Integration of Design Geometry with “Computational Making” in Basic Design Studio

A Case Study of Lanterns Project

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Basic design education, as an introduction of design principles to novice students, has two-way of teaching which are design thinking and professional training, since Bauhaus. Initiated in 2009, the Computation-based Basic Design Studio creates a common ground through discussions between students, academics, and professionals from various backgrounds. In this paper, the implementation of parallel courses named Computation-based Basic Design Studio and Design Geometry is discussed upon final assignment of the first semester- New Year's Lanterns. The given assignment structured as a cyclic process through constant feedback between geometric relations, material performance, and, joinery details to achieve novel outcomes that exceed the preliminarily set structural criteria. In relation to individual processes and outcomes of the final assignment, observed tendencies developed by students', at the end of their first-term in design education, will be discussed as final remarks.

Keywords: design education; basic design; design geometry; polyhedra

INTRODUCTION

Basic design education has evolved since Bauhaus as a combination of design thinking and professional training. Due to the advances in technology, the professional training has started to include CAD/CAM training along with learning by doing in terms of physical interaction in order to reduce cognitive load in computing (Gürsoy, 2012).

Initiated in 2009, the first-year curriculum at İstanbul Bilgi University creates a common ground through the first-year of design education among architecture, industrial design, and interior design students. Computation-based Basic Design studio introduces the design principles to novice students, while Design Geometry courses teach the geometric modeling with the aid of digital interfaces. This specific curriculum, which consisting of two conjoint courses is developed to integrate computational design thinking with hands-on making. In this scope, computing is recognized as a way of thought and reasoning (Stiny, 2001), and the basic design studio initially aims for students to develop a conscious approach to their creative processes incorporating reasoning through reflective thinking (Gürsoy, 2012). Within this context, synchronical exercises from 2D, 2.5D to 3D are conducted to introduce basic design...
concepts such as rhythm, hierarchy, part-whole relations as well as geometrical constructions such as tessellation, pattern deformations, modeling and unrolling polyhedra (Figure 1). These exercises develop reasoning and reflective thinking through studio crits. After the preliminary exercises, the final assignment of the first-year first-term studio is called the New Year’s Lanterns. Students are asked to design a lighting element with an approximate volume of 1m³. The students are encouraged to investigate geometrical relations, material performances, and develop custom joinery details considering the structural performance of the final form. In this paper, we discuss the implementation of computational making and design geometry in a specific curriculum of first-year design education.

**DESIGN GEOMETRY COURSE**

First-year architecture, interior design, and industrial design students in Istanbul Bilgi University Faculty of Architecture attend to the Design Geometry course as a complementary technical study of the Computation-based Basic Design studio. The main subjects of this course are the Euclidean constructions of shapes, tessellations, pattern deformations, and modeling and unrolling polyhedra. These consecutive subjects are organized to create a constructivist learning environment, which is believed to be a suitable pedagogical approach for the education of digital design (Yazar, 2009). Students are introduced to Rhinoceros as a learning interface however, the main objective of the course is not to teach any computer-aided design (CAD) tool. On the first weeks of the course, students are introduced to the Euclidean construction of two-dimensional shapes, in which they only utilize an abstract compass and ruler. This method puts students in an effort of finding ways of defining shapes by their basic geometric relationship; the Euclidean distances between points in the design space. These are called as “constructions”, denoting a special type of theorem that requires the proof in the form of a recipe, or an algorithm (Martin, 1998). Students use CAD software by imitating compass and ruler constructions by simple circles and lines, without utilizing any ready-made commands.

