PEDAGOGIC APPROACH IN THE AGE OF PARAMETRIC ARCHITECTURE

Experimental Method for Teaching Architectural Design Studio to 3rd Year Level Students

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Abstract. In this era, Architectural Design Practice is faced with a paradigm shift in its conventional approaches towards computational methods. In this regard, it is considered a pedagogic challenge to boost up knowledge and skills of architectural students' towards an advanced approach of architectural design that emphasizes the potentials and complexity of computational environments and parametric tools for design problem solving. For introducing the concept of Parametric Oriented Design Methods to 3rd year level architectural students, an experimental pedagogic course was designed in the scholastic year of 2012-2013 at German Jordanian University GJU (School of Architecture and Built Environment SABE) to approach this concept. In the preparation phase, the experimental course was designed to incorporate structured instructing and training method to be consecutively performed within experimental lab environment to target predetermined learning outcomes and goals. The involved students were intentionally classified into three levels of previous involvement associated with the related software operating skills and computational design exposure. In the implementation phase, the predetermined instructing and training procedures were performed in the controlled environment according to the planned tasks and time intervals. Preceded tactics were prepared to be executed to resolve various anticipated complication. In this phase also, students' performance and comprehension capacity were observed and recorded. In data analysis phase, the observed results were verified and correlations were recognized. In the final phase, conclusions were established and recommendations for further related pedagogic experiments were introduced.

1. General Introduction and Definitions

1.1. ABOUT COMPUTATION TOOLS AND PARAMETRIC DESIGN

"Parametrics is more about an attitude of mind than any particular software application. It has its roots in mechanical design, as such, for architects it is a borrowed thought and technology. It is a way of thinking that some designers may find alien, but the first requirement is an attitude of mind that seeks to express and explore relationships" (Woodbury, 2010).

When talking about Parametric Design, one finds it puzzling framing this approach into its proper definition without looking at it from the computational point of view. Therefore, for both involved educators and students, and to gain the potential of this novel design trend, an appreciative comprehension is to be established towards identifying the recognizable components that accept computing in this scope.

The need to compute is the need to be involved in the design process, to break down the intricacy of a design problem i.e. the form, into a computable formula or say an Algorithm. The main distinction between computation and computerization lies in information processing, "one increases the amount and specificity of information, while the other contains as much information as is initially supplied" (Menges and Ahlquist, 2010; Terzidis, 2003).

Architectural artefacts as objects are defined by a set of components, parameters, attributes, and multiple layers of relationships that govern the geometrical distribution and interconnections between those elements. This indeed puts an end to CAD (Computer Aided Design) processes as we know them, where design reaches its peak when the singular object is best visualized.

On the other hand, computation is about multiplicity, and about developing a dynamic system that would generate and mutate better versions of the object whenever the input is changed. Providing that "Design is change" (Woodbury, 2010), parametric modelling represents that change (Woodbury, 2010).

In his paper, Parametric Diagrams, Patrik Schumacher outlined a future for architecture through the parametric diagram and new Parametricism style. For him, Parametricism is "the appropriate architectural response to the need to organize and articulate the increasing complexity of the post-Fordist society" (Schumacher, 2009).

The idea of this discourse is not new to architecture, through history, architecture, math and other associations have been always present, in an indirect manner perhaps. However nowadays, generative mathematical driven designs are highly applicable through the use of computer, that's enabling repetitiveness, simulation, and an accelerating speed at which it executes complex and recursive mathematical operations.

Through computer, it is easier to visualize the outcome, being the form perhaps, and moreover animate that form, as such, the parametric model becomes a "living " model with a degree of design flexibility never been present before. This flexibility in specific is where the importance of the parametric tool lies, the domain to which this is applied is truly unlimited. Whether it is form finding, structural optimization, environmental conditions simulations, material behaviours, performance analysis, program planning, data visualization or many other applications, the concept is always unchanged, and the novelty of the open ended design process is always there.

Designers are not searching anymore for one static and defined formal solution; they are designing the steps and formula that will achieve that form. Adding this level of intelligence to the design process gives the reward of exploring the possibilities that parameters can bring and the possible surprise in discovering the unimagined outcomes generated by the designers' conceptions (Website, 2013).

