GAMIFYING ORIGAMI

Rule-Based Improvisation for Design Exploration

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Abstract. Origami, which originated as a folding paper game in Japan, has turned into a source of learning and inspiration for design and engineering studies. Complex two-dimensional patterns of origami sustain visual rules of space transformation. So, this paper proposes to gamify origami to get users more involved in the design space exploration process. For the gamification of origami, the study alters the origami patterns in a 3D modular composition with rules, scoring, and rounds in a design context. Gamifying origami becomes a tool for a learning experience for first-year architecture students in the early design phases. Accordingly, this paper presents a gaming experience model based on origami for the foundation studios. This model consists of three main stages: start, rounds, and finish. The teaching of the model is the mereological relationship providing continuity concerning improvisations with visual rules. The reward is the model complexity, such as folding numbers, and regular or modified folding. The penalty is losing scores if the continuity is not maintained. The presented experience model is performed twice in the foundation studios. The former is for understanding how much preliminary knowledge is required for the first-year students to grasp and complete the game. The second is for testing the experience. The results of the study prove the role of visual reflection-on/in action by creating pauses during the origami design and the importance of sustaining the visual inference with transformations between individuals to experience form to formation, complexity, unity, and creativity in origami design. This study would contribute to the literature on experimental methods for design pedagogy.

Keywords: *origami, folding, design exploration, gaming experience, visual rules.*

ملخص. تحولت لعبة الأوريجامى التي نشأت كلعبة ورقية قابلة للطي في اليابان إلى مصدر للتعلم والإلهام لدراسات التصميم والهندسة. تدعم أنماط الأوريجامي المعقدة ثنائية الأبعاد القواعد البصرية للتحول الفراغى. لذلك تقترح هذه الورقة استخدام لعبة الأوريجامي لجعل المستخدمين أكثر انخراطًا في عملية استكشاف الفراغ التصميمي. بالنسبة لعملية "تلعيب" الأوريجامي، تعمل الدراسة على تغيير أنماط الأوريجامي في تكوين معياري ثلاثي الأبعاد

باستخدام القواعد والتسجيل والجولات في سياق التصميم. أصبحت تجربة تلعيب الأوريجامى أداة لتجربة تعليمية لطلاب العمارة في السنة الأولى في مراحل التصميم المبكرة. وفقًا لذلك، تقدم هذه الورقة نموذجًا لتجربة الألعاب على أساس الأوريغامي لاستوديوهات التصميم المعمارى فى المراحل التأسيسية. يتكون هذا النموذج من ثلاث مراحل رئيسية: البداية والجولات والنهاية. إن تعليم النموذج هو العلاقة المجردة التي توفر الاستمرارية فيما يتعلق بالارتجال مع القواعد البصرية. وتكمن المكافأة في درجة تعقيد النموذج، مثل الأعداد القابلة للطي، والطي المنتظم أو المعدل، والعقوبة فى خسارة درجات إذا لم يتم الحفاظ على الاستمرارية. تم تنفيذ نموذج التجربة المقدم مرتين في الاستوديوهات التأسيسية. ركزت المرة الأولى على فهم مقدار المعرفة الأولية المطلوبة لطلاب السنة الأولى لفهم اللعبة وإكمالها، والثانية على اختبار التجربة. أثبتت نتائج الدراسة دور الانعكاس البصري على/ في العمل من خلال إنشاء فترات توقف أثناء تصميم الأوريجامي وأهمية الحفاظ على الاستدلال البصري مع التحولات بين الأفراد لتجربة الشكل إلى التكوين والتعقيد والوحدة والإبداع في تصميم الأوريجامي. ستساهم هذه الدراسة في الأدبيات المتعلقة بالطرق التجريبية لعلم أصول التدريس.