In Basic Design studios, this subject becomes helpful not only in designing rule-based patterns, but also constructing the underlying lattice of any two-dimensional system. By learning the geometric and mathematical underpinnings of tessellations, students easily apply the concepts such as repetition and hierarchy to their own designs with an analytical perspective. Pattern Deformation is another subject of the course, which is essentially a classical Basic Design topic, originated to William Huff. The original exercise is about tessellations of the plane that gradually shapeshift on one or more directions by predetermined or improvised transformation rules. Students are encouraged to think about topological relationships between the sequences of a continual shapeshifting while developing a reasoning about a pattern as a structural whole. In the classical application, this is expected to be studied by morphing the cells of a pattern while sustaining its linear continuity without leaving gaps or overlaps (Yazar, 2017). In the Design Geometry course, this is a complementary exercise for the previous subjects, helping students to design and fabricate their own rule-based patterns. Students learn laser-cutting along with this subject. 3D pattern deformations are also exercised, parallel to the Basic Design exercise called “Structural Components”, which is explained in the following chapters.

The final phase of the Design Geometry course supports the final project of the Basic Design studio by providing students with necessary knowledge on the geometry of polyhedra. Students are introduced to the construction and fabrication methods of polyhedra. This is a complementary topic that benefits from all previous ones explained above. Students generalize the Euclidean construction approach to three-dimensions, introducing a spherical compass and a planar rule in the space. This knowledge helps students to construct basic Platonic Solids of Tetrahedron, Octahedron, Icosahedron, and...
Dodecahedron. Then, they are encouraged to produce these objects. They learn how to apply three-dimensional transformations to unroll these polyhedra flat on the plane. This requires them to think about a strategy of unrolling to create single-sheet non-overlapping pieces. After adding flaps and labels, they experiment with laser cutting to create physical outcomes. The basic Platonic Solids are followed by more complex Archimedean and Catalan Solids, which are essentially created by transforming Platonic Solids. Truncation, rectification, dualing, snubification, and stellation are among these transformations. Some of these operations are already studied in the tessellations subject. Finally, students are asked to design and fabricate their own polyhedra.

COMPUTATION-BASED BASIC DESIGN STUDIO

In the first-year Computation Based Basic Design studio at İstanbul Bilgi University, the aim is to help students understand that design, due to its prevalent relational nature, incorporates different forms of reasoning as indispensable constituents within the creative process (Yalınay Çinici, 2013). The studio integrates the 1:1 scale construction via computational thinking which consists of geometric relations, material computation/performance, and CAD/CAM technologies. The aim of the studio is to develop awareness to immediate or far surroundings in terms of shapes, forms, figures, colors, textures, materials in different scales through abstraction and conceptualization. The same construction method is also applied in two-dimensional tessellations. Tessellations are dealing with the problem of covering an area without gaps or overlaps. Students learn how to create tessellations with increasing complexity by only defining simple geometric rules, such as truncation and dualing. Such methods are also re-utilized in the future subject of polyhedra.

The Computation-based Basic Design studio is structured to explore design space through tasks with gradually increasing complexity, in 2D and 3D by focusing on hands-on approach through material performance as well as geometric relations. The studio operates on individual critiques based on the tangible work and interpretation of the students to given tasks, by at least three instructors with diverse backgrounds and approaches to design. This collaborative teaching method allows creating an environment of dialogue which is constantly evolving, encouraging students to reflect on their design process. Figure 1 shows the synchronical relationship between the Computation-Based Basic Design studio and Design Geometry course. The studio exercises begin with two-dimensional rule-based patterns and evolve into multi-layered and multi-dimensional design systems by applying different materials and production techniques.
Before initiating the final project, there are preliminary studies on integrating digital modeling and fabrication of polyhedral shapes and material computation. In the project named “Structural Components”, students are asked to span a predefined distance by combining given pieces of cardboard with predefined dimensions. They are encouraged to think about creating components out of these pieces, by considering their combination potentials to seek for multiplicity. The structural requirement of the exercise motivates students in creating three-dimensional sections, resulting in research for more complex relationships. This exercise benefits from the pattern deformation study of the Design Geometry course, and help students to elevate the pattern deformations into component-based three-dimensional structures with intrinsic variations. The “Lanterns Inside” was another short-term individual project, aiming to introduce students to the geometrical basis of polyhedra, material properties, and joint details. Students analyze and study precedents made of various materials and forms. They experiment various approaches to achieve three-dimensional and volumetric outcomes, composed of rule-based component systems. The initial ideas raised from this project are further developed in the final project that fit a larger scale and outdoor conditions.

