Learning to Compute in Design by *Making* Geometry

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Basic design education has its origins in Vorkurs, or the basic course of Bauhaus, established in 1920's. Vorkurs was founded as the basis for all further development and was conceived as "a general introduction to composition, color, materials, and three-dimensional form that familiarized students with techniques, concepts, and formal relationships considered fundamental to all visual expression" (Lupton and Miller, 1993, p.4). The course is considered as a form of play and experimentation where students are claimed to be "gathering experience" (Wingler, 1978). The experience is gathered through making and hands-on engagement, acknowledging the importance of a continuous relation between mind and matter. The ideal of an introductory, universal studio for diverse design disciplines of Vorkurs is still inherent in contemporary basic design education. The abstract visual language of basic design exercises provides a theoretical and practical basis for any design discipline. The abstract tasks that are generally detached from the complexity of real world problems in a basic design curriculum engage students with intensive reflective thinking, and enable them to directly "reflect on their reasoning over a simpler and formal vocabulary" (Gürsoy and Özkar, 2015). Promoting systematic and relational thinking, these tasks increase students' awareness of their design ideas and operations, and help them in understanding that designing involves different forms of reasoning as indispensable constituents within the creative process. Hence, basic design education can be seen as an early integration of computational thinking to design education where students learn to compute while also learning to design (Özkar 2007, Özkar 2011).

Material Aspects of Computation in Basic Design Education

Previous studies have already dwelt on the possibility of inquiry into design through its visually computational aspects in the computational theory of Shape Grammars (Stiny 2006) and of learning design by visual computation (Knight 1999). In visual computations, shapes are abstract (non-symbolic). They are indeterminate: they can merge to create new shapes or divide into sub-shapes in many possible ways depending on the viewer's will. Part-whole relations are constantly subject to change. The indeterminacy of shapes enables "embedding" in visual computations, and is considered the basis for creativity. Rules for shapes serve as instructions in visual computations, and are tools not only to understand, communicate, and control the relations between shapes but also to learn the know-how (Gürsoy and Özkar, 2015).

Reflecting on uncertainties of visual perception is part of the basic design education agenda. While visual perception plays an important role in basic design education, computation in basic design is never purely limited to visual aspects and ideally includes material aspects as well. Diverse exercises where students are asked to achieve unity (in the form of two and three-dimensional compositions or more generally systematic wholes) by consciously establishing spatial relations between parts are common in basic design education. In these exercises, students usually make the designed thing itself, rather than producing its representation. They work with shapes that have a physical and tangible existence, which we refer as “material shapes” (Gürsoy and Özkar, 2015b). Material shapes in basic design are obtained by shaping the materials through cutting, folding, bending, carving, etc., and can be assembled through gluing, riveting, interlocking, stacking, etc. They can be transformed in 2D and 3D space just as shapes can be during a shape computation. By trying new configurations, students ascribe new perceptions to material shapes, and explore new possibilities.

Within this framework, the focus of this paper is on the material aspects of computation in basic design education, and how geometry can be used as a tool to enhance learning. To support the claim that learning in basic design can be through visual, spatial, and material computing, a design exercise from the Basic Design Studio at Istanbul Bilgi University, College of Architecture is presented in detail.

In the Basic Design Studio that defines the context of this exercise, basic design is considered as an early integration of computational thinking to design education. We aim to convey to the students that design, as a creative process, incorporates different forms of reasoning. To foster this idea the studio underlines the computational aspects of design through several design exercises. These exercises intend to develop the skills of students in establishing relationships between parts to achieve unity. While the constraints of the exercises guide them to concentrate on specific aspects, hands-on explorations within 2D and 3D space expand the design possibilities. Form is not the objective of these exercises of which abstractness is a common feature. Rather, consciousness in producing form is the aim of the studio. Hence, the design process is equally valued as its outcome.

Geometry as a Basis for Design Reasoning in Basic Design Education

In order to strengthen this approach to design as a reasoning process, the studio is supported by two courses offered in subsequent semesters in the first year of undergraduate design education: Design Geometry and Design Computing. Through these courses, students are introduced to digital tools, and the logic behind these tools in constructing relational (geometric) systems. While the digital tools and technologies constitute an inherent part of the studio, the students are mostly encouraged to use these tools as design supports, and compute mostly with material shapes in the studio.