الكلمات المفتاحية: *الأوريجامى، تقنية الطى، الاستكشاف التصميمى، تجربة الألعاب، قواعد بصرية.*

1. Introduction

Today, origami began as a figurative folding paper game and has turned into an architectural and engineering discipline. Thanks to its compliant mechanical and structural layouts, origami offers innovative solutions for functional use in engineering problems. The layouts that answer these innovative solutions are mainly based on regular patterns, such as Miura-ori, Ron Resch, and Waterbomb. These regular patterns are widely preferred in existing and emerging literature due to the ease of making two-dimensional patterns and the association of the two-dimensional patterns with three-dimensional free forms through their geometric configuration. These patterns, such as in Figure 1, are repetitively used in early design processes of architecture as well. However, the students, who choose to work with origami in a design process, find it challenging to engage with well-defined origami patterns in a situated and dynamic early design process. Although the design problems are ill-defined and iteratively re-structured throughout the process, the lack of ability to understand and manipulate the complex geometry of regular patterns limits the designers' action parallel to design decisions. Consequently, the resulting designs are limited to the exact copy of the same patterns and poorly adapted to the design context. Beyond copying the same pattern formally, each origami pattern's underlying rules promise to extend the design-space exploration in an early design process.

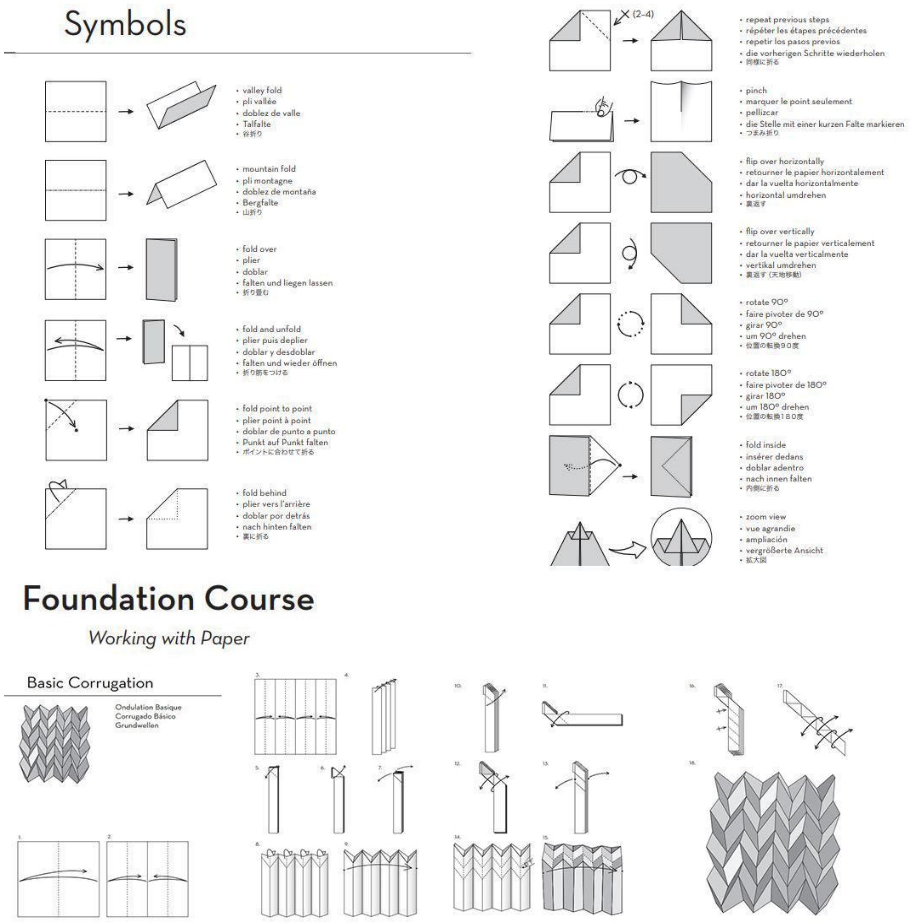

Figure 1. Bauhaus foundation course exercise (source: Gjerde, 2017).

Vyzoviti (2003), Gjerde (2017), and Megahed (2017) studied with architecture students using origami as a source of inspiration for design applications. However, this study questions how to incorporate the visual rules behind origami patterns in early design phases to obtain new forms beyond repetitive patterns. To integrate the catalog of visual rules into the activity of folding, this study proposes gamification as a design method. Gamification refers to the use of game design elements such as scoring, levels, and rules in non-game contexts (Deterding, 2012). In this study, we bring gamification with an aim to get users more involved in the origami design space exploration process. To do this, we propose to change the experience of complex origami patterns through simple origami modules, rules, scoring, and rounds in a design context. Although it is an easy start to use the above-stated repetitive geometric patterns, the difficult part of this process is breaking the pattern organization if needed. To do this, it is essential to capture the rules that govern patterns' geometric configuration. The rules are the relations between visual design elements such as fold lines and edges, the relations between this visual composition, and the affordances of three-dimensional configuration. Capturing, externalizing, and manipulating the visual rules set the play, improvisation, and exploration.