"The Phenomenon of architecture can be most adequately grasped if it is analyzed as an autonomous network (autopoietic system) of communications" (Schumacher, 2011).

1.2. ABOUT DESIGN METHODOLOGY

Since the emergent of the computational technology it became a fact that architectural design process is being totally rethought of. With its uncountable advantages to many scientific and artistic fields, Architects have been struggling for few decades now with how to fully utilize and integrate this new tool in the actual design process.

Unfortunately until now, this integration was limited to replacing the pen and drawing kit with the virtual working space, drafting and modelling tools. On architectural thinking, the drawbacks of this replacement are represented in the difficulty to convey the process behind the final results in addition to the limited inheritance of the know-how, that's been passed from one to another through the history of the architectural education and practice (Tifadi and Iordanova, 2006).

Recently, few enthusiasts have been investigating how to better couple technology with architectural design, looking more into buildings and what conceives those artefacts to formulate better understanding of what architects actually are trying to obtain (Tifadi and Iordanova, 2006).

According to Dr. Huda Salman, there's always a paradox associated with a designed product, and its design methodology, " Is it the produced artefact or the process of the artefact production? Which one characterises design methodology? "(SALMAN, 2011) . On this regard, this pedagogic experiment followed a methodology that aims “to improve design processes" (KROES , 2002), a problem solving approach, and a process of systematic thinking and solution evaluation.

1.3. THE INTENTION OF THIS STUDY

In Parametric design studio at the School of Architecture and Built environment (SABE) of German Jordanian University (GJU), this study was intended to fulfil the mission of striving for the novelty of the process.

Advancing toward that mission, a pedagogic design methodology was proposed that was totally unconventional nor digital, but experimental. This study is intended to offers details and observations related to this performed pedagogic experiment.

2. Pedagogic Methodology and Experimental Approach

In this part, the methodology and approach of the performed pedagogic experiment will be explained. The involved objectives, tools, environment, procedures, performance, considerations, results and conclusions will be introduced:

2.1. INSTRUCTIONAL MISSION AND GOALS

The main instructional mission of the proposed pedagogic experiment was to advance students' knowledge and skills towards the following goals:

- To introduce the architectural design tools offered by the computational environment;
- To brainstorm and emphasize on the newly emerged design methods made possible by the computational environment;
- To illustrate the importance of communicating the design process;
- To define and work with open ended processes;

- To explore parametric design tools and to examine the generation of multiple formal expressions through these tools; and
- To investigate on how a tool affects the design process results, therefore, changes architectural practice and consequently the built environment (Tifadi and Iordanova, 2006).

2.2. EXPERIMENT TOOLS AND ENVIRONMENT

To approach these aforementioned goals, digital parametric tools were involved to allow students to design within an environment that is based on rules and generative descriptions. This environment was employed to amplify the students design understanding and learning outcomes. Within this environment, the students were allowed to utilize their previously accumulated computational skills and knowledge to support creating their own design proposals.
The setting for this experiment was a Studio/Lab space within SABE (School of Architecture and Built Environment).
Apart from the advanced computer equipment, the studio was looked at as a contemporary studio (SALMAN, 2011), one that hosts learning by doing and discovering, a creative field of exploration and collaboration. It is been researched recently, the effect of applying CAD in early design phases, and according to Dr. Huda Salman (SALMAN, 2011), for students and within the context of education, this new trend had a great influence on enhancing the creativity level, given that tutors maintain a positive attitude towards this approach.