In cultivating computational thinking, the abstract visual language of geometry is a fundamental component: the abstractness of geometry eases out the learning process, and helps the students to focus on the relationships that they establish between parts. A solid background in geometry is essential not only for form-finding studies in design but also for accurate communication of design ideas. Core topics of the Design Geometry course that is offered in parallel to the Basic Design Studio covers Euclidean constructions, tessellations, Platonic and Archimedian solids, Boolean operations, surface discretization methods in an attempt to introduce students the foundations of modern geometry. Through these topics we initiate discussions on concepts such as emergence, recursion, iteration, repetition, variation, and parametric relations. Design Computing course in the subsequent semester builds skills on top of the given ones in Design Geometry course, but moves it a step further by placing computing (via computer) as the driver of the studies. While geometric knowledge helps students build precisely controlled geometrical compositions, algorithms become the exploratory tools to investigate emergent forms of design. The courses take place in the computer labs, yet the primary aim of these two courses is not to teach the students how to use the software. While learning design geometry and design computing, students learn how to use the software as a by-product. This dialogue between the Basic Design Studio, and Design Geometry and Design Computing courses helps students harness computation in design. The exercise presented in this paper exemplifies the mutual relation between these two courses and the Basic Design Studio at Istanbul Bilgi University.

*Learning to Construct **Geometry***

The basic design exercise presented in this paper involves the design and making of material systems that serve as lanterns. To guide their design explorations, students are introduced to polyhedral geometry in the Design Geometry course prior to the lantern design exercise in the studio. The geometric construction logic of Platonic and Archimedean solids are demonstrated using Rhinoceros 3D as a supporting design interface. As an initial exercise in the Design Geometry course, the students are first asked to explore different ways to *unroll a sphere* and construct it using paper. In this exercise, they are required to think how the sphere surface can be discretized into smaller components, so that it can be constructed with a planar sheet material (paper). The students are also asked to develop materialization strategies for their 3D computer models. The aim is to convey that the transition from the digital to the physical is not seamless, and requires intermediary design steps, such as the development of connection details and a clear assembly sequence. Figure 1 shows some of the paper spheres built as part of this exercise in the Design Geometry course at Istanbul Bilgi University, College of Architecture in Fall 2012. The integration of a similar hands-on exercise to an upper level digital design studio curriculum has been previously explored by Sorguç et al.(2013).

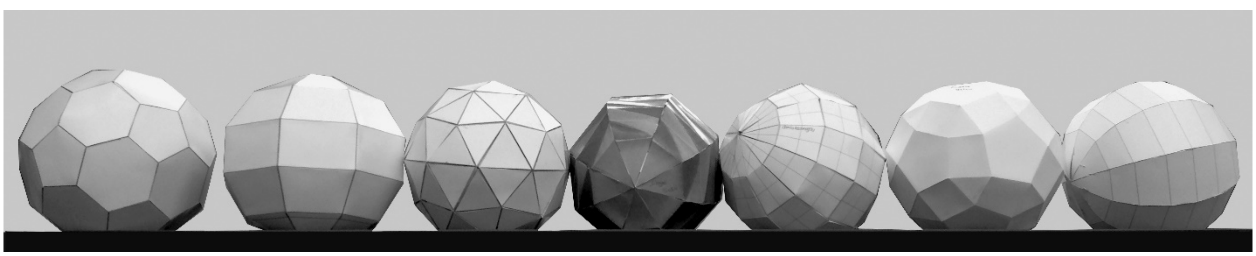

Figure 1 *Paper spheres designed and built by first year students in the Design Geometry course (Fall 2012).*

In the following exercise in the Design Geometry course, called the Stellated Spheres, the students are asked to use their previous sphere surface discretization as a base to place pyramidal components, and create a stellated sphere. They are again required to develop materialization strategies for their 3D digital models, which in this case is more challenging than the materialization step of the previous exercise. Figure 2 shows the digital and physical submissions of a student for the two subsequent exercises in Fall 2012. The figure shows the step-by-step geometric construction of the 3D objects in the computer, as well as how the 3D objects are unrolled to obtain discrete components for fabrication.