The objectives of forming a situated bottom-up process from a small starting module with visual rules vs. adapting a structurally complex form had been defined thus:

- Experiencing co-creation of a holistic, consistent, new design product with unpredictable results.
- Describing / externalizing / evaluating what is produced in the process and enabling the student to discover new ideas and ways of doing.
- Seeing the possibilities of actions by doing together as a group enriches the design space, students' experience, and learning.

The significance of the aforementioned objectives for education has been defined thus:

- learning by doing
- learning by each other
- reflection in-on action
- idiosyncratic expression through sensory experience
- externalizing individuals' sensations through rule-based expression
- taking advantage of uncertainty
- shifting from form to formation
- retrospective thinking
- reverse engineering

Moreover, its significance for the basic design has been defined thus:

- The importance of visual rule-based composition in design-space exploration
- mereological relationship
  - seed-motif-pattern
  - continuity
  - boundary, inner-outer
  - volumetric and spatial transformation

2. Background

Paper folding has been widely used in the education context. Fredrich Froebel is the most recognized pedagogue who adopted paper folding to enhance kindergarten students' self-expression, social participation, creativity, and motor skills. He formulated three-category of exercises: The first one, "folds of truth," aids the students with the basics of geometrical principles; the second category, which is called "folds of life," consists of figurative models; The final exercise, named "folds of beauty," are based on manipulating the learned figurative model for a new creation (Fiol et al., 2011). Froebel teaches abstract concepts by showing students how to use them first-hand in action, then scaffolds students with figurative models; lastly, he asks them to apply these concepts in free will to form their own creations. Another notable teacher, Josef Albers in Figure 2, asks students for open-ended experimenting and spontaneous playful tinkering with paper through folding as the initial exercise of the Bauhaus preliminary course (Barker, 2011). Folding paper, Moholy-Nagy (1938) declares as one of the means of the method of Bauhaus is to keep in the work of grown-up the sincerity of emotion, the truth of the observation, fantasy, and creativeness of the child. While the Bauhaus model emphasizes the individuals' idiosyncratic perception and sensation experience for creativity, they teach to externalize and regulate their sensations, and perceptions through visual and other forms of expressions. These rule-based expressions, in turn, teach students how to interpret things in relation, how to focus the parts' relation to the whole, and how to abstract the whole in different forms. As Barker (2011) states, the objective within Albers's Vorkurs was not to create finished works of art but was how to design and explore the duality and latent potential of materials. Moreover, externally expressing students' exploration is critical to furthering their design exploration.

Figure 2. Josef Albers and Volkurs (source: Wingler, 1978).

The expression of origami art and externalization of its production process is always a part of origami when one needs to transfer knowledge. Robert Lang, who designs very complex origami figures, makes the calculation of these intricate patterns with his software and brings origami as a solution to many engineering and science applications. Lang (2011) depicts the basic origami actions (such as valley-mountain fold, fold point to point, pleat fold, fold and unfold, repeat the previous step, pinch, rotate, turn over, fold inside, inside reverse fold, sink a corner, inside crimp fold, rabbit ear fold); He uses them to diagram the production process of figurative designs in his publications. These expressions are aimed to use for producing a final product. The novice designers cannot transform and modify these steps and go outside of the boundary of a pre-defined product. However, Jackson (2011) proposes to depict the techniques and strategies for transforming one's action, instead of the production of final figures. In other words, he expresses not the form but the formation by showing the continuity between each folding action with visual rules. When we go back to the method of Froebel, we can say that Lang's focus is on the "folds of truth" and "folds of life", Jackson centers on the method for "folds of beauty". From a designer perspective, Jackson presents folding techniques by discussing how a single sheet of paper can transform into distinct formal expressions that can be used by designers. On the other hand, prominent researchers, such as Demain et al. (2011), tightly engage in the mathematics of origami regarding 3D transformations of folding types. These studies are significant in understanding relative relations and formations among the fold lines and surfaces during deployment.

