Incorporating Problem-Based Learning for Promoting Parametric Design Thinking in Architecture Studios: Insights from an Experiment in India

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Received	Reviewed	Revised	Published
07.10.2023	20.10.2023	27.10.2023	31.10.2023

https://doi.org/10.61275/ISVSej-2023-10-10-23

Abstract

The curriculum of architectural studios needs to incorporate the demands of the present professional world. Advanced design thinking approaches like parametricism help tackle various complexities of the design process that is the need of the hour.

In this context, this paper delves into the insights gained from introducing problem-based learning for parametric design thinking in an architectural studio in India. It thus examines students' learning experiences through a hands-on problem solving utilizing a research method referred to as action research.

The action research methodology, a highly participatory and collaborative approach focused on practical problems solving within a specific context. It was employed by first identifying the problem of how traditional teaching learning processes do not get students ready for tackling complexities of design that are in demand in the current industry. A research question was then formulated, exploring the effectiveness of Problem Based Learning as a teaching methodology for integrating parametric design thinking into architectural studios. The planning phase involved designing a suitable problem for the studio, with the expected solution achieved through student's application of parametricism knowledge followed by an action phase. The process was continuously monitored, with data collection, analysis, and dissemination.

Various challenges have been observed with the integration of parametric design thinking in traditional architectural studios which follow a linear design process. Problem-Based Learning (PBL) is a student-centered approach in which students learn about a subject by working in groups to solve an open-ended problem that tackles the complexity of parametric design thinking. This problem is what drives the motivation and involvement of students in the course.

Key Words: PBL, Architecture, Design, Parametricism, Pedagogy.

Introduction of Parametric Design Thinking in Architectural Studio

The curriculum of architectural schools universally consists of various types of teaching such as design and supporting subjects in which contextual/technology-oriented design studios also exist. In the architectural profession, processes are rapidly evolving, and the way design is being approached is evolving. The challenge for designers is ever increasing due to an increase in desire for creative forms, inventive design tactics, environmental considerations, and technical as well as structural innovations. The advances in technology also facilitate methods like digital fabrication and advanced construction techniques in architecture.

This in turn is causing a paradigm shift in the role of an architect. In modern practice, it is crucial to comprehend the ramifications of designs, including their production and construction. It has become vital that architects also tackle non-conventional techniques and incorporate this line of thinking into architectural pedagogy. Parametric thinking is one such design paradigm that incorporates complexity, variety & open-endedness. These tools of parametric design thinking can also drastically reduce the time one needs to invest in the exploration of alternatives in the design that they create and provide much more visual clarity in different aspects of design.

Challenges

Digital design technologies are commonly used as shallow form-finding tools in the area of architecture, and their use is regularly subjected to superficial scrutiny. Experimenting with non-conventional forms without the appropriate tools yields improper results. For example, a student exploring non-conventional forms for their design through physical model making is limiting their possibilities and in turn increasing the time needed to create more options as shown in the Figure 2. This example shows that there is room for experimentation if the same thought process is dealt with advanced parametric tools**.** The parametric design process is characterized by three principles according to which either the designers develop rules and define their logical relationships while creating 3D visualization models or they can modify their model at any time. In fact, design alternatives can be developed in parallel at any stage of the process (Woodbury, 2010).

This paper examines this issue. It presents an experimental course conducted involving students using parametric modeling tools to refute this. The tools were used for more than just form development; they were also used to think about engineering and construction specifics. The goal of the course is to investigate the architectural studio from a fresh perspective to question the conventional notions of how to teach parametric design thinking.

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The main objectives of the course were as follows.

1. To enhance creative Problem solving by encouraging innovative and unconventional approaches to design challenges
2. To embrace complexity and variety
3. To prepare students for the rapidly evolving architectural profession by equipping students with tools knowledge and skills needed to incorporate digital fabrication and innovative technologies into their designs and hence encouraging technological innovation.
4. To facilitate efficient design exploration
5. To enhance visual clarity.

The above objectives were integrated in the architectural studio curriculum with an aim to empower students to become more versatile and well-rounded architects. The achievement of these objective shall ensure that the students are better equipped to address the complex and ever-evolving challenges in architectural field while emphasizing on creative solutions.