Learning to Compute with Geometry

While the students are learning how to construct polyhedral geometries using the computer in the Design Geometry course, in the Basic Design Studio, they are encouraged to make hands-on explorations with *material shapes* to define spatial relations. In an initial design exercise, the students are asked to design a 3D self-standing surface by folding business cards. We guide them in formalizing their design moves: the students are first asked to generate five 3D components (by folding business cards). These make their *material shapes*. They are then asked to define at least ten different spatial relations between these *material shapes* by manually translating them in 3D space. The spatial relations that can be defined between the *material shapes* are unlimited. Introducing constraints as rules help students to guide their spatial reasoning. They are asked to formally represent the spatial relations in 3D on a physical presentation board, such as the one exemplified in Figure 3 below. This physical board, while guiding their design process, also serves as a tool to communicate the underlying relations in their final product with their peers and their instructors. The top row of the board on Figure 3 shows the five *material shapes* that one student generated by folding business cards. She has given them different names (A-B-C-D-E) to ease the communication. The bottom two rows show ten different spatial relations she explored between the five *material shapes*. Different spatial relations can be generated using the same *material shapes*. The final design that the student generated using the spatial relations on the board in Figure 3 is shown on the right in Figure 3.

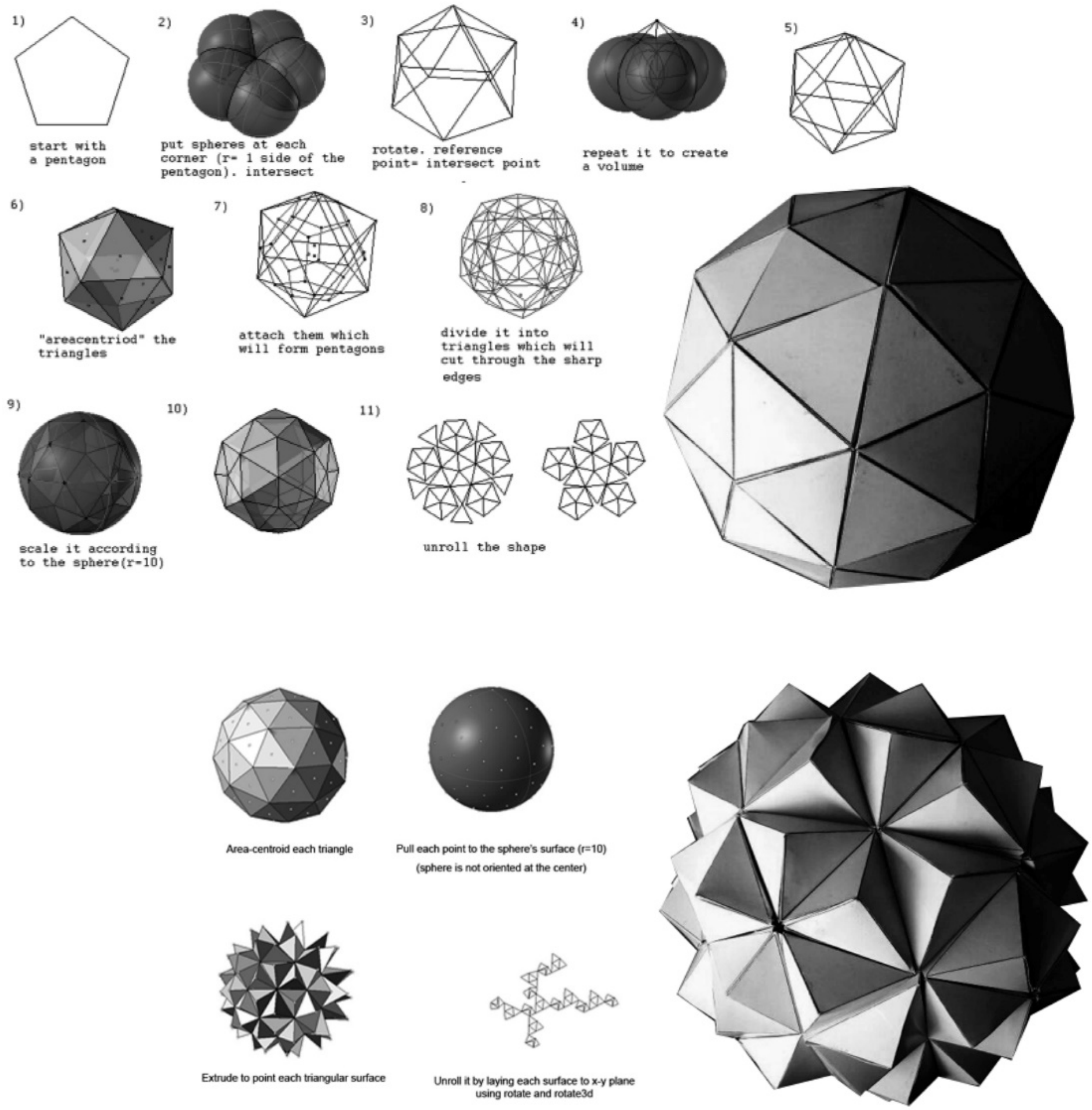