2.3. EXPERIMENT STRUCTURE AND TASKS

The studio tasks progression was structured in a way that divides the design exercise into two main blocks:
1- Minor Project.
2- Major Project.
This division is based on the fact that students at GJU do not have a previous knowledge in Parametric Design tools and theory, therefore the minor project will be introducing the different terminologies and gear the design habits towards research and experimentation, within a limited time frame and a simple function - environment - form association. Students here were not obliged to use the computer or any parametric tool as the aim was to focus on shifting their mindset and on understanding the world of Parametric, and of course this can be done at a very basic level with the tools that they already are familiar with.
Because of the semester's very limited time, it was necessary to carry the knowledge gained from the Minor Project a further step and integrated it within the Major Project. This latter has more programmatic and spatial complexity. The students were asked to use the association created in the Minor Project as a point of departure for the Major Project.
The following is an elaboration on the design nature of both tasks:

2.3.1. Task 1- Minor Project: Environmental Responsive Pavilion

This small project, or say installation, was required to engage with the environment, instead of avoiding or ignoring it. This engagement for this studio’s purpose was to happen on one level only; the sunlight and its unique behaviour and characteristics. Sunlight coupled with the basic concepts of parametric architectural thinking was the driver for the growth and

development of this project in order to achieve certain criteria, whether the approach is energy efficiency, sustainability, pure aesthetics or any other.
Students worked in small teams on this task and were asked to consider this following list.
Should or Should Not Be List:
- Should not exceed 20 m2 in footprint total area.
- Should not exceed 5m in height.
- Should respect human scale and experience.
- Easy Assembly and transportation.
- Material better be low cost and available on site.
- Should contain an enclosed volume.
- Maintains continuity between floor, wall ceiling.
- Have some flexibility for adjustment and control on site.
- Should be self supported structurally.
- Should optimize structural elements.
- Should optimize material use.
- Should optimize the form.

2.3.2. Task 2- Major Project : Sports and Recreational Venue

The Major project was a Sports complex. Mainly, it is a structure, a building or a cluster of buildings or smaller entities, allocated within the body of the German Jordanian University's campus. A medium scale project of a BUA of about 3000 m2 with moderate level of functional complexity.
Being investigated within the Parametric Architecture design studio, the diversity of functions and variety of areas, volumes and atmospheres across the project, provided a wide platform for students to look into multiple ways of finding, perhaps, structural, spatial, programmatic, environmental, social, topographical, formalistic and many other entry points that will define the way you they approach this project as a whole.
It was the student who defined the level of involvement the parameter will have in his/her design, based on the direction followed as early as the conceptual phase, where problems are identified and solutions to those problem are to be envisioned.
Students were provided with a site and basic program that could adapt to any design idea.

2.4. EXPECTED OBSTACLES AND RESULTS

From the beginning to the end of the course, students were expected to have the ability to explore creativity through novel definitions of finding form and generating structure with emphasis on environmental and technical issues.
One of the main expected obstacles of this experiment is the lack of previous knowledge in the researched field, and weakness in using the digital media as information generator. The complexity lies in the student being only in third year, and still not very confident of their technical and theoretical abilities, although this same weakness might be a strength factor for the fact that students do not have any previous attachment to certain styles, way of thinking, specific tools ... etc, which makes it easier to break out of conventional design methods.
Students are expected to brainstorm in groups, develop as designers and researchers, grasp the new knowledge passed to them and be able to use it to arrive to mature solutions. Moreover, on a higher level, learn new tools and design methods, and develop a project with

the integration of parametrics, feedback loops, evaluation and evolution of multiple design solutions.
In this experiment, a certain percentage of the students' sample was expected to arrive to different level of creativity. As this experiment is driven by the novelty of parametric design methods, the targeted category of creativity was set from the beginning of the course. However, there were another percentage of students that were not expected to reach a level of innovation for many reasons, in both cases it was important to define and clarify for both tutors and students the meaning of "Creative" for the purpose of fair assessment and rich discussions.
In the context of a Parametric Design Studio, and as a first trial, being creative was being able to generate original parametric ideas and association, bringing something new and fresh to the computational discussion table. These ideas had to reflect a level of complexity in defining the nature of that problem, breaking it down to its very basic components and associating them back for a multi dimensional solution to emerge. Indeed students could arrive to very sophisticated results but here creativity lied in the sophistication and transparency of the process.

3. Experiment Implementation

3.1. THE PREPARATION PHASE

3.1.1. The Learning Plan

The pedagogic design exercise was structured to assist students to understand, think and produce in three predetermined learning targets:

- Architectural design problem solving.
- Parametric methods utilizing.
- Computational environment handling.

