start up cost but also costs related to maintenance, materials and operations (Marcus et al, 2014). Our general research question is: How does the case of rapid prototyping (Kolarevic, 2001) in smart manufacturing domain contribute to the formation of a pedagogical method of design? A second, more specific question, regarding the case study is: How does the prototyping contribute to the process of creating new comprehensive strategies for merging educational approaches with new technologies (Valdés et al, 2013)? The main objective is the analysis of the deployment of a process of smart manufacturing, extrapolating the possible effects on design pedagogy and identifying potential avenues of future innovation in the educational field (Hemsath et al, 2009). Finally, it traces some characteristics of a new design culture for educational approaches, in order to prepare the workforce of the Fourth Industrial Revolution. The methods applied are a detailed analysis of the definitions and theories that bring together all the above-mentioned issues. Then, we pass to the presentation of some case studies that have illuminated important factors that appear in the application of rapid prototyping in the architectural curricula. Lastly, we present the example of the work of the Fabrication Lab of the Department of Architecture of the University of Patras, as an case of personal observation. The overall purpose of this study is to state and present the challenges of traditional model teaching techniques and of the insertion of rapid prototyping in architecture schools.

EXPERIENCE FROM THE USE OF SMART, DIGITAL AND RAPID MANUFACTURING – DEFINITIONS AND IMPACT ON DESIGN

The physical model occupies an important place in architectural design (Kvan, 2001). Contrary to two-dimensional representations, physical models allow for a closer approximation of the finished product. Although advances in digital representation technology - such as virtual and augmented reality - may alter this fact, it can be argued that the tangible model retains a privileged position in design thinking and praxis (Kenzari, 2005). On a separate note, the tools of production have been closely linked to the development of design (Klinger, 2001), in other words the available means of production have to a certain extent dictated the form of design products. The introduction of Computer Assisted Manufacturing (C.A.M.) in the design field has led to a re evaluation of the role of the model in the way we conceive design (Arpak et al, 2009) as well as the resulting products of the design process. Certain aspects of this influence will be examined here.

The first point on which the present paper would like to elaborate is one of definition. The introduction of C.A.M. in design has led to a proliferation of relevant terms in related discourse, such as Digital Fabrication (Kolarevic, 2001; Valdés et al, 2013) and Rapid Prototyping (Junk & Côté, 2013) (van der Zee et al, 2014). Generally, these terms refer to the utilization of Computer Assisted Manufacturing tools and methods in order to aid in the construction of architectural form, either as scale models or as parts of the final construction. Furthermore, one can find differentiations between various definitions. On one hand, the term Rapid Prototyping refers...
to the direct production of a physical artifact from a three-dimensional model (van der Zee et al., 2014), although it has been argued that the term is not confined to this method (Pupo et al., 2009). On the other hand, Digital Fabrication is utilized as a broader term covering all forms of C.A.M., from laser cutting and C.N.C. milling to additive or subtractive 3D prints (Kolarevic, 2001). In other scholars rapid Prototyping (RP) is represented by “a range of technologies that are capable of taking virtual models created in CAD systems and fabricating them in a physical form” (Gibson et al., 2002, p. 3). While, the first techniques of rapid prototyping were used to produce models and prototype parts back in the 1980s, today rapid prototyping techniques have given a new impulse in the building industry, especially when a BIM is present (Thompson et al., 2014). Layered Manufacture (LM) and Virtual Reality (VR) are two of the technologies that usually are referred to as Rapid Design and Manufacture (RD & M). Both Rapid Prototyping as well as RD&M offers a number of significant advantages over conventional modeling techniques such as speed and versatility. It should be noted that most of these terms, originating in different fields of engineering are not readily applicable to the design domain (Pupo et al., 2009), which has a radically different context from them. Nevertheless, although further examination of the nuances and differences of various terminologies escapes the scope of the present paper, it is argued that all these terms fall into the broader category of “Smart Manufacturing” conceived as an approach to manufacturing that aims at optimizing the conception and creation of products, utilizing advanced information and manufacturing technologies.