**Case Study: “The New Year’s Lanterns”**

The individual projects explained above lead to the final assignment of the semester where students work in groups to design and construct a lighting element suitable for outdoor use. Students are encouraged to investigate the geometrical relations, material performances, and developing custom joinery details considering the effect of light, regarding reflections, shadow, transparencies, etc. (Table 1).

As Lim (2010) asserts, students are more interested in tectonic factors such as joint, detail, material, structure, construction when they are discussed through CAD/CAM media. In the New Year’s Lanterns project, students are asked to consider geometric relations, material properties, mechanical joinery systems and overall effects of light and transparency, while referencing the previous exercises and their cumulative outcomes such as abstraction, patterning, rule-based and component-based systems (Figure 2).

The parallel tutorials of Design Geometry Course enable students to explore and fabricate the components and underlying geometric reference systems. The mutual feedback of two courses provides an engaging environment for the students where they can
implement and test their designs simultaneously.

The student project, “Mego” began with an experiment on vacuum forming with various thicknesses of polypropylene (PP) sheets (Figure 3). The group of students studied a space-filling tesselation, Bitruncated Cubic Honeycomb made of Truncated Octahedra. On the material research side, they were challenged with the fabrication of the wooden molds, experimenting various vacuum temperatures and timings, and various material thicknesses and interlocking details. After several experiments, they realized that both sides of the vacuum-formed faces could be useful to create an interlocking detail with male and female halves of a mortise and tenon detail, similar to a snap fastener. With the help of the vacuum forming technique, this single detail could be used bilateral, enabling a safe interlocking. Students created various components made up of the same mold. The final design developed from this system was determined by considering the inner light and transparency levels.

In another student group’s project, called “Stratum”, a different kind of multiplicity and aggregation was realized by nesting multiple layers of polyhedra on the same centroid (Figure 4). A Truncated Icosahedron was the main geometric reference placed at the outmost layer. In order to create a three-dimensional volume with various levels of light transition, several

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layers of copies and duals are placed inside of the reference solid. After several experiments, students managed to join the edges of the nested layers together, enabling them to unroll multiple layers at the same time. After merging and unrolling the layers, they developed an interlocking detail with flaps and slits. In the final production, students chose to use aluminum sheets for better structural stability and reflection of light.

The use of nested layers of polyhedra came forward from a need to create three-dimensional and volumetric outcome with a solid system of geometric reference. In the project “Confluent”, students experimented this approach from a different perspective (Figure 5). They created a geometric reference based on the duality of the two Platonic solids; the Dodecahedron and Icosahedron. Instead of modeling and unrolling their faces, they studied on how to produce and join the edges of those polyhedra with wooden plates. Students studied the ways of modeling the normal directions of the polyhedra and determining the interlocking details with half cross method. After a few digital and physical experiments; they realized that it was difficult to solve the interlocking detail for the vertices, where three edges meet at one point. This is why, they revised the design by rotating the faces of polyhedra around their normal direction and centroids, applying a transformation called snubification.
“Distorted” began as a structural components study. Using sheet paper, students explored ways of creating a systematic 3D component logic that can geometrically adapt to variative surface conditions to achieve a sturdy spanning structure (Figure 6). This hands-on process allowed them to explore the edge and surface conditions as well as folding techniques to develop a structural component that can create different lighting effects by manipulating the physical parameters of the initial study. The transition from paper to aluminum sheet made them conscious of the covered surface area to optimize the overall material usage while sustaining the structural performance. Another aspect considered for finalizing the component development was to create a diffused lighting effect by illuminating the reflective surface itself and hiding the actual lighting source. At this stage, with the input of a different material performance, and based on the studio critics, students focused on developing strategies to achieve a closed, controlled form while minimizing the number of different components used. This brought the need to transfer physical knowledge to digital in order for them to calculate the overall material usage and design the macro form. While this transition was challenging for the group, they managed to overcome it by translating the basic parameters of the components to create a sufficient 3D model. Hence, making it possible to finalize their component design and overall form.