Theoretical Basis

Prior attempts at teaching parametric design to students invovled manual folding of materials and rudimentary plane manipulations to demonstrate how physical movements produce geometry. The resulting geometry is utilised as a starting point of scripting, which is used to transform points and curves to create parametric-driven forms (Howe, 2011). In their approach to teaching parametric design, Lecourtois and Guena (2012) claim that students should be taught analystical methods that allow them to experiment with architectural design activities rather than specialised parametric design tools. Students are then allowed to choose, evaluate, and use the digital technique that could be able to achieve their design goal.

The Rhinoceros 3D software was utilised in series of digital workshops as part of an effort to include computational design into studio curricula, according to Carraher (2010). Similar to this, Erlendsson and Erk (2012) gave architecture students an assignment that was based on parametric design. They made use of the grasshopper plug-in and standard Rhinoceros NURBS modelling. They came to the conclusion that digital crafting needs a “different way of thinking” but that only one half of the studio accomplished the essential paradigm change. Which establishes the fact that an innovative teaching methodology is essential.

A viable strategy for promoting parametric design thinking in students of architecture is through incorporation of problem-based learning in the design studio. It gives students the freedom to investigate difficult design problems while developing their critical thinking abilities, multidisciplinary teamwork, and holistic problem-solving abilities. The appropritate integration of parametric design thinking and faculty readiness are however essential for the successful application of PBL in this context, ensuring that students can successfully navigate the rapidly changing field of architectural design practise. To better educate students for the challenges posed by parametric design thinking, future research in this area should study best practises, assess outcomes, and develop instructional methodologies.

Benefits of PBL for Parametric Design thinking in Architectural studio are as follows:

1. Foundational Ideas: The basis of PBL is the notion that knowledge is constructed effectively when students work on real-world situations. The value of active learning through authentic experiences is stressed by theorists like Dewey and Vygotsky (Dewey, 1916; Vygotsky, 1978).
2. Structured Learning Environments: Behaviourist thinkers like Skinner, who emphasised the importance of controlled environments and reinforcement, are frequently linked to parametric approaches to education (Skinner, 1957). These methods use predetermined guidelines and a structured manner to direct learning.
3. Goal-Oriented Learning: In the context of parametric techniques, Locke’s thought on goal setting and motivation are pertinent (Locke, 1968). These methods establish specific learning goals and give pupils a well-organized path to reaching those goals.

Problem-Based Learning Approach to Incorporate Parametric Design Thinking in an Architectural Studio

Generally, in architectural studios students study the main design concepts and the paths to construct the building. They do so by breaking down a greater project into smaller manageable design tasks (Essa). Problem-based learning is another practically oriented pedagogical model, in which students develop their expertise on the content area under study by working with cases and problems that represent real-life situations (Yew-Goh 75-79). Parametricism as a part of a design studio must deal with complexities between elements by assigning values to organize the constraints and they bear a relationship to real-world circumstances. The most relevant pedagogical positioning for a parametric plugin in an architectural design studio, is the incorporation of parametric modeling in the project which has been broken down into identifiable and understandable subsystems with simple interactions which are then modeled using patterns. Algorithms developed in parametric design thinking as a solution to a design problem can often be open-ended. Without these parametric tools, it is difficult to achieve dynamic design solutions, open-ended and complex. Problem-based learning is an apt methodology to achieve these desired outcomes.

Review of Literature

The interaction between architectural education and practice benefis both parties and is constantly evolving and changing the outcomes of architecture. Salama and Grosbie(2010) stated that while practice of design professionals has significantly altered, and design education is slowly catching up which is true to this day. The challenge for designers has increased due to the demand for unique forms, creative design approaches, environmental considerations, and technical innovations. On the other hand, contemporary architectural education attempts to equip students with the necessary skills to successfully enter the field in future. To bring students up to speed with the evolving design paradigms like involvement of advanced digital tools tools, teachers must adopt creative pedagogical intentions.