3.1.2. The students sampling

This experiment was established in correlation with the students' level of architectural design knowledge side by side with computational knowledge.
The students were selected from the third year study level and the architectural design knowledge was established by that indication. The advanced computational level of students was not considered, since the advanced computational studies were still not a core part in the study curriculum and students were usually basic educated and self motivated to be advanced through non-curriculum computational activities.
For that, the involved students were intentionally classified into three levels of previous involvement associated with the operating skills and computational design exposure related to the involved software and the supporting plug-ins.
This classification was intended to verify and relate any observed deficiencies in students' results to its correlation to computational verses architectural design knowledge. These levels were as follows:

- The advanced level: for students with substantial computational skills. This level included students with a good previous knowledge in operating system, basic texting software, 2D-3D CAD, 2D-3D-4D graphics and supporting parametric plug-ins.

- The intermediate level: for students with average computational skills. This level included students with a fair previous knowledge in operating system, basic texting software, 2D-3D CAD, and 2D-3D graphics with no considerable previous knowledge of supporting parametric plug-ins.
- The basic level: for students with fundamental computational skills. This level included all other students with a previous knowledge in operating system, basic texting software, 2D CAD, and 2D graphics with no considerable previous knowledge in 3D-4D graphics and supporting parametric plug-ins.

3.1.3. The time frame

The time frame was determined to be around one scholastic semester of 16 weeks (October 2012 to January 2013). Each week, two studio sessions (five hours each) were conducted to instruct and supervise students.

3.1.4. The computational environment

Rhinoceros 5.0 or Rhinoceros 4.0 supported with plug-ins such as grasshopper and its additional features. These were utilized to introduce parametric software support. Workshops, demonstrations and tutorials were offered to students.

It is important to clarify here that the tools used were not pre-determined as students had the freedom to introduce any tool they find helpful.

3.1.5. The evaluation milestones

Four mile stones of critique and evaluation were performed to monitor the performance and progress of students. These milestones were the following:

- Design theme background researching, site analyzing, functional program introducing, and parametric logic exploring.
- Conceptual design proposing (parametrically oriented).
- Detailed design developing (parametrically approached).
- Final design defending (parametrically executed).

3.1.6. The evaluation criteria

In order to improve the learning outcomes of this experiment, work assessment criteria was planned ahead, and carefully executed and communicated.

This is often a complicated task, especially in non-traditional academic disciplines, such as the teaching of professional skills, which demand experiential testing (Brown, 1999), mainly because of the ambiguous nature of the design process.

In this experiment, grading reflected many achievements, in alignment with the course learning objectives discussed earlier. The grade distribution varied from one phase to another, following a certain pattern complementing each evaluation milestone.

The table below shows the grades ranges and their relationship with major and minor achievements.

Many other qualitative layers affected the assessment, to mention a few: graphic presentation, focus and explanation, critical thinking, clarity, process and idea narration, level of details ... etc.

TABLE 1. Performance Assessment

Item	Grouping 1	Grouping 2	Grouping 3	Grouping 4
Range of Grades	94%-90%	89%-80%	79%-70%	69%-60%
Qualitative Measures	outstanding	above average	average	below average
Major Achievement Development of Computational Skill and Creative Implementation	All	Most	Some	Few or none
Design Thinking Level	All or Most	Most	Some	Few to none

3.2. EXECUTION AND EVALUATION PHASE

Students' evaluations were categorized in four sets of grouping to help put correlations together. These sets were pointing to ranges of evaluated grades starting with the highest grouping of outstanding performance (grades between 94% and 90%) and ending with the lowest grouping of below average performance (grades between 69% and 60%). Categorization were also itemized to correlate the measured range of grades with the variables of qualitative measures, number of occurrences (students), category percentage from all occurrences, computational skill level, and design thinking level.
According to the executed phases, the distributions of the total cumulative grades for all performance stages for the observed sample of students in this control environment were as shown in table 2.