The second point regarding the introduction of C.A.M. methods in design disciplines refers to the influence they exert on the process of design. As has been previously mentioned, the physical model retains a crucial position in the design workflow (Arpak et al., 2009). It is well documented in related discourse that models are a form of representation (Kvan, 2001), and as such play an important role in the development of a project. In this context, the role of Digital Fabrication techniques is twofold. On one hand, it facilitates the production, leading to the quicker production of higher quality models. On the other hand, it allows for the physical representation of more complex forms with higher precision. Beginning with the first aspect, i.e. the faster creation of models, this leads to a resurgence of the role of the model in the design process, a role that due to the introduction of Computer Assisted Design (C.A.D.) software applications had been severely diminished in recent years (Pupo et al., 2010). This has led to a concurrent increase in aspects of the design connected to materiality and fabrication, that is to say the choice of materials, concerns surrounding structure and fabrication and so forth (Arpak et al., 2009). This brings us to the second aspect mentioned above, namely the physical representation of complex forms. It is a well-documented fact that the introduction of C.A.D. media in design has led to the production of curvilinear and complex forms. Furthermore, it has been theorized that that one of the problems facing such forms is the difficulties in “constructability” (Kolarevic, 2001). Therefore, Digital Fabrication methods have assisted in the translation of the digital forms into physical reality, which would not have been possible before the advent of said methods.

The third point regarding the impact of Digital Fabrication on the design disciplines is related to the production of the design product. On the one hand, the increased interrelation between the design process and the digital manufacturing techniques outlined above has led to an emergence of a new aesthetic (Loh et al., 2017). This is linked both to the ability to realize the complex forms created by C.A.D. tools as well as the increased role of materiality due to the
feedback provided by various digital fabrication methods. On the other hand, we are witnessing an increasing cooperation between industry and academia in the field of Digital Fabrication. This has led to the shifting of focus from education to practice (Fok, 2012) and to a development of new fabrication methods in order to achieve the construction of the new forms proposed by designers (Coleman, Cole, 2017). On a final note, the scale and time frames in contemporary projects make the utilization of digital fabrication indispensable (El – Masri et al, 2012).

As a result, we would like to argue that rapid prototyping shows fully the potential to be considered as a fruitful sector that can link design product development, teaching techniques and technology. The overall idea of producing fast and in low costs a physical model, aesthetically very strong and with precision, as well as their simultaneous ability to give an impulse to the building industry make it appealing as a sector for focus. For this reason we consider as important to see if the use of rapid prototyping can generate skills that could be inserted in the form of knowledge for the future workforce.

**ANALYSIS OF CASE STUDIES**

1) Theory

In light of the issues briefly outlined previously, certain results coming from publications regarding the introduction and implementation of rapid prototyping methods in schools are presented. These have been chosen chronologically from Cumincad Database, covering the period from 2005 until 2017, over a spectrum of 538 papers in the field. The presentation of said case studies will not focus on an in depth description of their respective methods. Rather only certain aspects pertaining to them will be highlighted in order to further the present paper’s investigation regarding the introduction of Digital Fabrication methods in design education. The articles chosen discuss how a curriculum involving rapid prototyping was created and implemented and we will summarize the major claims of the publications, both in implementation and usage strategies.

a. Technological impact on teaching design and representation

The first case study chosen (Stavric et al, 2007) highlights as important educational instance the separation of the didactic process into two stages. The first focuses on geometric knowledge and development of visual and spatial thinking while the second on integrated design process, i.e. the process from concept sketch to digital fabrication. This means that using the specific technique users are required to acquire the specific skills (in geometry and spatial thinking) and they become aware of this distinction in the process of using the technology. Also of interest is the analysis of the concept of representation, as a crucial factor in the process of design thinking and the identification of two separate types of representation, the external representation in visual reasoning as well as representation as a tool for design visualization. In other words, users are familiarized with the visual representation of their works through digital and fabricated means, instantly, in the same way that it would be required later in an architecture firm. These
factors provide two points regarding the integration of new technologies in
design education. On the one hand, the separation of theory, which consists
of lectures on geometry and introduction of tools is considered separate to the
design process itself. The second point is the conceptual models presented as
underpinnings to the educational approach. These include the aforementioned
concept of representation as well as the Eizenberf model (analysis –
transformation – synthesis) utilized in the second stage of the didactic process.
Therefore, the first case revealed that Rapid Prototyping is important because
it highlights important inputs in the didactic process of teaching design both
at a geometrical point of view but also in better representing the project, skills
that previously were not directly connected with the use of technology, but
was separate in the educational strategy.