Parametric design thinking is one of these evolving design paradigms. The phrase "Parametric design" "implies the use of parameters to define a form, when what is actually in play is the use of relations", suggested Monedero (2000:371). A more precise definition was given by Karle & Kelly (2011:110) "a series of questions to establish the variables of a design and a computational definition that can be used to facilitate a variety of outcomes." An overview of advancement of ideas and models supporting parametric design thinking was published by Oxman (2017). The designer begins the parametric design method by articulating parameters that define a form and constraints, or rule-set, that determine the relationships between these parameters rather than by designing the form or starting from a preconceived pr predetermined design solution (Karle & Kelly, 2011). To put it another way, with parametric design, as opposed to conventional design, the designer creates and models the "logic" rather than the "object" (Leach, 2009). A new form is generated whenever the values of any one or more of these parameters change. This enables the designer to examine a wide variety of potential compostion's diversity permits. It also addresses the designer's requirement to comprehend how to visualize buildings as a dynamic system of rules and relationships, not just the visual representation and model of buildings (Senske, 2011)

Research Methodology

1. The Experiment

In broader terms teaching refers to a process of transmission of knowledge by a knowledged person. Learning refers to the process of acquiring knowledge by any means. Altet (2006) defines pedagogy as the articulation between teaching and learning processes, involving knowledge and aims. Oxman developed the definition by stating "any new framework for design pedagogy must be responsive to conditions in which digital concepts are integrated as a unique body of knowledge consisting of the relationship between digital architectural design and digital design skills" (Oxman,2008). De Boissieu (2013) highlights that in order to define the most relevant pedagogical positioning for parametric modeling in architectural design several skills need to be developed including theoretical knowhow and soft skills. For learning, these two kinds of knowledge shall be acquired: one fundamental and stable, and the other evolving rapidly according to the development of the tools necessary for numerical parametric modeling.

The aim of the method proposed is to encourage innovative approaches to design challenges through problem-solving. The intention is also to imbibe parametric design thinking as a design paradigm in student's minds, with the given limitation of time and resources. The preliminary step involved identifying the constraints of the complex problem and breaking down the constraints into further parameters or variables allowing one to visualize the problem in simpler terms until it can be solved. Rule-sets need to be articulated to formalize the relationships between the parameters. This algorithm will allow the student to develop various iterations of the possible solutions to the problem. From this understanding a problem assignment can be designed to plug in this pedagogical position about the idea of parametric design thinking in an architectural studio. The problem was to simply design an installation and then fabricate it for the site specified. The challenge for this particular exercise was that the installation has to be based on the concept of 'disruption' and should conform to the restrictions of the context. The methodology should progress with experimentation of concepts, then methods and forms leading up to the materiality of the installation. The main idea behind this methodology was that even a simple installation process based on a certain type of concept would be a test bed of form generation working hand in hand with material practices and would allow participants to orient their thinking in a paradigm that includes complexity, variety, and open-endedness.

2. The Design Task

The brief of the studio instructed the participants to do form-finding exercises on the given concept. Participants individually tackled the concept of disruption with various visual narratives of the three-dimensional form that could represent the idea. Various suggestions of waves, ripples, and splashes brought the students to look at water as inspiration and go about designing around it. Whilst working on a narrative for the concept evolution the participants also had to think about the design with its surrounding context. A part of the problem also elaborated on the site that was selected for installation.

The design problem for the particular studio was conceived to test the parametric modeling tools for facilitating form generation, fabrication as well as construction detailing as opposed to just form generation.Following process was adopted to facilitate the desired results for the studio problem:

a. Encoding of a computational geometrical and functional representation of the design in a virtual form. To build a virtual prototype with an associative parametric definition, Grasshopper plugin for Rhino was used.

b. Fabrication as a part of Parametricism in the design, students were also expected to investigate various digital fabrication methods, test them and then generate physical prototyping. This was critical in their understanding of correlation between the virtual and physical environments.

c. Students were also introduced to the identified site, which was within the campus. The identified location for the installation was the porch of the college located in Navi Mumbai, India (As indicated in Fig. 7) and the design expected to be ceiling hung. The main constraint for the participants here was to address in their design the notion of public and design gathering spaces with the installation adding value in terms of micro-ambiances.

Fig. 1: Initiation of the studio with fundamentals of parametric design tools.
Source: Authors.