TABLE 2. Distribution of Performance Grading

Item	Grouping 1	Grouping 2	Grouping 3	Grouping 4
Range of Grades	94%-90%	89%-80%	79%-70%	69%-60%
Qualitative Measures	outstanding	above average	average	below average
Number of Occurrences (Students)	3	4	6	2
Percentage from all Occurrences	20%	27%	40%	13%
Computational Skill Level	Average to High	Average To High	Poor	Poor
Design Thinking Level	Average to High	Average	Average to Poor	poor

The execution and assessment of the design methodology was divided into four phases as explained below, each of which followed structured time and task planning in order to maintain the flow of the educational process.

3.2.1. Design theme background researching, site analyzing, functional program introducing, and parametric logic exploring
At this initial stage, students were prepared to comprehend the domain and the limit for the conventionally involved design factors that will affect the design components. The potentials of the involved computational tools supporting the process were also investigated. In the time

frame of this phase, specific tasks and academic inputs were under monitoring and control within the following criteria:

a) Time Frame: Two weeks / 4 studios / 20 contact hours
b) Students' groups performed Tasks :
   - Researching and investigating the term "Parametric Design"
   - Differentiating between conventional design process and parametric design process.
   - Exploring the history of Parametric Design & its current applications.
   - Examining the offered Parametric Tools.
   - Comprehending the projects theme, nature, function and correlations.
   - Investigating the site, its tangible- intangible dimensions, and layers.
   - Working in teams through tasks distribution and coordination (Fig.1).

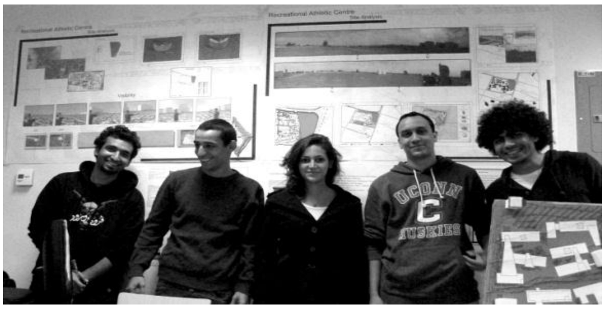

Figure 1. Team work during analysis phase

A. Supervisors' Input:
   1. Lecturing about the Design Process in general.
   2. Lecturing about Parametric Design in general.
   3. Offering software tutorials.
   4. Visiting the site.
   5. Performing desk discussions.
   6. Group discussing and Pin ups.
   7. Encouraging physical models to simplify and solidify the analysis and conclusion (Fig.2). In addition, physical models connects this novel design approach to the conventional methods that students are familiar with.

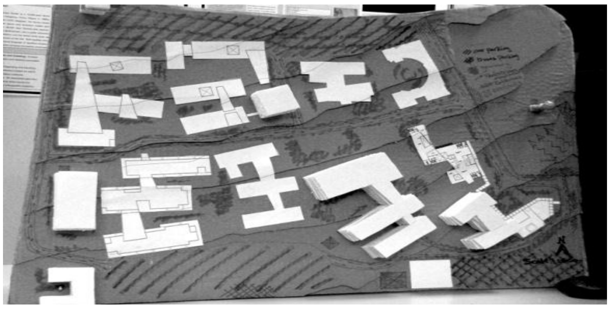

Figure 2. Physical model - site analysis phase

3.2.2. Conceptual design proposing (parametrically oriented)

At this second stage, students were required to individually put efforts to integrate the computational tools into the conventional design process (Fig.3). In this phase, time frame, specific tasks and academic inputs were also under monitoring and control within the following criteria:

A. Time Frame: Two weeks / 4 studios / 20 contact hours
B. Students' individually performed Tasks :

- Understanding Program.
- Using case studies as references.
- Developing an architectural / parametric concept.
- Introducing a parametric diagram.
- Getting control over a parametric design tool.
- Exploring the potentials and limitations of the parametric design tool.
- Setting up zoning and basic programmatic diagram.