Figure 2 *Digital and physical submissions for the Unrolling the Sphere and Stellated Sphere exercises in the Design Geometry course by Seda Öznal (Fall 2012).*

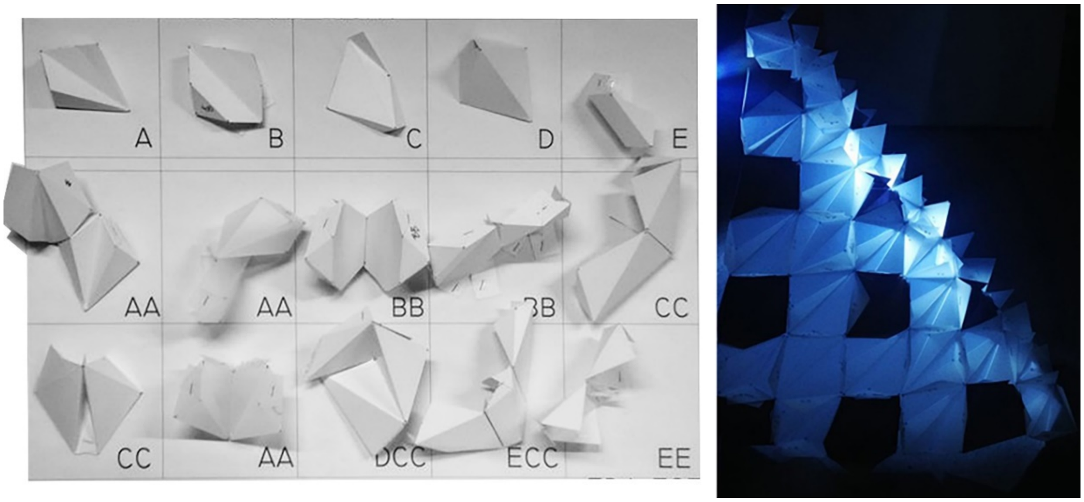

Figure 3 *Student (Eda Esen) work in Basic Design Studio (Fall 2015). Left: Material shapes and formal representation of spatial relations between material shapes, right: 3D self-standing surface design using spatial relations.*

While designing the 3D self-standing surfaces, the students are allowed to use only the spatial relations on their physical board. They have, however, the freedom to go back and change the spatial relations/rules to adapt to different configurations and introduce parametric variations if needed. These spatial relations serve as guides and design constraints for the students in formalizing their design thinking. There is visible evidence that this computational approach help them to come up with more conscious, consistent and systematic arrangements of *material shapes*. It increases their awareness on their own reasoning process. This way, design process becomes something that they can talk about. Students are encouraged to carry this exploration into the subsequent design exercise where they are asked to design a *material system* to serve as lanterns. During the 4-week long lantern exercise, the students are also encouraged to use digital design tools and their knowledge of polyhedral geometry construction from Design Geometry course as design supports. The required outcomes, besides the digital models, are full-scale material artifacts. This situates the design exploration at the intersection of the abstract world of geometry and the physical world of material things. In return, students learn to compute through making geometry.