Participants and the Environment

Workshop environments are based on overarching knowledge structures that are necessary for a shift in participant involvement and learning. A participatory problem-based learning approach was adopted and designed a workshop methodology based on the main tenets and tools of parametric design thinking. This methodology was tested to initiate the incorporation of parametricism in an architectural studio to allow students to explore more non-conventional designs.

None of the studio participants had any previous experience in Rhino + Grasshopper or parametric design techniques. (As detailed in the Table 1). Studio methodology was structured to teach participants not only the use of computational tools (grasshopper) as a generative tool but also how to integrate them to solve the design problems. The studio was initiated with participants learning the fundamentals of working with the Rhino & Grasshopper interface and establishing the logic of definitions, building, and eventually managing parametric data structures. After equipping themselves with the necessary parametric tools, they moved on to the architectural installation design work which was in a problem-based learning format. The studio was concluded by executing the design solution on-site on a 1:1 scale model, learning the digital fabrication techniques in the process. The outcome of the studio reflects the concept of disruption between the form and patterns and represents the participant's aesthetic sensibility.

Table 1: Detailed teaching program and activity plan of the course.
Source: Author

Session No.	Main Topic	Description	Independent Learning	Teaching Methodology
1	Introduction to parametric design	• Defining parametric design. • Basic understanding of parametric thinking. • Developing parametric thinking through design parameters and development process. • Building material and construction techniques.	Built example of parametrically designed buildings	Blended learning

2	Introduction to parametric modeling software & basic modeling skill	• Bridging parametric thinking and parametric modeling software logic: • Basic interface of digital modeling software of Rhino and Grasshopper • Developing modeling skill based on attractor point case	Basic command in Grasshopper	Flipped classroom
3	Rhino Modeling & Workspace understandin g	• Surface manipulative commands • Attractor point algorithms • Parametric Skyscraper Algorithm	Basic command in Grasshopper	Flipped classroom
4	Grasshopper Basics & algorithms	• Interface |Material & Command Library • Basic Components • Developing one's own algorithms • Introduction to brief of the problem	Skill development through model exploration	Tutorials & Problem Based Learning
5	Digital Fabrication Techniques	• Introduction to various fabrication Techniques • Additive Fabrication • Subtractive Fabrication	Experimenting with various techniques	Direct Instruction
6	Integrated parametric design thinking - 1	• Developing creative design proposal supported with advanced modeling skill	Skill exploration on surface and BREP component	Blended learning
7	Integrated parametric design thinking - 2	• Preparing design proposal for fabrication process	Exploration of fabrication techniques	Participatory Learning
8	Final Assessment	• Assessment conducted on completed creative design proposal: • Poster explaining design concept, goal, etc. • Physical model Digital modeling file • Complete documentation on fabrication process	-	Assessment Jury
9	Building the installation	• The selection of appropriate digital fabrication techniques and the development of architectural detailing.	Experimenting with construction details	Participatory Learning

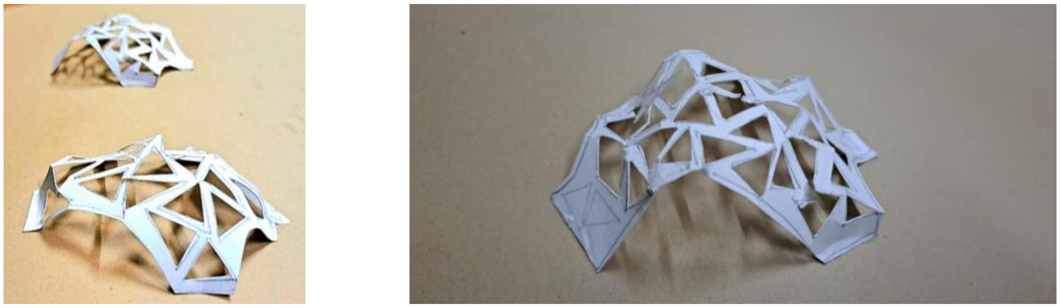


Fig. 2: Exploration of non-conventional forms for their design through physical model making without using the advanced tools.
Source: Author