b. Technological impact on educational goals and methods
Two other case studies focus on the “what” and “how” of the educational
process utilizing fabrication technologies. The first case study (Arpak et
al, 2009), conceives the studio as the production of a physical object. This
indicates simplified objects, such as walls (Fok, 2012) or installation artifacts
(Diniz, 2015) as best studio practices. This preference might lead users to
better connect with the development of a product immediately and also helps
them acquire a construction mentality at the early educational stages. The
second case study (Valdés e al, 2013), focuses on the process of organizing
teaching in relation to fabrication. In other words, the educational roadmap
emerges as important. This allows to better plan a pedagogical approach as
well as offering the ability to students and educators to critically evaluate the
results vis a vis the objectives stated (Gu et al, 2010). It remains an open
question if these educational approaches, which focus on new technologies
can function as well in more complex architectural projects, or whether the
simultaneous teaching of new technologies and intricate architectural issues
is too much to be contained in the course of a single educational studio.

c. In relation to the development of a new technological culture
An extensive review of cases and publications (Greenhalgh, 2009) revealed
that rapid prototyping better prepares students from a technological point
of view and offers technological literacy. This means that users acquire a
digital fabrication design culture. Furthermore, the study revealed that rapid
prototyping improves communication, provides opportunities to students with
limited construction skills and understanding and encourages them to learn
how to correct design flaws.
Furthermore, there appear to be a shift in expended time, from sketching and
conceptualizing to 3D modeling, while using rapid prototyping processes. The
study also examined the instructor’s point of view, which made clear that the
method of model construction assigned to the students had an influence on
their design.
2) Practice - observations from the Department of Architecture of the University of Patras Fabrication Lab

In this part of the article, the authors present their observations from the Fabrication Lab at the Department of Architecture of the University of Patras. This is drawn from their experience as coordinators of the Fabrication Lab from its very beginning in 2010. The analysis is presented in two parts. On the one hand, the authors will describe the administrative experience during this period. On the other hand, data from a specific period will be presented so as to extract important information on the implications of using the Digital Fabrication techniques from a user’s point of view.

Setup

The Fabrication Lab at the Department of Architecture of the University of Patras began functioning in 2010 after the purchase of a C02 Laser Cutter. Initially it was part of the Departments Computation Center but due to increased usage as well as practical reasons related to the operation of heavy machinery (safety and health concerns) it was decided in 2011 to create a separate Lab, nominally under the supervision of the Computation Center, but to practically functioning as an independent entity in the Department. This illustrates the first point of interest regarding the setting up of similar Labs, namely its position within the Departments organizational structure. Experiences demonstrates that especially in the early phases of the Lab’s development, a close relation with the Computation Center proves beneficiary. The main reason for this is that the Fabrication Lab is able to take advantage of the infrastructure already available, both on the level of administrative procedures as well as regarding available equipment, factors that a nascent Lab may not have yet in place. Once a Fabrication Lab is established, it is optimal that it functions as an independent entity within the Department, since the nature of its operation differs considerably from the Computation Center. Nevertheless, it is recommended that it remains in close proximity, since there is significant overlap in the work carried out (for example digital designs and printouts to aid during the fabrication process).