Based on this background study and our teaching experience at Istanbul Technical University, we deduce the importance of first-hand experience (1), self-expression (2), self-reflection on action (3), and abstraction of regulating rules based on reflections (4) both for the unity and the creativity of origami designs. Moreover, we observed that peer learning is another factor to enhance the students' experience. To bring the aforementioned factors and strategies into experiencing origami design, we find a solution to gamify origami activity.

To experience origami design as a situated formation process:

- We propose to play origami as a modular step-by-step game.
- We offer a digestible origami module by starting with a simple pattern and asking students to depict the pattern with visual rules.
- We asked students to pause in each action; depict each module production with visual rules.

To enrich the design space and students' experience and to arrive at unity and complexity:

- we asked students to observe the depiction and 3D module production of another student.

- We demanded to add a new module by transforming the other students' 3D modules based on his/her visual rules.

3. Methodology

The first-year architecture students are asked to retrieve visual rule sets of the 3D patterns based on protocol analysis and think-aloud techniques. These rules are further evaluated to generate new formal alternatives. The participants' direct engagements with the paper intend to rely on Husserl's phenomenological epoche/bracketing method, which demands the existence of the object satisfying the content of the intentional act (Husserl, 1962). The gaming model is shaped according to the pre-experiment with the first-year students to understand the required level of knowledge that should be given to the students to grasp and finish the gaming experience. Three students' production made during the pre-experiment session are shown in Figure 3. According to the pre-experiment session, difficulties are determined to develop the model.

The results of the pre-experiment determine the difficulties that occurred during the experiment. The main difficulties are briefly listed below.

- grasping the examples demonstrated over pictures
- understanding and interpreting the 2D pattern to fold and 3D folding pattern created as a result of deployment
- breaking the folding pattern's rules to differentiate it
- the complexity and size of the module

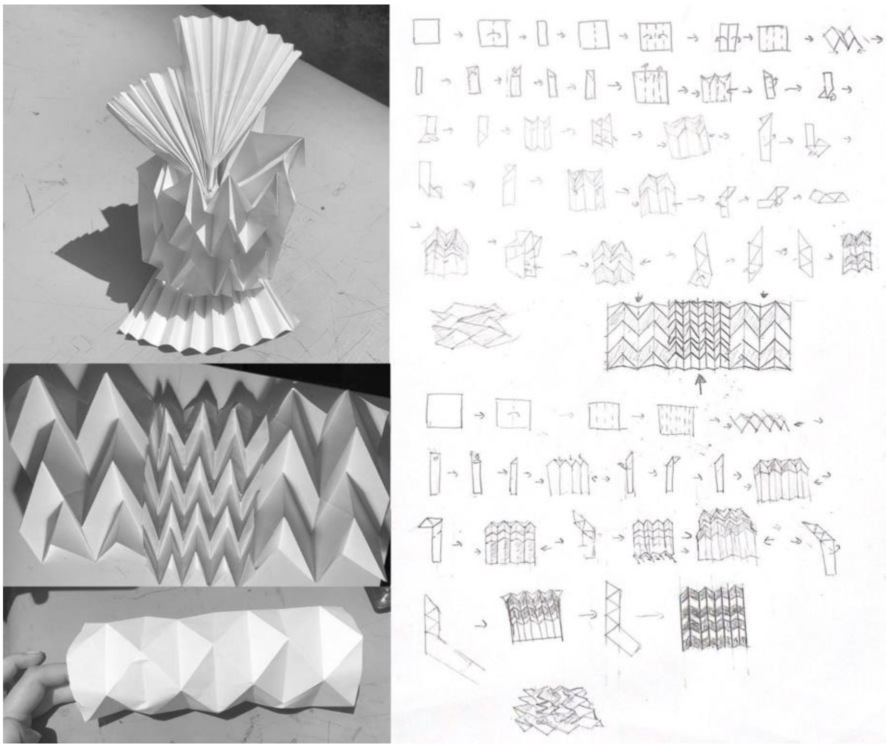

Figure 3. Three student productions from the preliminary physical experiment.