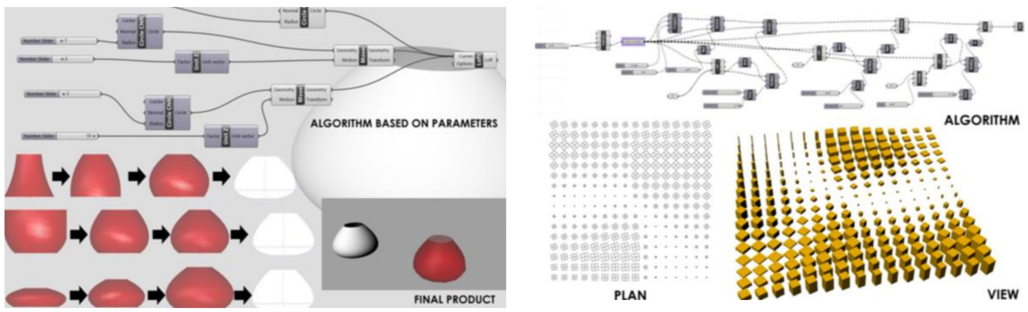


Fig. 3: Algorithms created to explore form finding.
Source: Author

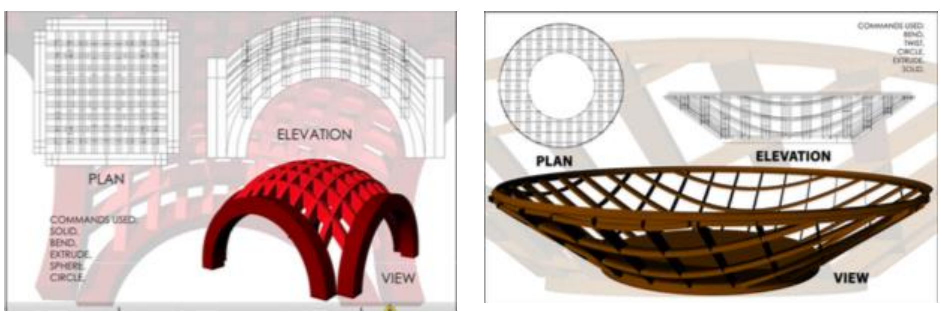


Fig. 4: Form exploration by the students keeping the fundamentals of geometry and form development through a parametric model.
Source: Author

Research Methodology

The experimental assignment for this studio was designed to see how parametric modeling tools may be applied to think about engineering and construction detailing as well as for form generation.

The characteristics of the methodology applied in the course undertaken are as follows:

6.1 Identifying an algorithmic approach to solve the problem:

As a part of the initial phase of the course, the students theorized an algorithm identifying the constraints of the problem. Lectures were conducted to bring awareness to the principles of parametric design thinking and its applications in problem-solving through case studies and literature review. Tutorials were conducted to learn the fundamentals of Rhino + Grasshopper workspace and establish the logic of algorithms, definitions, and build and manage parametric data structures. After working on a few exercises on the logic and the principles of this designing medium, participants applied the learned techniques in a design exercise of modeling various objects in the Rhino Workspace (Fig. 3).

Participants analyzed the algorithms created and developed parametric data structures & explored form finding by developing three-dimensional models. This exploratory feedback process breaks away from the traditional linear design methodology and arrives at a more bottom-up-oriented approach to generate possible forms and spatial patterns. For the development of conceptual models, students formed groups of four, through parametric design thinking, mapped the data gathered, and generated an algorithm through visual scripting with Grasshopper to form various iterations of the basic form (Fig. 4).

The selection of an appropriate material for the construction of the prototype was critical and the groups explored various applications of the materials. Students engaged with the properties of these materials with the purpose of selecting a material to investigate how design can be influenced by the qualities of the material. This study is crucial for its application to the development of geometry and the construction of the parametric form that correlates with the selected material.