C. Supervisors' Input:

- Lecturing about developing a parametric diagram and open ended design process.
- Giving students clear references to successful parametric examples and research, and explaining the novelty and value of the approach.
- Offering software tutorials, general to all students and specific for each.
- Emphasizing on form composing approaches, form finding techniques, and associate modeling instruments.
- Stressing on the significance of process documentation and graphics communicability.
- Performing desk discussions.
- Group discussing and Pin ups.

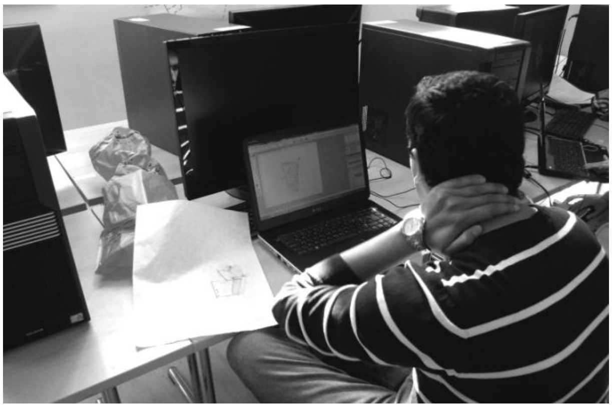

Figure 3. Students struggle trying to integrate the computer into the design process

3.2.3. Detailed design developing (parametrically approached)

At this third stage, students were required to individually work on developing the design efforts through engaging the examined computational tools. In this phase, time frame, specific tasks and academic inputs were also under monitoring and control within the following criteria:

A. The time Frame: Four weeks / 8 studios / 40 contact hours
B. Students' individually performed Tasks :

- Performing form finding approaches and assessments.
- Documenting the Processes.
- Planning the project milestones.
- Integrating form, functions and architectural language into one comprehensive whole.
- Producing architectural technical drawings.
- Developing architectural details.
- Introducing project image and geometrical articulations.
- Assessing the utilized parametric tool and its implementation in the design process.

C. Supervisors Input:

- Intensive one to one desk discussing.
- Close observation of parametric form finding process and maintaining its integrity and transparency.
- Clear guiding towards parametric evaluation criteria and selection process.
- Close working with students on developing architectural drawings and details.
- Juries executing with instructional critiquing and students defending (Fig. 4).

Figure 4. Detailed design development project Pin up discussions.

3.2.4. Final design defending (parametrically executed)

At this fourth stage, students were required to individually work on developing the design efforts through engaging the examined computational tools. In this phase, time frame, specific tasks and academic inputs were also under monitoring and control within the following criteria:

A. The time Frame: Two weeks / 4 studios / 20 contact hours

B. Students' individually performed Tasks :

- Finalizing process and form finding.
- Reflecting the previous phase assessment on the design decisions.
- Developing richer architectural details.
- Developing detailed architectural drawings, and rich annotations.
- Full design process documentation.
- Developing a physical model of the final geometrical expression.
- Skillfully use the right graphics and presentation techniques and medium to present the project (Fig.5).

Figure 5. Example of student's final submission

C. Supervisors' Input:

- Intensive following up on final design decisions.
- Advising for presentation methods and tools (Fig.6).
- Observing documentation process.
- Declaring final submission contents in advance.
- Setting up the work assessment criteria.
- One to one discussing with students.
- Group discussing and Pin ups.

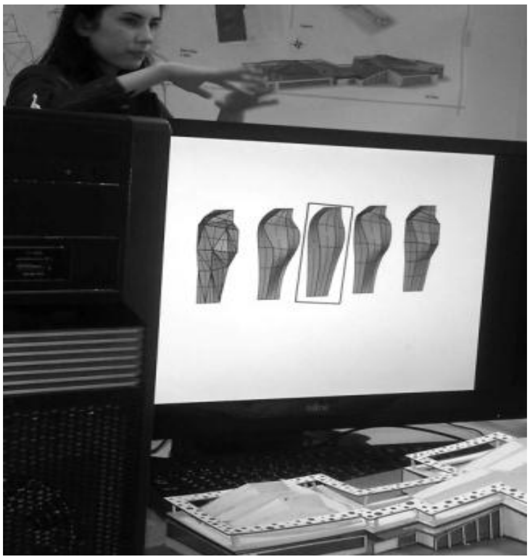

Figure 6. The use of different presentation mediums

4. Findings and Conclusions:

4.1. WRAPPING UP

This pedagogic experiment involved students from GJU-SABE of Jordan and was supported by faculty members from the same school. It was started on October 2012 and was finished in January 2013. A group of architectural design studio students of the third year level performed as the experimental target group. The experiment mission was established to offer to selected students novel methods of parametric thinking to boost their gained knowledge.