Decisions are taken after the preliminary physical experiment, and they are indicated as follows.

- reduce the model complexity and component redundancy
- start with smaller modules
- start by giving a 3D module as a folded model instead of a 2D pattern
- increase the module diversity and count
- make the sample pool consisting of well-defined folding modules
- give a limited time to the students to complete a module
- shift the folding module to the next person on their right to differentiate the pattern

The game framework is established taking into account the difficulties and decisions stated above. Accordingly, the following principles are defined.

- teaching: mereological relationship providing continuity, 3D transitions, and understanding the idea of form to formation.
- reward: based on the model complexity, such as folding numbers and being a regular or a modified folding pattern.
- penalty: if passed with empty submission or if the lines and surface slopes are not maintained, they get -2 points.

- definition of the module: the transformation of the previous module (isometric transformations like reflection and rotation, changing, number of folds, type, and direction, type of curve, etc.).
- result output: 3D modular composition

In light of the pre-experiment, the gaming process is created based on 3 main stages: start, rounds, and finish, which are briefly illustrated in Figure 5. Groups of four students are formed, and the students in each group are assigned numbers as nicknames. Students are expected to choose a base module from the pool in the first stage. The pool is indeed a box consisting of orthogonal and curved folding modules. The base modules can be seen in Figure 4. Orthogonal folding modules are distributed to odd-numbered students, whereas curvilinear folding modules are distributed to even-numbered students. Curvilinear and orthogonal folding modules are thus evenly distributed.

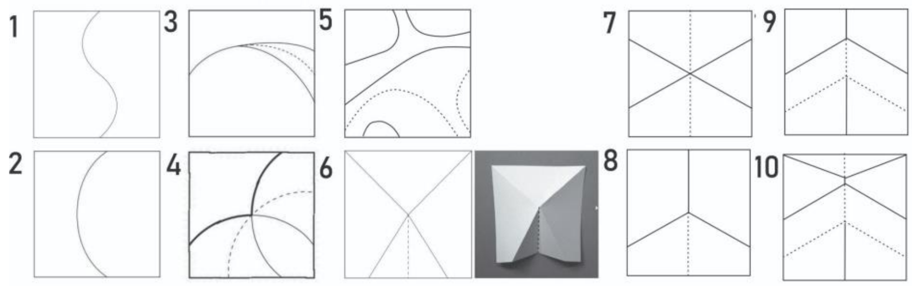

Figure 4. The two-dimensional templates of the base modules were folded. Each student chose one of the folded module to start the game.

In the second stage, a rule is defined for the students, who are expected to create a new module accordingly (Secondary modules can be seen in Figure 5). This study describes this rule as maintaining continuity and part-whole relationship to develop a new module. That is, spatial organizations should ensure the continuity of lines or surface slopes concerning continuity, unity, and design variety for 3D geometric compositions. The developed module becomes a cell in the 3D pattern composition and is attached to the previous module. At the same time, students define the visual rules with keywords. They get points for the composition when the process is completed, or time runs out. After scoring, students forward the module they created to the person on their right. In this way, the first round is over, and this iteration ends after the 4th round.

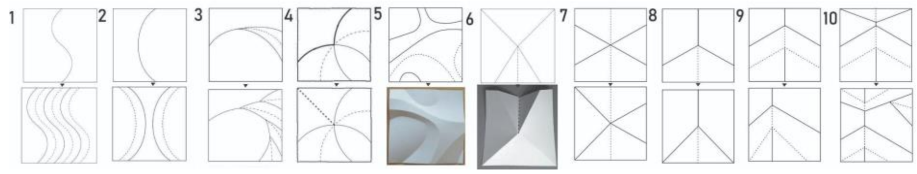

Figure 5. New modules were added at the second round. The visual rules show the transformation of the constitutive elements from the based module into the second module.

All the points are calculated after the rounds are completed. They get +2 points if successful, -2 points if passed, and -1 points if wrong. Afterward, students examine the visual rules and composition. They give feedback on sketch paper.