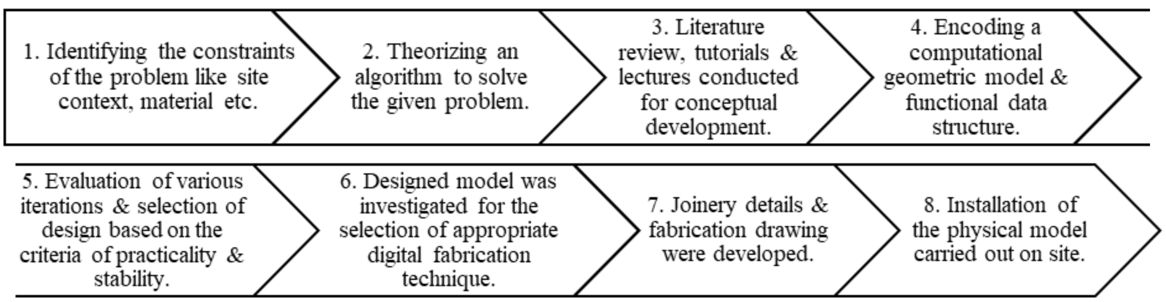


Fig. 2: Methodology used for the course.
Source: Author

Table 2: Detailed marking sheet of the group-wise assessment conducted.
Source: Author

Assessment Parameters	Conceptual Study Model	Parameter Defination	Algorithm Development	Application of Parametric Tools	Problem Solving Capabilities	Design Geometry	Finalization of Model	Fabrication & Detailing	Total
Max. Marks	10	10	10	10	20	10	10	20	100
Group1	7	7	8	6	10	5	5	10	58
Group2	8	7	6	7	13	7	7	13	68
Group3	8	6	6	7	11	6	7	11	62
Group4	5	5	5	6	10	6	6	10	53

After the model development, the course conductors organized an evaluation and discussion to select one design (Table 2) for the installation to be detailed and worked upon in the installation stage. The main criteria for the selection during the evaluation are discussed in Table 2: namely the design, problem-solving skills, etc. which focuses on the stability of the prototype as well as the practicality of the fabrication process.

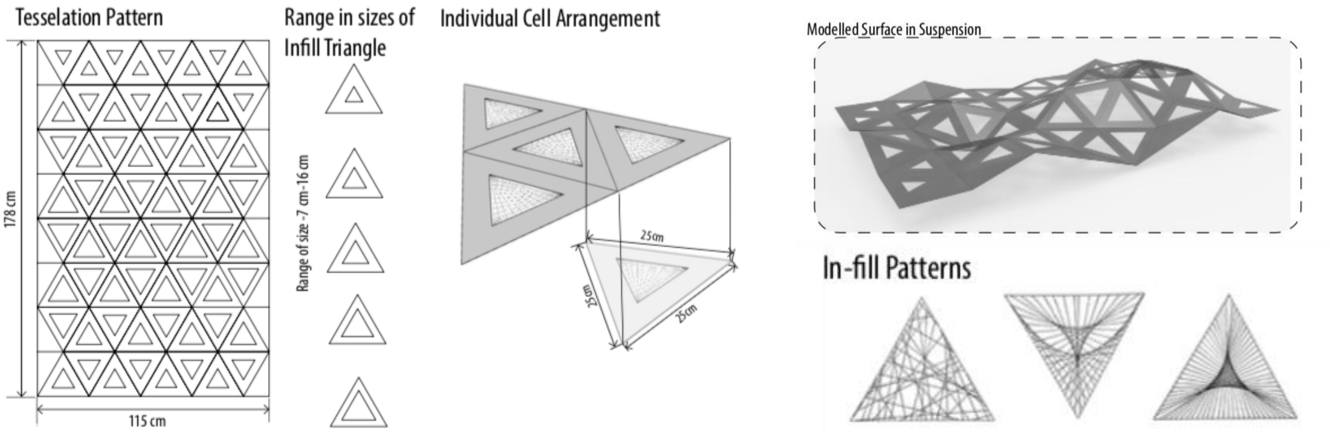
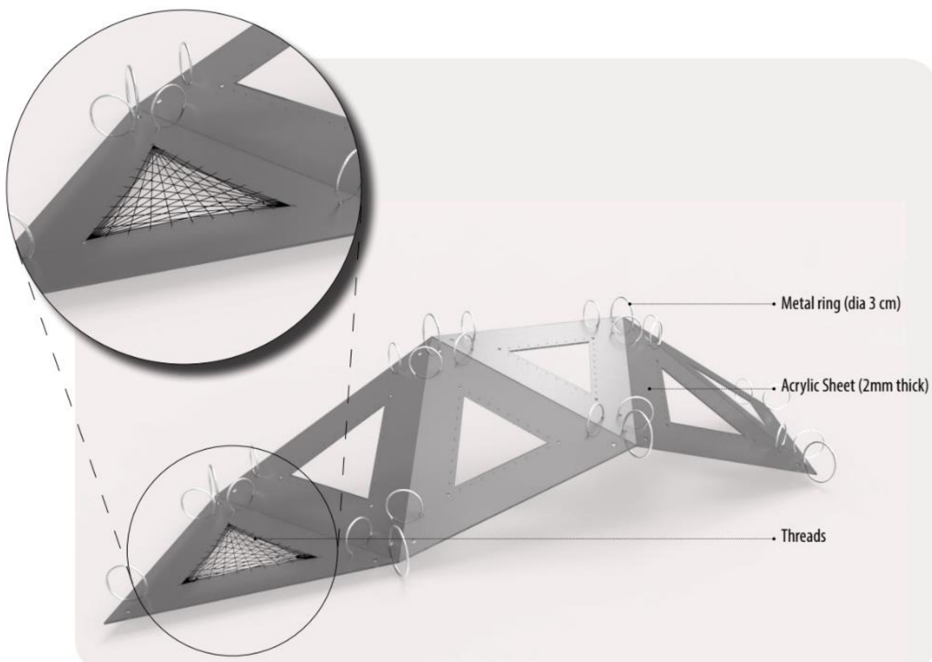