The experiment procedure was to expose students to structured supervised activities and to monitor their performance, their evolved awareness and comprehension of architectural design thinking. The structured activities were targeted towards advancing design problem defining and solving skills and parametric thinking logic within computational environment. The process of the detailed impacts was observed on the students throughout the course timeline. The findings were concluded in the form of a pedagogic approach to teach parametric oriented architectural design for third year level architecture students.

The students work, teaching methodology, project theme, encountered challenges, supervision tactics, evaluation processes, and the results of this whole effort were documented and analyzed for pedagogic research purposes.

4.2. RESEARCH LIMITATIONS

For exercising a complete design process, the time interval was critical as it was limited to one semester course time.

To limit the experiment impact to a sample of students, and to maintain the curriculum integrity towards the typical learning outcome of the design studio for the 3rd year level students’, this experimental design project was offered to one of four sections of the 3rd year level of Architecture students.

Another important limitation was the availability of the course material and the fabrication related resources. For example, the lack of library references, precedents from previous students' work, fabrication labs, funding, and the absence of exposure.

One major issue that arose during this experiment, was the lack of general understanding and familiarity with the topic from academic staff and architectural students, which after some time affected the expected outcome and pushed some students to give up on the process and lose the enthusiasm early in the course despite the continuous encouragement and assurance from the studio’s tutors.

Previous knowledge of parametric design methods and tools was important in this experiment, as with the time frame given, the missing level of tool proficiency enlarged the gap between students and slowed down their progress dramatically. The limitation here was in the curriculum itself as a studio similar to this was expected to have few pre-requisites.

The final limitation here lied in the very small number of available professionals in the field, being tutors, industrials or invited critics.

4.3. OBSTACLES AND TACTICS

On the timeline of the course, students faced reoccurring challenge in all the phases of the work. That challenge negatively influenced the student's enthusiastic attitude. The challenge was the frustration of trying to handle the undefined and sometimes the unknown variables of the computational tools when combining the use of them to develop the architectural design assumptions. This pedagogically unconventional challenge was handled by a set of tactics as follows:

- In every phase, the students that suffered from uncontrolled time waste that was spent to make things work, were asked to temporarily think conventionally and to delay the involvement of the parametric tool to the next design phase. This tactic of delaying computational tools involvement to the next design phase intended to give student time to adapt and to implement the tools in a more reduced and controlled scale. The scale of tools involvement started from site zoning scale to plan conceptualising, to building form finding, to building parts composing and finally to the scale of building elements and details engaging as the lowest level that the tools must be involved in creating.
- Grade bonuses were offered throughout the course timeline which were intended to give students incentives to confront challenges and reduce frustrations in the offered design problems with the new thinking combinations. Some of the challenges resulted from the lack of experience in the advanced computational tools and some were from the unconventional design thinking combination. The grades bonus was offered to students that showed substantial personal initiatives to spend efforts of parametric training and design thinking performed intensively outside the studio time in addition to the studio time.
- Additional after studio ungraded Pin ups and group discussions were performed to offer demonstrations and explanations to help reducing the complexity and to help solve challenges related to integrating computational tools with conventional design methods. These offered incentives, and for all students, changed their performance to a better situation (as in one average case from 72.5% to 78%). Instructors were keen to stress that this incentive should not to be considered or lead to guaranteed privilege, overestimation, misjudgment or false evaluation and was controlled to not give a misleading evaluation also. For that, evaluations were clearly verified, well considered and very indicative for students’ performance with the Bonus incentive.