The discussion of proximity brings us to the second point of interest, regarding the workspace per se. As has been already mentioned close proximity with the Computer Lab is recommended, as well as adjacency with the work area of the students. It has been observed on multiple occasions that students working in adjoining rooms would make frequent use of the Fabrication Lab, even during the assembly of the models. This, as will be discussed later, assists in the educational aspect of the Lab. On the other hand it is important to highlight that the operation of heavy machinery creates significant health and safety hazards that should be taken into account when designing the Lab space. Crucial factors include sufficient ventilation and air filtering as well as sound insulation. Taking these factors into consideration, the 2011 renovation that created the Fabrication Lab of the department of Architecture of the University of Patras in its present form created a double space (machine room and office) that houses the Department’s CAM machinery, consisting of 2 CO2 laser cutters, a 3D printer and assorted machinery (air compressor, air filter, computers) necessary for its operation.
As discussed previously, the Fabrication Lab operates autonomously, under the supervision of the Computation Center Committee consisting of 3 Faculty members. Although nominally the Computer Center Supervisor is also in charge of the Fabrication Lab, it has proven useful to institute a separate position, that of Lab Supervisor. This is due to the fact that the Fabrication Lab’s operation is significantly different from that of the Computer Center, requiring a different set of skills and knowledge, which will be discussed later. The Lab is staffed by undergraduate students, which are hired by the Computation Center Committee and trained by the Lab Supervisor. A new employee is required to complete a certain period of training next of a more experienced member of the Lab before being cleared to operate the machines unsupervised.

The solution of utilizing students as employees has proven to be the optimal one, since the fluctuation in workload – as will be demonstrated below- renders the hiring of normal employees inefficient. Furthermore, the utilization of students leads to the development of a certain esprit de corps which aids in the Lab’s operation.

The Fabrication Lab is available to all students of the Department, as part of the Lab’s policy, since it has been proven that students that are introduced to Digital Fabrication methods earlier in their studies are significantly influenced by it. This is apparent in two distinct ways. On one hand they learn to avoid errors or sub optimal practices in the preparation of files and use of fabrication techniques as referenced by (Rügemer, 2008). On the other hand they are more probable to create models of advanced complexity, that take full advantage of the machines capabilities, having acquired experience through simpler designs in previous projects.

Through the course of the Lab’s operation, it has been proven that the optimal method of communication with the students is as follows. Instead of keeping regular work hours, which due to the fluctuation in workload is a waste of the limited manpower and resources, the Lab operates on a as-needed basis. The students are required to send an email, with the fabrication drawings and other details (material used, deadlines etc). Instructions are available for the preparation of these drawings Students are strongly advised to send their projects as soon as possible in order to avoid overloading the Lab during presentations, although as will be mentioned later, this is an issue that is not avoided. The Lab personnel then evaluates the drawings, checking for errors, making a rough estimate of the time required and specifying available dates for the fabrication. The student is then notified to make any corrections necessary and given an appointment to bring the necessary materials. If the estimated completion time is brief, the student remains in the vicinity, otherwise the staff contacts them upon completion, but in either case outside the Lab work area. A drawback of this policy is that students are not on hand in case of unforeseen errors or necessary adjustments, but this has proven a necessary measure since a great number of non qualified persons in the Lab area hampers the operation as well as creating safety hazards.

Normal operation peaks during final presentations (a period of roughly 2 - 3 weeks at the end of each semester) , as will be evidenced in the data presented below. Unfortunately, due to this fact, as well as a general lack of cooperation exhibited on part of the Design Studio tutors (as mentioned by (Celani et al 2010), there is limited chance for the Fabrication Lab to affect the design process, since most fabrication takes place after the design has been finalized. Furthermore, due to the pressing deadlines (it is common for projects to be fabricated mere hours before presentation)
there is also little room for corrections or alterations to the models. This, from our experience is caused by the fact that designs are not finalized in time to allow a proper fabrication process. This can be attributed mainly to the lack of understanding of the process (from the steps required to the necessary time), in other words, the lack of a Digital Fabrication Culture on part of both tutors and students. Much better results have been observed in the case of students that work in halls surrounding to the Lab facilities (usually students working on their diploma projects). These students, due to their close proximity, they are more familiar with the Lab’s operation and as a result space out the necessary fabrication tasks in a way that allows for feedback and corrections, while also taking advantage of low workload periods. It has proven that these cases are among the most successful regarding the models produced.