Another student project, “Remix” also began the process by exploring ways to use nested layers of polyhedra, aiming to play with the perception of depth with the use of lighting and various levels of transparencies (Figure 7). Starting with a Truncated Icosahedron as a reference geometry the students experimented on ways to create different surface subdivisions to achieve three-dimensional components that would allow them to manipulate the definitive form of the Archimedean Solid. Using stellation on the inner geometry allowed them to both form the outer layer, and connect the two together while creating different reflective surface con-
ditions. The group chose to use aluminum sheets and aluminum mesh sheets for the final design as they experimented with different materials and transparency levels. After a few trials with different fabrication techniques, the tool effect led them to use a CNC to cut their final pieces. The circular holes formed by the selected tool for the CNC cutting were used both for folding the components and for determining the location of the nuts and bolts detail for the final production.

For the project “Stardust”, students initially focused on designing a single component that can form various results by using different overlapping techniques (Figure 8). Using an equilateral triangle and creating scores that connect the corner points with the centroid formed their basic component. The students further developed their concept by experimenting with ways of manipulating the component via reversing the folding direction, changing the edge dimensions and, moving the central connection point to achieve different forms. Working with polypropylene sheets and using riveting for joints, the group quickly became able to form any desired shape. At this stage, they began investigating on polyhedrons as a reference geometry while experimenting with layering the folded surfaces. After some trials, the students ended up using Truncated Octahedron for its properties of creating space-filling tessellations. This decision was shaped by both the lighting studies and material researchers which they have been working on simultaneously. For the final design, students developed a three-layered system that grows out from the folded surfaces of central solid. For a better lighting effect, translucent, reflective and opaque polypropylene sheets were used for each layer, respectively.
CONCLUSION
The implementation of computational making and design geometry in the first-year design education is explained as a specific curriculum through the cases of the final assignment named New Year’s Lanterns. The aim of this curriculum is to gain students consciousness of their design ideas and operations through reasoning (Özkar, 2004; 2007) due to the early encounter with the computational thinking, which is inherently an analytical process. Reasoning builds upon process and process builds upon personal interaction with the object (Özkar, 2004). Upon observations throughout the process of the assignment, two tendencies of reasoning became prominent in students’ approaches. While all above-mentioned factors are still part of both tendencies, the preliminary approach to design differentiates by the handling of the workflow within the design cycle. We can distinguish these tendencies briefly as, concentrating on the segmentation/partitioning of a solid, and designing a variative component to create a system.

One of these tendencies is to predetermine the geometric information about design, keeping the final macro form at least partially predictable by relying on polyhedra. The students made material and detail research, and hands-on experiments to reach the formal results they determined. In this tendency, the experiments on the materials and joint details have led to emergent situations, which also redefined the geometric assumptions. The main advantage of this tendency was that the structural challenge has already been solved by rigid polyhedra used as a reference.

In another tendency, the formal assumptions are not deliberately constrained but instead, information on materials and details are predetermined, keeping the material effect predictable. This tendency has usually occurred in the search for possible geometric constructs that would lead to a particular material or joint detail. In this tendency, material explorations can create several final macro forms and light effects. However, structural problems can be difficult to solve due to the lack of guiding references.

The main difference between the two tendencies is the operational difference between the information initially considered as a hypothesis and the information released as the experimental field. The material research in the first tendency covers the “development” and even “optimization” of the most appropriate (lightweight, robust, workable) material and joint detail (e.g. interlocking) to form a particular geometric shape. In the second tendency, students push a position of “exploration” to the forefront, studying the emergent forms created by the material and detail at hand. In most projects, groups of students switched these two tendencies or positions because of the new challenges they have encountered.

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The Design Geometry course mentioned in this study is coordinated by Tuğrul Yazar, at İstanbul Bilgi University Faculty of Architecture, since 2011. Mentioned exercises are selected from 2017-2018 Fall semester. Course instructors of the mentioned exercises are: Cemal Koray Bingöl, Ertunç Hünkar, Gamze Gündüz, Serkan Uysal, and Tuğrul Yazar.
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