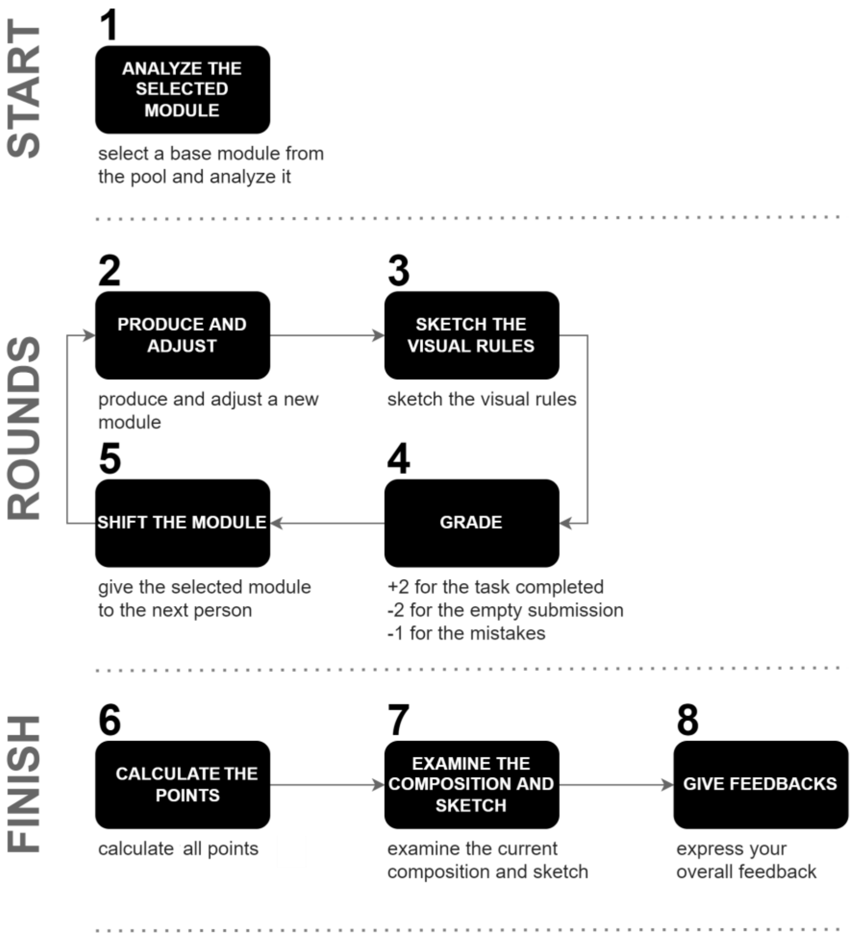

Figure 6. The process diagram

4. Results and Conclusion

The process diagram in Figure 6 was implemented as a one-hour exercise by thirty students which were divided into several small groups of four to five.

Each student started with a base module and an empty paper for depicting their visual reflections in/on actions. Firstly, each student observed and depicted the composition of the base module with the aim to understand the visual and spatial relations of the base composition. She/he numbered the first depiction with the number 1. Later, she/he continued to add new modules, depicted each modular action step by step, and numbered each depiction incrementally. After she/he added several modules, some of the students went back to previous steps and modified the composition of the previous module. In that case, she/he depicted this action as well and used the previous number of that module in her/his depiction. The purpose of pausing the origami process through making depictions was to enhance the students' conception of the continuity between each modular element and the unity of the whole composition. At the end of the rounds, each student finished one origami design configuration (three of them can be seen in Figure 7). Each origami design configuration diverged from regular patterns and the process of formation can be traced by students 'visual and verbal depictions. Based on students' origami design configuration and visual & verbal depictions, we grouped tendencies in students. The tendencies of the students are summarized below.

- The final origami configurations and the transformation types between modules differ between groups and are similar between group members' production. This shows the influences and learning from each other.
- While driving the design decision with visual rules maintained the continuity of two-dimensional origami modules, the continuity in three-dimension was not succeeded in a couple of groups of works.
- A difference between students' ways of thinking when they are explaining the visual rules has been obtained. Some of them express with analogies such as "create a winding road", the others with mathematical terms such as "turned 90 degrees and increased the curvature of a curve", or some of them use the geometrical elements of modules such as "added another wavy mountain folds"; moreover, the ones integrate the appearance and affordances of materials into their expressions such as "add two curved folded modules to get stiffness".
- Shifting the eye between micro to macro and cyclic movements between the parts and the whole has been read in the students' depiction of visual rules. Some students referenced the whole composition when they express the relations between design elements; Others solely focused on the properties and the relations between the parts of single modules.
- While the first module ruled the whole process in a group of works, the other groups' choice of the transformation type caused to fade the dominancy of the first module. Moreover, the complexity level of the processes varied between groups.