### Data

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<th>DESIGN STUDIO 4th YEAR</th>
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<th>DIPLOMA</th>
<th>INTERIOR DESIGN</th>
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<td>4.46</td>
<td>1.8</td>
<td>20.09</td>
<td>7.5</td>
<td>3.77</td>
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</table>

*Figure 1. Number of Students, Sheets and Averages per Course*

In the following charts are presented the data from the Fabrication Lab operation between 14/01/2013 and 08/02/2013. This period has been chosen as a typical example operations during final exams. Due to the fact that only laser cutters were operational at the time, the term “Sheets” refers to the individual sheet of material the Laser Cutter processes.

*Figure 2. Timeline (Blue: Number of Sheets, Red: Number of Students)*
From the data presented a number of observations can be made:

- The massive increase in workload in dates closer to the final presentation. This has been already discussed and is especially evident in the number of students (32 compared to a previous average of 10).
- The 28% increase in number of sheets of the 4th year compared to the 3rd. This indicates a higher level of complexity in the models, given the fact that the number of students is roughly equal (41 to 46).
- The average number of sheets per course: In **Urban Design**, which requires larger scale models averages 1.8 sheets per student, while **Interior Design** where projects are of a far smaller scale averages 7.5. Diploma averages justifiably are far higher, at 20.09 sheets per student.
- It must be noted that the number of sheets does not reflect the time required, since that is also dependent on the complexity and thickness. Due to practical reasons, it was not possible to collect time related data.
- Group projects are registered as a single student for expediency.
Therefore, based on the experience drawn from 8 years of operation, certain recommendations can be briefly presented.

The necessary equipment requires a significant investment early on, but the expenditure can be spaced out according to use. The laser cutters prove to be the most utilized machines, while the addition of a CAM router would significantly lighten the workload placed on the laser cutters, due to its ability to manufacture large objects. 3D printers have not proved as popular, due to the partly to the complex file preparation required as well as the slow manufacturing speed. It is also noted that the fact that they produce full models instead of parts to be assembled limits the tectonic aspect of the model and therefore part of its educational value. Regarding the Lab space, in depth foreplanning is essential including necessary power supply, HVAC and safety regulations. Allowance must also be made for future expansion as new machines are added. This will help avoid costly and time consuming renovations as well as and need for new spaces in the future.

The cooperation of the Faculty, especially the Design Studio tutors is of paramount importance. As has been already discussed, the lack of communication leads to the suboptimal use of the Lab's machinery as well as not providing the students with enough experience regarding the new methods of Fabrication. It is suggested that Lab personnel takes part in the Design Studio, in order to provide assistance, and tutors should familiarize themselves with the Lab's operation in order to be able to adjust their Projects accordingly.

Although costs and availability are an inevitable concern for all Academic Institutions, every effort should be made in order to make the Lab available to all students, regardless of year or economic status. As has been mentioned previously, the solution of limiting the use to Diploma students is counterproductive regarding the educational aspect of the Lab. On the contrary, the imposition of a small fee (around ¼ of commercial prices) based on the duration of use has proven necessary to the Lab, while not imposing a disproportionate burden on the students.

From an educational point of view, it is important to note that the experience gained from utilizing the Fabrication Lab facilities provided a new skill set to the students, allowing them to pursue careers in related industries after their graduation. This falls within the theory of the “skilled user” (Komninos, 2008), in the 4th Industrial Revolution, with a focus on future development and growth. Beyond this, the operation of the Fabrication Lab fostered the development of a Digital Fabrication design culture among the student population, that persists to this day. This phenomenon, as previously mentioned, creates a esprit de corps among students and staff. Furthermore it aids in the amelioration of the education provided as well as promoting teamwork and cooperation.

The emergence of a new working force

Following the specific case study, several observations on the role and nature of the people involved in the function of the Lab were drawn.