Lanterns: Geometric Material Systems

Traceability is especially relevant in design studio environments where students are asked to communicate their acts and decisions with instructors and peers for the sake of learning how to reason in design. More than just for accountability to fellows, formalizing reasoning allows the students to have control over the design process. As part of the lantern exercise in the Basic Design Studio, students work in groups of 3-4 to design and fabricate a set of lanterns in two different sizes (40” and 20” in diameter) and create guidebooks that visually illustrate the step-by-step rules for the assembly of parts. This corresponds to creating a relational system and it requires having control over the underlying principles of that system. The change in size also introduces a challenge for the students to make variations in geometry, materials, and connection details, while still maintaining the similarities that make a set. Figure 4 shows some of the larger lanterns designed by the students in Fall 2015, and are hung at Istanbul Bilgi University, Santral Campus. The students design the larger lantern designs (40” in diameter) to be hung outside in the campus area for at least a semester. The lanterns need to withstand various weather conditions. The students have to carefully consider the form, the connection details, the materials used, as they all affect the overall weight, as well as structural stability of the lantern designs.

Figure 4 *Larger lantern designs (40") in situ at Istanbul Bilgi University, Santral Campus (Fall 2015).*

The smaller ones (20" in diameter), shown in Figure 5, are designed as do-it-yourself projects. Each lantern comes flat packed with a guidebook and a video. The difference in size and the necessity of the do-it-yourself projects to be easily produced by everybody requires careful shifts in geometry, materials, and connection details. For instance, while in the larger lantern designs, the connection details need to be sturdy so that the lanterns can carry their own weights, and withstand wind and snow loads; the connection details in the smaller do-it-yourself lanterns need to be simple so that anyone can easily build the lanterns by themselves. So, while a simple interlocking detail might be perfectly suitable for the smaller do-it-yourself lanterns, it might not work with the larger (and heavier) lanterns. This is exemplified in Figure 6-A. In the smaller lantern, students designed the components to interlock to each other, making the assembly process very simple. However, interlocking detail was not suitable for the larger and heavier version. Therefore the students stitched the components to each other to ensure durability in the larger version. Similarly, the number of components used in larger lanterns can be more than the components used in smaller lanterns to have utmost control over the deformation of form. The lantern design exemplified in Figure 6-B shows a change in the geometry. The total number of components used is different yet the formal similarities that make a set in two different scales are maintained.

Figure 5 *Smaller do-it-yourself lantern designs (Fall 2015).*

The idea behind the do-it-yourself project is to increase the students' awareness on their own design processes so that they can communicate their design moves with others, in a formal way. Each lantern comes with a guidebook. This can be seen as yet another formal method where they define this conversation. The pages of one of the guidebooks can be seen in Figure 7.