- As the complexity of the origami design increased through the progressive rounds, the interaction between students raised. Even though the students were responsible to transform a single module, some of them intervene in the previous module and transform the adjacent modules according to his/her visual rule.

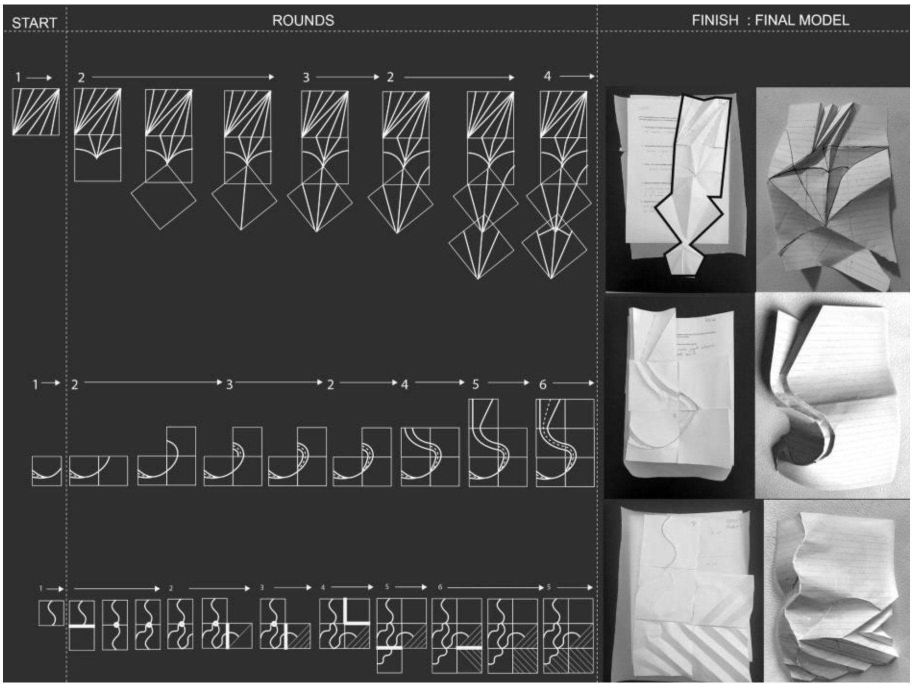

Figure 7. Three selected examples out of thirty student productions.

The result of the study proves the potential of gamifying origami for the early design process. Accordingly, this study would contribute design space explorations with novice designers in finding new forms through low-fidelity prototyping. This gain extends the students' perception and abstraction ability by being aware of the underlying geometric organization with visual rules.

The limitations of this study are the limited number of students and time constraints. We kept the rule of each set equal. Changing the rule can be aimed to teach a module from the basic design education. Further study can consider integrating the following categories to the rule sets: material, color, light/shadow, solid / void relationship, and structure.

New concepts and rules can be integrated as exemplified below.

a. pre-conceptive aids (samples of geometric properties, relations, and transformations)

b. make

c. evaluate and explain (applying pre-conceptive aids to the creation and transformation of rules, integrating the affordances of three-dimensional configuration to the visual rules)
d. re-make

This study would contribute to the literature in model making provoking creativity, and detail development, and is significant for gaining 3D thinking over visual rules and increasing design variety in design studios. Folding, as a means of connecting mind and hands, fuels the imagination. Seeing and explaining the folded composition in an unanticipated way is the definition of imagination and the sign of creativity. Depicting what is seen with visual rules and sharing it with others scaffolds the continuity of the design process and promotes its transformation and diversion. Besides, the transformation of two-dimensional patterns to three-dimensional configurations with folding operations, students discover materials' possibilities and become conscious of volume and space.

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