Fig. 5: Final concept selected for installation.
Source: Author

Fig. 6: Triangular



components of the installation. .
Source: Author

6.2 Fabrication process selected for the construction of the installation.

The latter half of the design studio was focused on the materialization of the selected design. The design was further developed by the selection of appropriate digital fabrication techniques and the development of architectural detailing like the creation of hinge joints etc. Fig. 7 depicts the design of the installation on-site and a visualization of the design after the selection of the right material. Sectioning and triangulation techniques were used to draft digital fabrication drawings for the fabrication of the installation. Fig. 5 depicts the conceptual model selected during the evaluation, which was to be fabricated as a conclusion of the course by applying the triangulation system. Additionally, the participants engaged with the design of the installation by designing appropriate joints and connections to allow for the fabric -like behavior. The selection of construction material, the dimensions and thickness available in decided the structural stability that could be achieved through the design of the joinery details and support anchor points to afford easy assembly, strength and rigidity. The design developed for the installation by the participants was worked upon initially in the development of the fabrication drawing and digital fabrication model to the available market size of sheets of acrylic which fits on the bed of the laser cutter (70x100 cm). Anchor points for support & flexible joinery details were further developed.

Appropriate fabrication drawings were developed to facilitate laser cutting resulting in less waste of material. Triangular components of acrylic sheets are joined by metal rings creating a hinged joint to make the surface flowy to adapt to any freeform shape. Different colored threads were woven through the triangular elements of the model to add depth & complexity. Anchor points were marked on the site and the installation of the model was carried out. During the conclusion of the curriculum of this course, after the installation of the model on the site, students were finally able to physically interact with the model. The effect of crease behaviour, drape, and formability allowed the fabric-like behavior of the final surfaces due to the flexible joinery design for the installation allowed the final form to be determined with the help of gravity (Fig. 8).

The participants of the course appreciated the experience of constructing and installing a life-scale model, the efforts taken to combine engaging with the digital model & the possibility of fabricating and assembling it as a whole.

Fig. 7: Proposed Design intervention
Source: Author

Fig. 8: Final Design intervention after installation.
Source: Author

Fig. 9: Participants preparing the model for installation on site.
Source: Author