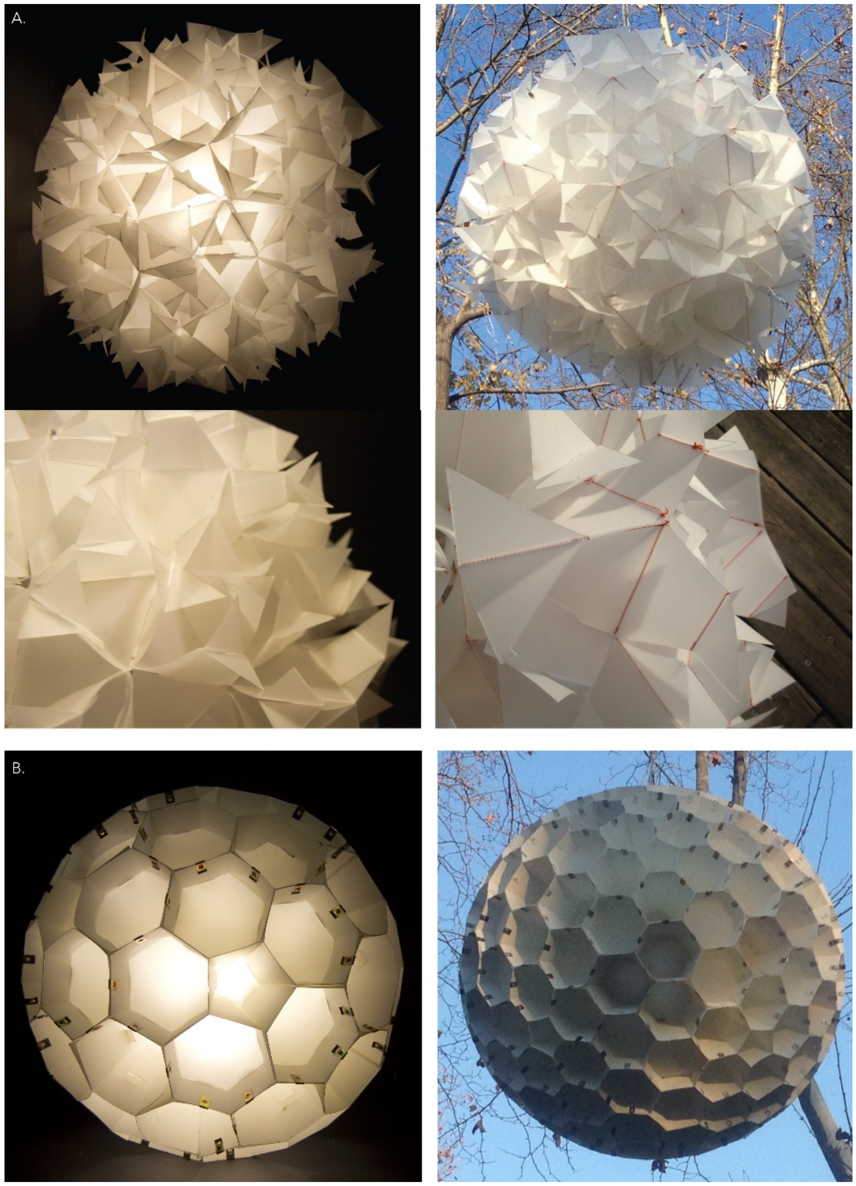

Figure 6 *Comparisons between different scales of two sets of lantern designs (Fall 2015).*

In Fall 2015, the students also built a website to share their designs and know-how. From building of the website to the creation of the guidebooks and the videos, the process evolved as a larger collaborative group work in which each student took a part. Once individual design groups advanced in their designs, we asked the students to form new sub-groups for different tasks. One sub-group produced the instruction manuals, one sub-group filmed and edited the production videos, one sub-group took the photos of all the projects, one sub-group designed the website and one sub-group generated a common detail to hang the lanterns. So, in the last week of the exercise, all the students worked together and collaboratively. This way, they all knew about each other's works. All of do-it-yourself lantern designs are available as open-source projects on the following website: bilgiarchbasicdesign.wixsite.com/lanterns.