The first point, is that the primary characteristic of Lab supervisor should be a balance of managerial and teaching skills. This is paramount to ensure the smooth operation of the lab
since a supervisor will have to fulfill the dual role of educator and manager. On the one hand he must be able to impart knowledge in a concise and comprehensible manner, as well as creating relevant documentation. Ideally the Fabrication Lab can organize seminars or workshops that aid in the Labs visibility and assist in its integration in the Department. These also require a strong educational background. On the other hand, since the operation of the Lab is usually built from scratch strong managerial and organizational skills are indispensable. The Lab supervisor must be able to coordinate, train and motivate the student workforce, innovate and implement procedures and protocols to ensure the smooth operation as well as oversee and organize the Lab’s operation especially in periods of extremely high workload. Furthermore the supervisor is usually responsible for dealing with external actors (Faculty, suppliers, funding committees etc) which also requires strong managerial skills.

The second point involves the knowledge a Lab employee should have. This is divided into two parts. The first is the engineering aspect. Since the Lab involves a large number of machines, certain ability to effect repairs, regular maintenance operations and so forth is indispensable. This lessens the need to require external help, which is both costly and time consuming. The second part of knowledge revolves around the knowledge of CAD software and more generally computer expertise. Beyond the obvious mechanical aspect, digital fabrication involves the use of multiple software packages for the transfer of the necessary files as well as the functioning of the machines. Given the fact that usually an I.T. technician has poor understanding of the design aspect of these issues, a Fabrication Lab employee should be able to handle basic software problems with little or no exterior assistance.

It is obvious that these skills are not necessarily restricted to a certain discipline, be it engineering, design or I.T., rather a mix of skills is required. Furthermore, most of this particular skill set can only be truly mastered through practice, making a period of tutelage in a Fabrication Lab indispensable part of the required skill set. Given the continued evolution of Computer Assisted Manufacturing, its integration in an ever growing number of diverse industries, ranging from construction to fashion as well as the proliferation of Fabrication Labs, facilitated by the democratization of relevant technologies, it is argued that such an experience will prove an invaluable asset for the future professional development of any individual.

**Conclusions**

We consider that we have contributed to the field by analyzing this novel case study from the complementary visions of theory and practice. This is due to the fact that to our knowledge, there is still scarce literature bridging actual experiences of using the technologies from early stages of the academic curriculum and direct employment in engineering firms. Another limitation is the fact that the above-mentioned technologies might be expensive. This means that the effects of such presence of ICT in various architecture schools are not rich, but limited.

The process of using this specific technology acquires many layers of meanings, referencing the traditional educational systems, mixed with the technology of the present. In fact, the rapid prototyping brought about a re-evaluation of the role of the model in the way we conceive design (Arpak et al, 2009) as well as the resulting products of the design process. This, although based
on a traditional practice of teaching architecture made a smoother passage to the concept of smart manufacturing and therefore respond back to the concepts of smart factory. The effects of the use of such technology bring a different experience of the design process that could have cultural implications (e.g. the creation of a new learning community and workforce that feels more capable to express themselves in the most creative ways). As has been previously mentioned, is contended that beyond the specifics of each educational approach, what is of importance is to outline the common themes and the common issues that can be traced in them. Thus, we can highlight main points of interest.

- The structure of the pedagogical program and the role of new technologies within it (for example theory - practice)
- The goals and methods of the educational process (i.e. materiality, roadmap of process, fabrication etc)
- The object and context of teaching (collaboration with industry, wall or art installation project and so forth)
- The creation of a new technologically driven culture
- The creation of new skills that can open new possibilities for employment in the future

All the factors described above point to a paradigm shift in design due to the introduction of Digital Fabrication, which as has been pointed out can be conceived as a field of Smart Manufacturing. Of equal importance to the impact of these technologies is the response of the design discipline, especially in an educational framework to these challenges. It is useful to cite the German architect Mies van der Rohe, who stated that “That we produce goods and the means by which we produce them says nothing spiritually … But it is exactly this question of values that is decisive” (Neumeyer, 1991). Therefore, we should further examine how design education asserts itself vis a vis the givens of this new age.
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