Participant Survey

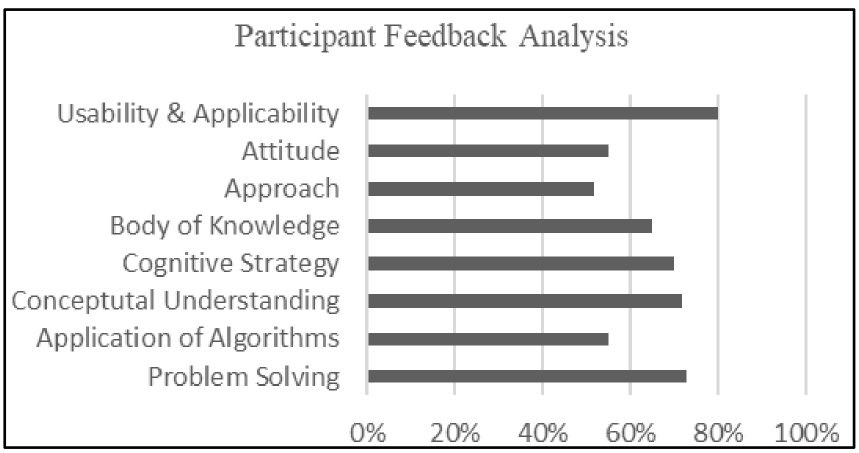
A survey was designed to assess learned capabilities of the participants based on classification of learning by Robert Gagne, broadly consisting of intellectual skills, cognitive strategies, verbal information, attitudes (Gagne et al., 1972). The survey consisted of 8 parameters, covering four out of the five learning domains proposed by Gagne (Gagne' et al. (1972), viz., Intellectual skills, cognitive strategies, and verbal information and attitude, which were deemed to be relevant to the study. Participants' feedback was obtained using a 5- point agreement scale. A total of 40 students participated in the survey. Graph 1 summarizes the feedback given by the participants about their experience throughout the course and the learned skills.

Findings

The outcome demonstrates that participants gave the majority of the parameter's positive ratings. This shows that the problem-solving approach to teaching has been effective in bridging the gap in conventional instruction and achieving the desired learning objectives. The statement inquiring participants if they preferred parametric design thinking to traditional design was an outlier in the results because it was predicted that students would generally use conventional approaches given their familiarity with them.

Results when students were asked about conceptual understanding, 72% agreed that they could clearly interpret the concept of parametricism. They were able to grasp the variability of possible outcomes for a design problem. The score of general problem-solving abilities and usability, was approximately 73% & 80% agreed with the propositions. Prior experience with CAD software like AutoCAD affected the acceptability of the use of parametric design. A student with knowledge of other CAD software appears to have a higher ability to understand and apply parametric design thinking. The general attitude & approach to design was redefined for the students due to their participation in this course.

Graph 1: Participant feedback analysis.
Source: Author



Discussion

The paper aims to convey and discuss the experience that the authors' teaching method has offered them, particularly regarding student engagement in the learning process, especially when dealing with parametricism to encourage non-conventional designs in an architectural studio. By delivering answers to the technical problems individually but still in coordination, the integration of technology in the design studio offers a chance to support the design process and reduce some of the workload related to the design project. According to the participants, thinking parametrically had been beneficial when looking for appropriate design solutions for the identified problem. They discovered that this thinking approach is consistent with the iterative design process in architecture, which is a self-evolving and cyclic approach to arrive at a solution through numerous revisions.

Working with participants throughout the studio course, utilizing the problem-based learning approach allowed the authors to imbibe in the participants the skill of analytical thinking required to handle challenges in real life as well, with apt use of parametric tools and interaction with construction materials and digital fabrication techniques.

Conclusion

This paper presents the successful integration of parametric design thinking through problem-based learning as a teaching methodology. It presents parametric design as pedagogic intention and design paradigm. The assesment of the parameters of feedback taken from the participating students demonstrated favourable evaluations. This in turn shows how well the problem-solving method for teaching has worked to close the gap with conventional instruction and meet the intended learning goals.

Before the commencement of the course, student's form finding explorations were limited. The introduction to parametric design thinking allowed them to embrace complexity and produce variety of unconventional design solutions. Fig.2 depicts a students form finding exploration through physical model-making and no intervention of digital tools or any understanding of parametric design which limited the number of iterations and innovation in terms of design on the contrary Fig.4 depicts the algorithmic explorations which enabled them to create a variety of solutions for the design problem. After completion of the studio course, it was concluded that the problem-based learning added depth to the design developed using parametric design thinking.

Creating a parametric data structure involved the programming of the digital algorithmic model that allowed the participants to interact with various iterations of a singular model which facilitated efficient design exploration, enhaced visual clarity and hence, preparing the students for rapidly evolving architectural profession.

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