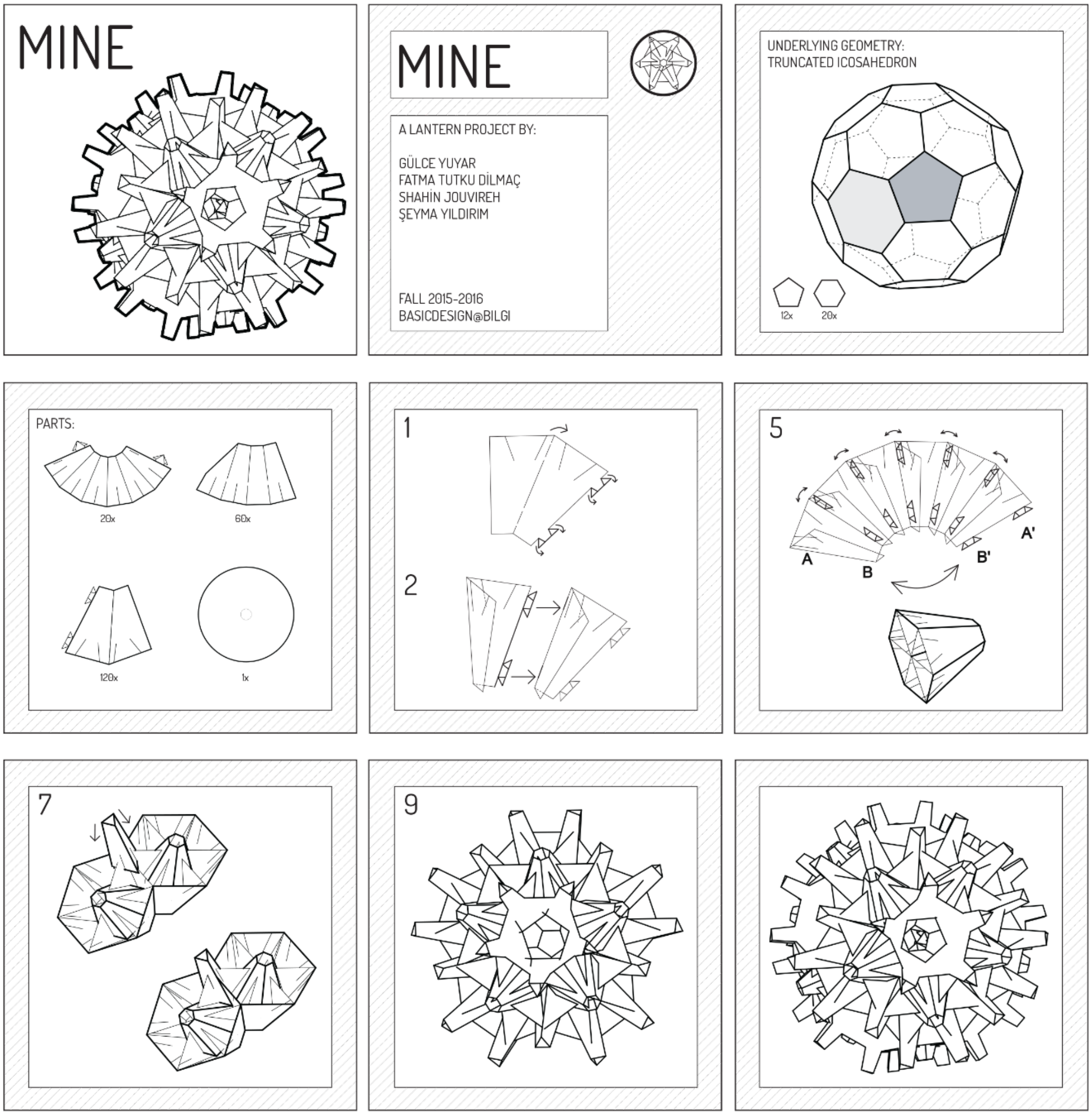

Figure 7 *Guidebook for one of the do-it-yourself lantern projects (Fall 2015).*

Conclusion

The foremost claim of this paper is that beginning design education can be considered as an early integration of computational thinking to design education, with or without the use of computers. Studio exercises that engage students with intensive reflective thinking can underline the computable aspects of design, and can help the students understand that designing involves different forms of reasoning. In cultivating computational thinking, the abstract and timeless visual language of geometry is a fundamental component: the abstractness of geometry eases out the learning process, and helps the students to focus on the relationships that they establish between parts.

Through the transformation that the students experience in Basic Design Studio, they are encouraged to grasp that design, as a creative process, incorporates different forms of reasoning as opposed to the romantic view of design shared by most of the beginning design students, which excludes any kind of reasoning from the creative process. In principle, what basic design education aims, is to create a consciousness in students for their own reasoning processes. Approaching design as a computable process in Basic Design Studio promotes systematic and relational thinking through analysis and synthesis processes which increase students' awareness of their design ideas and operations (Özkar, 2007). This consciousness can be developed through experience and experimentation. Hands-on experimentations with material things allow the students to try new definitions and ascribe new perceptions to materials to explore indefinitely many possibilities. Therefore, the students in Basic Design Studios test out visual and spatial configurations through making.

To support this claim, this paper presents a basic design exercise where the students are asked to design *material systems* as lanterns. They are encouraged to use digital design tools as design supports. Yet the expected outcomes are full-scale material artifacts. Basic Design Studio is supported by a Design Geometry course where the students learn the basics of polyhedral geometry and how to construct them in the computer. This situates the design exploration at the intersection of the digital and analog worlds. The students complete this exercise during their very first semester in design education (Fall semester of first year). The success of the outcomes is a testimony that computation (both with and without computers) can be introduced to undergraduate design curriculum as early as the first semester. Experience shows that the students introduced to computational thinking and computational technologies early on in their design education can easily adopt them.

Acknowledgements

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