4.4. STUDY CONCLUSIONS

In this parametric oriented design course, the supervising team performed more than seven evaluation sessions to look objectively into all the needed evaluation criteria on all possible levels. Grades showed that students did well and they can do better if they advanced their thinking and communication skills and their contemporary architectural knowledge. It would have been very helpful as well if students had little knowledge in computational and parametric design tools and methods.

The aforementioned table 2 shows that 67% of student’s performances (10 students with grades from 89% to 70%) were determined to be on the above average or on average level, not highly creative and on the other hand didn't poorly performed. The overall performance for this grouping indicated a hard working quality and commitment with average skills, average knowledge and average utilizing of computational tools. The table shows also that 20% of student’s performances (three students with grades from 94% to 90%) were in the outstanding zone and 13% of student’s performances (two students with grades from 69% to 60%) were in the below average zone.
The analysis of grades and observations of this study indicated the following:

- Students with medium to high design thinking abilities and with advanced computational skill level showed outstanding performance indicating the advantage of using this method when having control on it.

- Students with high design thinking abilities and with varied computational skill level showed above average performance indicating the advantage of using this method and its reflection on the design thinking logic even when not having full control on the tools.
- Students with varied design thinking abilities and with varied computational skill level showed average performance indicating that introducing this tool to the conventional design thinking methods didn’t have noticeable negative impact on students' performance even when using this method while having no control on it
- Students with low design thinking abilities and with basic computational skill level showed below average performance indicating that the advantage of using this method was not noticed when having poor design thinking skills combined with basic computational skills.

Based on these results the study concluded the following:

- The use of computational tools with students that have high design thinking skills can enhance students’ performance.
- The integration of preparatory courses to advance computational skills and tools can enhance design performance for groups with varied levels.
- Introducing the computational tools to design studios with conventional design methods is more likely to have positive impact on students' performance for all levels of design thinking and computation skill and tools, especially with such limited time frame and for students with lower level of study, such as the third year.
- Introducing the computational tools to the studios with conventional design methods is not likely to have a measurable negative impact on students' performance for all levels of design thinking and computation skill and tools.
- Introducing the computational tools to the studios with conventional design methods is in itself a limitation to computational thinking as this latter will call for open ended design processes and experimentation with design elements and systems and the conventional design methods are mainly final product oriented. However for the sake of being a first trial, this experiment did not take an extreme and accepted a partial to full involvement of parametric tools, leaving room for students and tutors to decide the percentage in order not to jeopardise whole learning process and the expected academic accomplishment at this critical level.

Please refer to Appendix A for a short review of some of the projects.

5. Recommendations for future studies

Based on this study the following recommendations were established:

- Studies with long time frames and larger groups of students are needed to verify the results of this pilot study.
- Performing these kind of studies is recommended for architectural design students of higher levels of study (4th year, 5th year, graduation, and graduate level students)
- Encouraging industry to develop and offer more architecturally related and parametrically oriented software and supporting plug-ins to support education of architectural engineering and design.
- Offering more oriented and related basic and advanced computational courser is recommended to be integrated in the architectural curriculums in the preliminary levels of study programs.

- The nature of the design challenge is important when such experiments have a very limited time and no previous preparations, for the fact that some problems are highly complex and need both computational and design proficiency to solve.
- More time should be given for group discussion and assessments to convey the information and feedback clear enough.
- More time should be given as well for the research phase and conceptual phase as the aim of this experiment is to seek a comprehensive design process not a final product.
- Working in small teams rather than individuals may give students and tutors some extra time to focus on research methods, findings, experiment more with digital or physical models and boost the tools learning speed.
- More focus should be placed on documenting the process and trials / errors, as this way of thinking and working was missing along the experiment time. Perhaps a change in the evaluation criteria and submissions format should be introduced for this documentation to take place.
- Public lectures are highly important to introduce the topic and tools to all academic staff and students other than the ones involved in this experiment. This is necessary to keep everyone aware of the difference between a parametric and a conventional approach, process and outcomes.

It is highly recommended to have another experiment following this one, to continue the intended learning plan, that will take in consideration the outcomes and recommendations of this previous exercise. Also, Access to digital fabrication tools is important for visualizing the different stages of this process.

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